THE PRAIRIE DU CHIEN GROUP OF THE MICHIGAN BASIN

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ABSTRACT

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By

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The Lower Ordovician Prairie du Chien Group of the Michigan Basin area has received little attention in the past. Due to a lack of drilling information and outcrops available for study in the Lower Peninsula only two regional studies of this Group have previously been conducted, by Cohee (1945, 1947, 1948) and Ells (1967). Within the last 10 years, however, a number of deep wells throughout the Basin have added greatly to the information concerning this interval and, in some areas, subsurface control.

The purpose of this study is to delineate the boundary contacts of the Prairie du Chien Group as well as define the extent, distribution and lithology of this Group in the Southern Peninsula. It is hoped that such a detailed examination will aid in interpreting and understanding the evolutionary history of the Michigan Basin in Lower Ordovician time.

The distribution of the Prairie du Chien Group indicates that basinal subsidence was occurring during this time and that it was complicated by a number of factors including isostatic sinking, subaerial erosion (Post-Knox Unconformity surface), subsurface solution, and post-Prairie du Chien faulting and folding (Devonian and Mississippian in age). The Prairie du Chien Group in the standard section is subdivided into the Oneota, the New Richmond and the Shakopee formations. In Michigan the writer has combined the last two into the New Richmond-Shakopee Interval. The Oneota can be subdivided into a lower sandy dolomite unit and an upper argillaceous dolomite unit. These Lower Ordovician formations indicate a series of transgressions and regressions culminating in the Post-Knox Unconformity surface at the end of Prairie du Chien time. Activity along the Findlay and Wisconsin Arches, flanking the Basin, is problematical. Thick sands in NW Michigan and erosion into Upper Cambrian formations in SE Michigan indicate that if these arches were not uplifted they were at least slightly positive features exposed to erosion by regressions of the Prairie du Chien seas.

A karst Prairie du Chien topography developed at the disconformity is overlain by an impermeable Glenwood Shale and may have acted as an avenue of updip oil migration. Post-Prairie du Chien faulting created channelways through the Glenwood which permitted dolomitizing fluids to create dolomite porosity in the Black River-Trenton Formations. These same channelways later permitted oil migration into the Black River-Trenton porosity. Thus some of the oil flushed from the Prairie du Chien karst zone may have found its way into Middle Ordovician, and higher traps along fault zones, the balance of the oil perhaps being flushed from the region into structurally higher traps nearer the rim of the Basin, as at Lima, Ohio. Thus oil accumulations in the Michigan Prairie du Chien appear rather questionable.

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ichael
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INTRODUCTION

General

The Lower Ordovician of the Michigan Basin is a little worked and poorly understood sequence of carbonates and clastics that locally may be of interest in petroleum exploration. In Ohio (Morrow County, etc.) Cambro-Ordovician oil and gas has been found to be closely associated with the Post-Knox Unconformity, usually in erosional remnants of the Upper Cambrian Copper Ridge (Trempealeau), and in the Middle Ordovician Chazy (Glenwood) carbonates.

Little detailed work has been done in Michigan on the Lower Ordovician Prairie du Chien Group for several reasons: (1) deep wells into the Cambrian are scarce and usually far apart geographically; (2) the Prairie du Chien has been eroded to a surface of high relief by the Post-Knox Unconformity and the overlying St. Peter Sandstone is missi~~on~~ng from three quarters of the state; (3) the exact contacts between the Glenwood and Prairie du Chien (Middle Ordovician-Lower Ordovician), and the Prairie du Chien and Trempealeau (Lower Ordovician-Upper Cambrian) have not been established and are disputed by various workers in the field; and (4) as no outcrops of the Prairie du Chien or older rocks occur in the Lower Peninsula we are also faced with problems in terminology of varying stratigraphic units and criteria for correlating Lower Ordovician and Upper Cambrian formations.

Purpose and Scope

The main purpose of this study is to delineate the boundary contacts, extent and distribution of the Prairie du Chien Group in Michigan and to correlate regionally the Prairie du Chien (PdC) formations throughout Michigan. Structural contour and isopach maps, as well as stratigraphic cross sections, will be used to relate the stratigraphy to the evolutionary development of the Michigan Basin during Lower Ordovician time. The Prairie du Chien crops out in the Upper Peninsula but there are few good exposures for detailed studies and regional comparisons. This study is confined exclusively to the Lower Peninsula of Michigan. Because of a lack of well control and the varying thicknesses of the Prairie du Chien Group as a result of erosion it is inadvisable to attempt subdivision into its standard classification, the Oneota, New Richmond, and Shakopee formations. Likewise it is unfeasible to attempt a detailed facies map of the Prairie du Chien Group in the Basin because of the lack of well control, unavailable and incomplete key well samples and the erosional disconformity at the top.

It is hoped that the Michigan Prairie du Chien can be tied in with the correlates in Illinois, Indiana, NW Ohio and the standard section in Wisconsin as a result of this study.

Procedure--Method of Study

A threefold approach was used in this study to define and delineate the distribution and extent of the Prairie du Chien Group in Lower Michigan.

(1) Gamma Ray/Neutron logs primarily were obtained from the State Geological Survey in Lansing and the Michigan State University Geology Department. All available logs reaching the Lower Ordovician, Cambrian or Precambrian were used. Because the Survey has regulations barring removal of the logs from the premises special permission was received to copy selected portions of the logs for comparison and correlation. In all 105 mechanical logs were copied and a total of 262 mechanical logs were used to varying degrees in constructing the maps of this study (Appendix I).

(2) Samples were used in conjunction with the logs and were again obtained from the State Geological Survey in Lansing and the Michigan State University Geology Department. Most of the samples perused were rotary samples although a few cable tool samples for shallower wells into the Prairie du Chien were examined. The cuttings from only 43 wells were examined statewide, the majority of these

being deep wells containing the entire Prairie du Chien interval (rotary samples). Special efforts were made to establish the contacts between the Glenwood and Prairie du Chien, and the Prairie du Chien and Trempealeau Formation. In both instances samples proved somewhat inadequate to the task, owing to the transitional nature of the Lower Ordovician-Upper Cambrian lithologies, the high degree of contamination in the sample, and the erratic nature of the disconformity between the Middle and Lower Ordovician. This will be discussed in detail later under Stratigraphy. Several well samples were studied with no mechanical logs available for comparison.

Samples were examined following the procedures outlined in the Quarterly of the Colorado School of Mines ("Examination of Well Cuttings," Vol. 46, No. 4, 1951) and Whiteside's Geologic Interpretations from Rotary Well Cuttings (1932). The description of samples were modified to include:

Coarse Clastics (Sandstones)

size: fine (.125-.250 mm), medium (.25-.50 mm), coarse (.50-1.0 mm), very coarse (1.0-2.0 mm).
shape: angular, sub angular, sub rounded, rounded, well rounded.
surface luster: coated, pitted, frosted, clear, vitreous.
color: clear, white, gray, yellow, pink, red, brown, black.
texture: loose, cemented, porous, overgrowths, in chunks.
cement: calcareous, dolomitic, ferruginous, silicious cherty, pyritic.

Fine Clastics (Siltstones and Shales)

size: very fine to "invisible" grains (< .125 mm or < .1 mm).
shape: visible grains (siltstone), invisible grains-lithified (shale).
luster: vitreous, clear, dull, opaque, earthy, resinous, silky, waxy.
color: clear, white, red, green, gray, dk gray, brown, black, mottled.
texture: loose, cemented (siltstone), massive, platy, laminated, foliated, fissile, flaky, fractured.
cement: calcareous, dolomitic, ferruginous, pyritic, silicious, cherty.
composition: sandy dolomitic, calcareous, pyritic, micaceous, glauconitic cherty gypsiferous, anhydritic, silty, argilaceous, ferruginous.

Carbonates (Limestones and Dolomites)

basic composition: dolomite, calcitic dolomite, dolomitic limestone, limestone.
crystallinity: very fine (< .05 mm), fine (.05-.25 mm), medium (.25-2.0 mm), coarse (> 2.0 mm), lithographic, dense, rhombs.
texture: rhombic, sucrosic, microsucrosic, grainy, sub-crystalline, oolitic, pelletal, fragmented fossiliferous.
structure: stylolitic, fractured, laminse, banding, con-cretious, whorls, brecciation.
color: white, buff, tan, brown, orange, red, green, purple, black, mottled.
porosity: dense pinpoint interstitial, vuggy, cavernous, intercrystalline.
composition: dolomitic, calcareous, argillaceous, sandy, silicious, cherty, pyritic, anhydritic, silty, gypsiferous.

Evaporites (Anhydrite and Gypsum)

shape: amorphous, tabular, sheet, fibrous, cleavage.
color: clear, white, gray, red, brown.
texture: soft, hard, brittle.
luster: translucent, sub vitreous, earthy, pearly, silky.

Chert

nature: primary, secondary.
color: white, gray, buff, orange, red, brown.
luster: porcelainous, earthy dull, sub vitreous.
texture: dense, banded, nodular, oolitic, vaggy.
composition: silicious, sandy, ferruginous.

Pyrite, glauconite, muscovite, vein quartz and other 'minor' minerals were recorded as they occurred.

All samples were examined under an Olympus Binocular Microscope under a 10X combination of lenses with maximum magnification up to 40X. Two light sources were employed, a focused light source and a fluorescent lamp, to accurately determine colors and details on the grains. For identifying and differentiating carbonates a mixture of 7 parts water to 1 part concentrated hydrochloric acid was utilized.

(3) Along with the gamma ray logs and samples a practical approach to assimilate the information was employed. Comparisons of logs and samples were made regionally and characteristic curves identified above, below, and within the Prairie du Chien Group. A review of the literature leads one to three assumptions:

(a) The Post-Knox Unconformity occurred at the end of Prairie du Chien time. Thus the Prairie du Chien, where present has an erosional surface;

(b) In Michigan, the Glenwood is transitional with the overlying Black River Formation; and

(c) Where the Prairie du Chien is missing, erosion has occurred to the Trempealeau or Munising formations.

Therefore, by starting in SE Michigan where it is well established that the Prairie du Chien is entirely missing a characteristic Glenwood gamma ray curve was found, and thus the upper and lower limits of the Glenwood established locally. Interestingly, this curve corresponds to what Catacosinos (19~~74~~72) called the "Extra Section," supposedly a basal limestone of the Black River Formation. While it is possible to follow this curve north through Huron County (and possibly Alpena and Presque Isle Counties) and west along the edge of the Basin through Lenawee, Hillsdale and Branch Counties, the curve loses definition basinward with the increasing thickness of the Prairie du Chien and questionable erosional contact. The absence of a readily identifiable St. Peter Sandstone throughout three quarters of the state (Dapples, 1955; Balombin, 1974) also makes correlations difficult. Thus at times the writer based local correlations on incomplete logs and samples and believed it necessary to rely at other times upon previous work (Cohee, 1948; Ells, 1967; Balombin, 1974; Seyler, 1974).

Statewide correlation of the lower contact between the Prairie du Chien and Trempealeau was established on the basis of gamma ray-neutron logs (and samples). Again, some difficulty occurred as a result of poor well control and possible lateral facies changes, as well as the lack of sufficient data on the Cambrian subsurface.

Reliability of Data

The main problems encountered in this study were poor well coverage for the state and incomplete logs and samples within and below the Prairie du Chien. As most oil companies have been concerned with production from the Trenton-Black River formations (Howell Anticline, Northville, Albion Scipio, Freedom fields) there are few logs available for correlation deeper than 100 feet into the Prairie du Chien. Therefore it was necessary at times to correlate in complete yet discernible intervals with nearby deep wells containing more complete Prairie du Chien sections. At times it was deemed best to refer to the previous work of Cohee (1948), Ells (1967), Balombin (1974) and Seyler (1974).

In some wells sample (rotary) contamination from overlying formations was heavy, approaching 70% in some intervals.

PREVIOUS WORK AND NOMENCLATURE

The varying terminology employed for the Lower Ordovician Prairie du Chien Group over the years is best illustrated in Figure 1. Sundry workers have proposed different names for the Lower Ordovician rocks of the Upper and Lower Peninsulas of Michigan relating them to different type localities in nearby New York, Wisconsin and the Upper Mississippi Valley. Confusion has resulted from the terminology used; the difficulties encountered in correlating stratigraphically to surrounding areas, as well as in the Michigan Basin; the questionable age of these rocks and the rocks below (Cambrian); the small isolated outcrops available; and the poorly preserved fossils used to date the formations. Therefore, important contributions to the developmental evolution of the nomenclature in the Michigan Basin (Upper and Lower Peninsulas) should be briefly considered to recognize the rationale utilized by geologists for the last 136(+) years.

In 1841 Houghton called the sandy dolomites overlying the Lake Superior Sandstones on the southern shoreline of Lake Superior the "Sandy Lime Rock" (equivalent to Upper Cambrian and Lower Ordovician). Subsequent workers

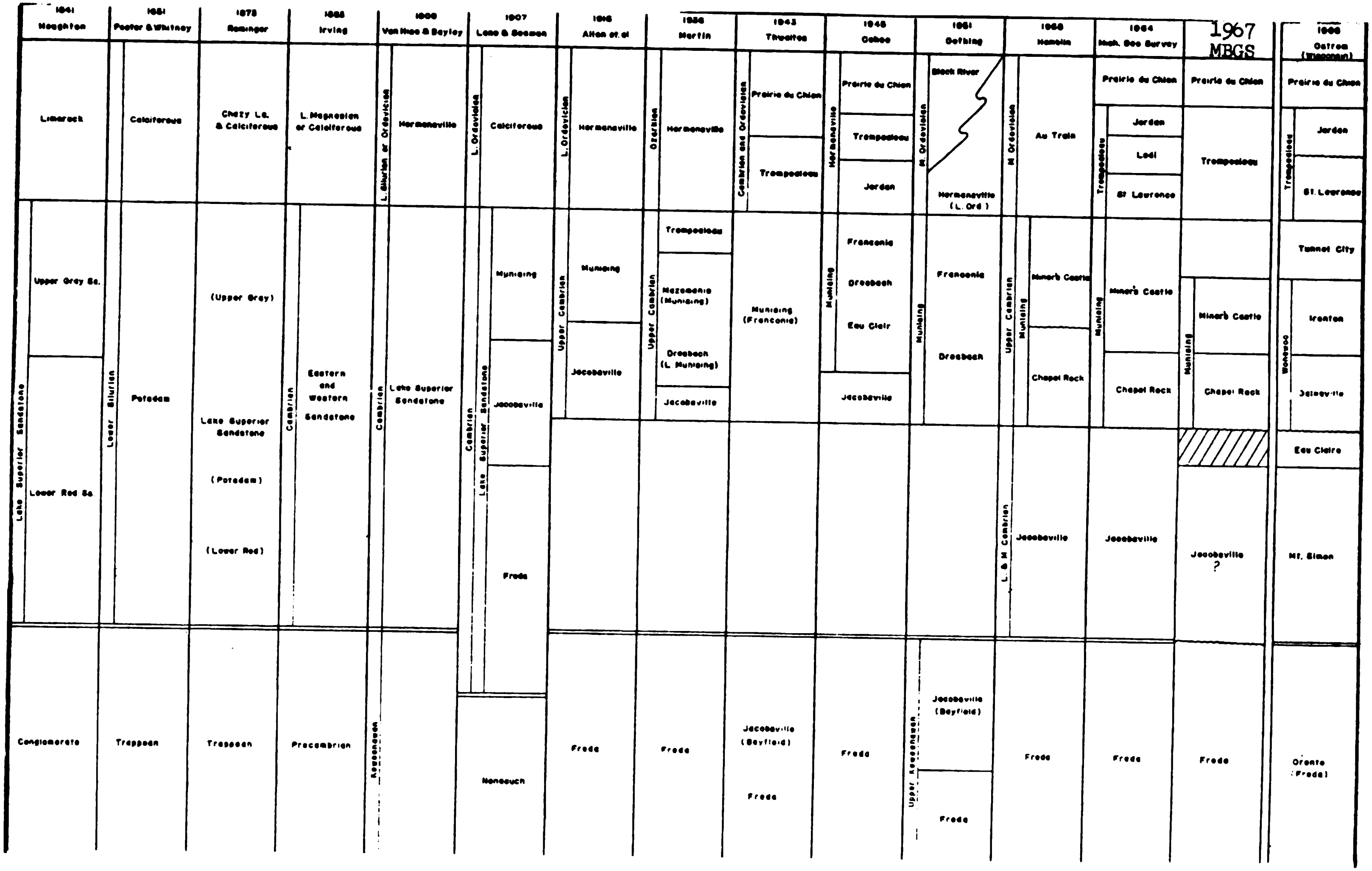


Figure 1

Development of Lower Ordovocian Nomenclature in Northern Michigan (after Hamblin (1958), Ostrom and Slaughter (1967)) such as Foster and Whitney (1851) described the same rock sequence as the Calciferous (type section - Champlain Valley at East Shoreham, Vermont). Rominger (1875) also retained the term Calciferous, but on the basis of stratigraphic position and similar lithologies included the Chazy Limestone (from New York). Irving (1883), too, called these sandy dolomites the Calciferous or the Lower Magnesium (Upper Mississippi Valley terminology, Owen, 1852) referring loosely to the rock underlying the St. Peter Sandstone and above the Cambrian strata (the Lake Superior Sandstone - equivalent to the Potsdam Sandstone of New York).

The name Hermansville Formation was proposed by Van Hise and Bayley (1900) for strata in the Menominee district of the Northern Peninsula. They believed it to be Lower Silurian or Ordovician in age and consist of a coarse grained sandstone with abundant calcareous cement, in alternation with pure dolomite or sometimes oolitic beds. However, the authors did not give a good type section in their report--only a general location. Lane and Seaman (1907) retained the term Calciferous, however, and believed the entire section to be Lower Ordovician in age describing it as a buff-bluish dolomite, often sandy with dolomitic white sandstone. They believed it to be synchronous with the Lower Magnesium Limestone and thought Bayley's (1900) Hermansville as part of this formation.

At Marinette County, Wisconsin, one well was described in descending order as: Calciferous--dolomite, brown, 60 feet; sandstone, white, 70 feet; and dolomite (Hermansville) 50 feet. They considered that this triple division may have been equivalent (in places) to the Shakopee Dolomite, the New Richmond Sandstone and the Oneota Dolomite of Minnesota, respectively.

In 1936, Helen Martin, of the Michigan State Geological Survey, compiled the "Geologic Map of the Northern Peninsula of Michigan" and showed the Hermansville to overly the St. Croixian. She considered the dolomitic sandstones to be Ozarkian or Canadian in age. In her "Centennial Geologic Map of the Southern Peninsula" (1936) she described the Canadian or Ozarkian as follows:

St. Peter

Ozarkian or Canadian	Prairie du Chien L. Magnesium	Greenish shale, red, pink, purple, fine grained sandy magnesium limestone and dolomite; white, pink, buff oolite and dense chert.
	Hermansville	White dolomitic sandstone and sandy dolomite, pure white sandstone, buff-red dolomite locally very sandy, ferruginous and glauconitic.

ε - undifferentiated

In 1911 Ulrich proposed a controversial system dividing the "Eopaleozoic" era into the Cambrian, Ozarkian, Canadian and Ordovician periods based upon unconformities present, lithology, stratigraphic position, fauna and fossil criteria, etc. His Ozarkian system included those rocks overlying the Munising sandstones and contained rocks of Cambro-Ordovician age. His Canadian extended from the Ozarkian to the base of the Middle Ordovician Chazy Formation. By Martin's time (1936) the Hermansville was generally considered equivalent to the Ozarkian. Berquist (1937) used the term Hermansville in his studies of the Cambro-Ordovician contact in Alger County, Michigan, and said it was separated from the Cambrian sandstones by an unconformity and belonged to the Ozarkian. Thwaites (1943) considered the term Hermansville to be equivalent to the Trempealeau and Prairie du Chien of Wisconsin and advised abandoning the term Hermansville because: (1) it included both Cambrian and Ordovician rock equivalents, and (2) the poor and incomplete description of VanHise and Bayley (1900) for their type section did not facilitate identification of the formation.

The term Au Train Formation was introduced by Grabau in 1906 to Northern Michigan stratigraphy for the considerable section exposed at Au Train Falls. He stated:

> In the Iron Mountain region Upper Cambric fossils are recorded from the basal sandstone but this does not prove that the basal sandstone of Marquette and the pictured rocks is of the same age. In fact, from their position with reference to the transgressions of the Cambric sea, these more northern sandstones must be regarded as of later age than that of the Menominee district. If the Hermansville limestone (Auxtrains formation would be a better name from more typical exposures on that stream) proves eventually to be Beekmantown rather than Chazy (that is,

> Upper Stone River or Lowville), the late Cambric or early Ordovician age of part of the Superior sandstone must be conceded.

Cohee (1945) considered the Hermansville to be equivalent to the Jordan, Trempealeau and Prairie du Chien formations as a result of subsurface stratigraphic work in the Michigan Basin that could be traced into northeast Wisconsin. Cohee said the Jordan sandstone formed part of the Hermansville with the Upper Hermansville equivalent to the Oneota in the Northern Peninsula. He recognized and subdivided the Prairie du Chien in the Lower Peninsula (on the basis subsurface stratigraphy and lithology) into the Oneota Dolomite, New Richmond Sandstone and Shakopee Dolomite, being underlain by the Trempealeau Formation. Cohee said the rock capping the Au Train Falls in the Northern Peninsula is the St. Lawrence member of the Trempealeau Formation.

Oetking (1951) studied the Lower Paleozoic rock in the Munising area and ascribed the Au Train, on the basis of fossils, to a Middle Ordovician age. He correlated the Au Train (or Hermansville, Calciferous) to the Platteville (Lower Middle Ordovician) of the Wisconsin section. He attributed the missing formations to overlap by the Black River Formation. Hamlin (1958) likewise put the age of the Au Train as Middle Ordovician, basal Black River, on the basis of gastropod and cephalopod fossils and believed that a considerable unconformity separates the Middle Cambrian Miners Castle and the overlying Middle Ordovician Au Train. No angular discordance between the Cambrian and Ordovician rock was found but he considered that some evidence of a basal conglomerate is in the lower units of the Au Train formation. Thus the Lower Ordovician is missing in most of the Northern Peninsula according to Hamlin. But according to the Michigan Basin Geological Society (MBGS) Annual Field Excursion (1967) certain fossil brachiopods found indicate that at least the lower part of the Au Train Formation is Late Cambrian supporting the contention of Thwaites and Cohee. Guldenzopf (1967) assigned a Canadian age to the Au Train Formation on the basis of conodont studies, relating them to the Prairie du Chien formations in southwest Wisconsin.

Ells (1967) prepared a stratigraphic cross-section of the Cambrian and Ordovician formations of the Upper and Lower Peninsulas of Michigan on the basis of gamma ray logs and similar lithologies for a limited number of wells. Based upon a reference well in Illinois he subdivided the Prairie du Chien Group into the Oneota, New Richmond and Shakopee Formations. Fisher (1969) recognized the absence of the Prairie du Chien from part of eastern Michigan (SE) in his regional study of the "Early Paleozoic History of the Michigan Basin," as did several earlier workers, including Cohee (1945, 1948).

Today, as they have since 1964, the Michigan State Geological Survey includes the Calciferous, Hermansville, and Au Train in the Trempealeau (Upper Cambrian) and the Prairie du Chien (Lower Ordovician), for both the Upper and Lower Peninsulas of Michigan. The Prairie du Chien Group may be broken down into formations in places but at this time subdivision into units regionally is not considered practical.

Other terms less frequently used but still found in the literature concerning the Michigan Basin are the Beekmantown (equivalent to the Calciferous) whose type section is Beekmantown, New York, and the Knox Sandstone (type locality - Eastern Tennessee). Both cases represent the introduction of terminology unsuitable for/and inconsistent with the present nomenclature of the Basin. Thus the questionable age and nomenclature, especially for the Upper Peninsula, remains a problem today, in correlating the stratigraphy within Michigan and with the surrounding states.

Lower Ordovician studies have been carried out: in Wisconsin (standard section) by Thwaites (1923, 1927, 1935), Trowbridge (1934), Kay (1935) and Ostrom (1966, 1967); in Illinois by Workman and Bell (1948) and Buschbach (1964); in Indiana by Gutstadt (1958); and in Ohio by Wasson (1932), Fettke (1948), Shearrow (1959) and Calvert (1962, 1963a, 1963b, 1964). Lower Ordovician rocks are not known to be present in southwest Ontario (Brigham, 1971).

STRUCTURE

The Michigan Basin is a roughly circular and symmetrical structural and sedimentary basin in the Central Interior platform of the United States. It encompasses (Figure 2) the Southern Peninsula and the eastern part of the Northern Peninsula of Michigan, Eastern Wisconsin, the northeast corner of Illinois, Northern Indiana, Northwest Ohio and parts of Ontario bordering Lake Huron, Lake St. Clair and the western end of Lake Erie (Cohee and Landes, 1955). Bordering the Basin is the Algonquin Arch to the east (Ontario), the Findlay Arch to the southeast (NW Ohio), the Kankakee Arch to the southwest (N. Indiana), the Wisconsin Arch to the west (C. Wisconsin) and the Canadian Shield to the north and northeast (Canada). Within the 122,000 square mile area of the Basin the only exposures of the Prairie du Chien rocks are found in the Northern Peninsula (Figure 3).

Over the years there has been much controversy over the age and even the validity of the structures flanking Michigan. It is generally agreed that the Algonquin Arch was a "positive" feature in Paleozoic time. Utilizing isopach maps, Sanford and Quillian (1959) stated

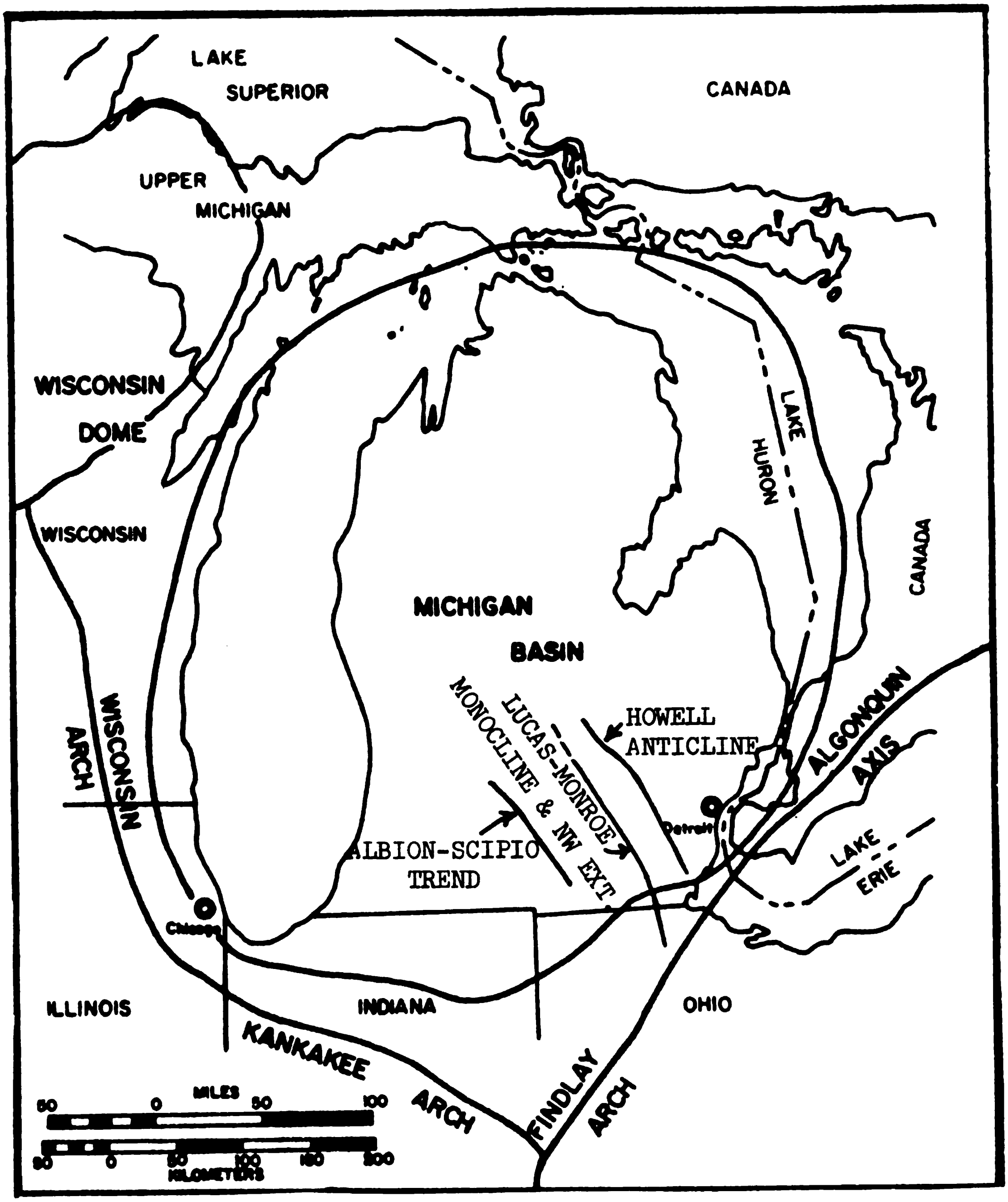


Figure 2

Regional Structure Map of Michigan and Environs
(After Catac~~a~~osinos (19~~74~~72) and Prouty (1974))

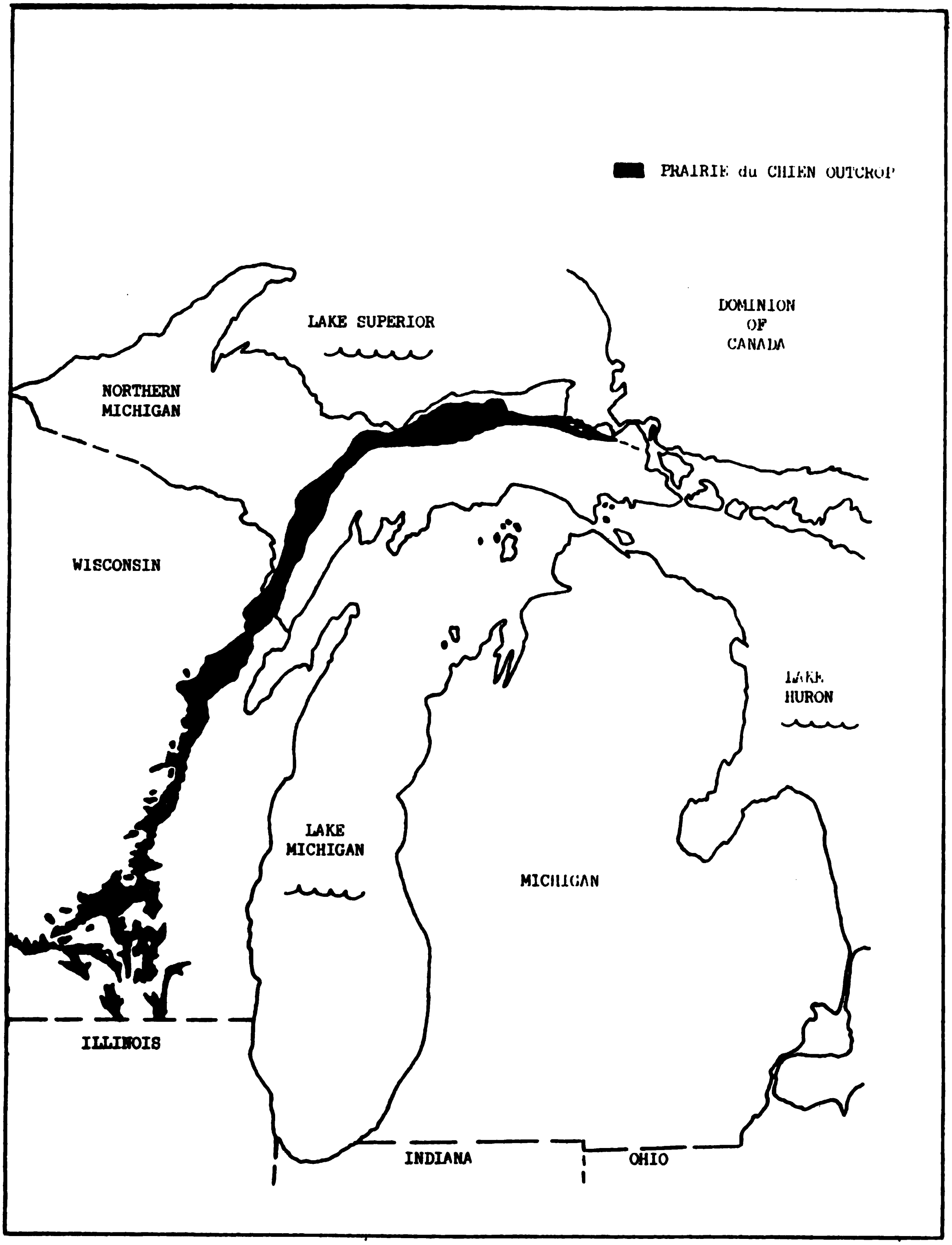


Figure 3

Geologic Map Showing Prairie du Chien Outcrop Locations in Michigan and Eastern Wisconsin (after Martin (1955), Hanson (1966))

that the transgressive overlap of Upper Cambrian units onto the Arch indicates its presence in Upper Cambrian time at least, while Sutterlin and Brigham (1967) give evidence of an earlier age (Precambrian), based upon the thinning of Upper Cambrian rocks over local Precambrian highs, indicating that the highs were previous erosional features prior to deposition. Cohee (1945, 1947), Kay and Colbert (1965), and Brigham (1971) all believe that the absence of Lower Ordovician rock from western Ontario and southeastern Michigan was the result of intense erosion at the end of Prairie du Chien time.

The presence and age of the Findlay Arch, however, is another story. Pirtle (1932) thought the arch developed largely in Cincinnatian time. Lockett (1947) tied the Findlay to the Algonquin Arch but this was disputed by Sanford (1961) who used isopach and lithologic data to show this erroneous association, and said the Findlay Arch was not prominent until Upper Ordovician or possibly late Trenton time. From the apparent offlap of Upper Cambrian units, the erosion of Lower Ordovician and Upper Cambrian formations in northeast Ohio and southeast Michigan, and the absence of Cambrian and Lower Ordovician rocks in Ontario, Cohee (1948) inferred the presence of the Arch in Upper Cambrian time. Woodward (1961) related the Findlay Arch origin to a Lower Ordovician or Upper Cambrian age. Calvert (1964) considered the Findlay Arch to have been formed in post-Lower Ordovician time by the westward migration of the central Ohio arch or north central Ohio arch. Others disagree to the mechanism but give a similar age to the Arch. A Silurian origin to the Arch was given by Janssens and Stieglitz (1974).

The Chatham Sag was thought to be a breach in the older Findlay-Algonquin Arches (Lockett, 1947; Fettke, 1948) formed by the subsidence of the adjacent Michigan and Appalachian Basins. Lockett and Green (1957) considered the Findlay and Algonquin Arches genetically related and a continuation of the Cincinnati Arch. Sanford (1961) said the arches were not tectonically related and thought the Sag a faulted basement block along which the Findlay Arch rose. The slight thickening of Middle Ordovician sediments is possible evidence of an early development of the Sag not found again until Upper Devonian or Lower Mississippian time.

The Kankakee Arch was believed by Pirtle (1932) to be a southwest continuation of the Wisconsin Arch of Precambrian age. Isopachs by Cohee (1945) and Swann (1951) indicated that the development of the Kankakee Arch did not take place until after deposition of the Prairie du Chien strata. This agreed with Ekblaw (1938), and later Buschbach (1964) who believed the broad regional structure occurred in L-M Ordovician time. Both Pirtle and Ekblaw believed the Arch not only separated the Michigan and

Illinois Basins but also connected the Wisconsin Arch to the northwest to the Cincinnati Arch to the southeast. Green (1957) related the structures of the Findlay and Kankakee regions to subsidence of the surrounding basins rather than to the uplift of the Arches. Since he saw no arching he proposed the term Kankakee Arch be dropped. A pre-St. Peter origin was postulated by Snyder (1968) while Bell (1958) thought that even though the Lower Ordovician isopachs are not very successful due to the difficulties with the Cambro-Ordovician contact, they do seem to show thinning.

The age of the Wisconsin Arch has been variously assigned to Cambrian or Precambrian dates. Workman (1935) believed the Arch had a pre-St. Peter age and was dissected so that formations as low as the Franconia were removed. Cohee (1947) considered an Upper Cambrian and Lower Ordovician age based upon: (1) the predominance of sandstones of these ages in Eastern Wisconsin; (2) the dolomite to sand ratio in rocks increased to the south and east from Wisconsin; and (3) in Michigan the Eau Clair, Trempealeau and Prairie du Chien formations were more sandy on the west side of the Basin than on the east. Road logs (1960, MBGS Annual Field Excursion, stops 7 and 8) from Mazomanie, Wisconsin show that the Wisconsin Arch was positive by Jordan time due to: (1) the thinning of the Jordan sandstone to 18 feet over the Arch, a facies change, and the presence of granules and pebbles of Baraboo quartzite in the Jordan; and (2) the Oneota rests unconformably on the thinned Jordan and 40 feet of Oneota is overlapped along the crest of the Wisconsin Arch. Ekblaw (1948) said the major movements of the Arch occurred in post-Cambrian time with less movement in Cambrian time.

The origin of the Michigan Basin has been the source of much debate since Houghton's study of the rocks of the Northern Peninsula in 1814. Pirtle (1932) thought that the Basin probably originated in Precambrian time. The Wisconsin and Kankakee Arches, he believed, were the cores of Precambrian mountains that stretched from central Wisconsin into NW Indiana and that principle folds that now exist in later sedimentary rocks were controlled by trends of folding or lines of structural weakness that existed in basement rocks. Folding by compression was most intense in Mississippian time. Newcomb (1933) also believed that the inherent structure of the Basin was of Keweenawan (Precambrian) origin. He stated that the present anticlinal trend (NW-SE) in the Basin was the result of reactions of zones of weakness developed in the basement during late Precambrian disturbances to the northeast. Lockett (1947) said downwarping of the basin was caused by sedimentary loading, causing block faulting in the basement. The source of these sediments were Precambrian mountains, the cores of which today are the

Algonquin and Findlay Arches. Cohee and Landes (1955) were of the opinion that incipient folding of sedimentary rocks (NW-SE) occurred intermittently in the Paleozoic with the main diastrophic activity during the Lower Mississippian-pre-Pennsylvanian emergence. Structural traps were believed formed or sharpened at this time with the greatest downwarping of the basin occurring during the Late Salina and Middle Devonian. Green (1957) believed that the Michigan and surrounding basins sank while the present bordering structures remained stable, with the age of the Michigan Basin being Niagaran. Hinze and Merritt (1969) used geophysical as well as geological data to state that:

> The major rift zone (Mid-Michigan Gravity and Magnetic High) is believed to have had a dominant role in the development of the Michigan Basin. The Basin may have originated from loading of the crust by the excess mass of the mafic rock in the rift zone. Subsequent deformation . . . has been associated with movements along lines of basement weakness, apparently related to the rift zone.

Fisher (1969), using Cambrian and Ordovician isopach maps gave a Middle Ordovician age to the Basin. Seyler (1974) considered a Middle Ordovician origin for the Michigan Basin.

Prouty (1970) concludes that the basic structural patterns of the Basin, including basement lineations and bordering structures, was inherited from the Upper Precambrian. He relates crucial episodic events to the "overall picture," and from structure and isopach maps used in conjunction with facies studies indicates evidence of the Kankakee Arch in Lower Ordovician (and later) time, the Findlay Arch in Upper Cambrian (and later) time and the Chathum Sag in Upper Cambrian (evidence in Middle and Upper Ordovician). Catac~~a~~osinos (19~~74~~72) believed a precursor of the Michigan Basin existed back to Late Cambrian time, at least.

A recent paper by Haxbe, Turcotte and Bird (1976) presents a thermal contraction mechanism for the evolution of the Michigan Basin. Their model involved mantle diapirs rising to about the Moho, heating the lower crustal rocks, causing their transformation from meta-stable gabbroic rocks to eclogite. They state "Initially the lighter mantle rocks nearly balanced the heavier eclogite. As the mantle rocks cool by conduction, the Basin subsided under the load of the eclogite."

Structures within the Michigan Basin (Howell Anticline, Lucas-Monroe Monocline, Albion-Scipio trend, etc.) are generally thought to be fault controlled with the faulting associated with the Precambrian basement rocks (Ells, 1969; Fisher, 1969; Harding, 1974). Ells (1962, 1969) has presented some excellent summaries on the trends in the Basin while Prouty (1970) has summarized notable trends within the Basin, including: (1) the NW-SE and NE-SW folding with evident lateral faults; (2) fairly definite radial-like fold patterns; (3) persistent joint patterns at several rim locations; and (4) the shift in the structural and isopach basin center in each system up to the Mississippian--that must be explained in any model of the origin of the Michigan Basin.

More recently Prouty (1976) has concluded on the basis of LANDSAT imagery studies that lineaments gleaned from the studies are shear faults, that most basin folds are fault related, that the principle faulting and folding was in pre Marshall-Mississippian time, and that the causative shearing stresses are related to structural activity in the east (Appalachians).

STRATIGRAPHY

General

In any consideration of the stratigraphic distribution of the Prairie du Chien Group in the Michigan Basin the effects of the Post-Knox Unconformity (post Lower Ordovician) upon its surface becomes of paramount importance. In southcentral Michigan erosional processes have removed large sections of the Prairie du Chien Group while in southeast Michigan not only is the Prairie du Chien missing but also portions of the Upper Cambrian formations as well (Figures 4b and 4c). Because many of the gamma ray logs that were used in conjunction with the samples were of limited extent beneath the unconformity surface, the general lithology of the Upper Cambrian units must be known and identified.

Upper Cambrian

The Munising sandstone (Figure 7) was named for exposures at Munising, Michigan by Lane and Seaman (1907). It included the later named (Hamlin, 1958) Chapel Rock sandstone (equivalent to the Mt. Simon and Eau Claire sandstone of the Southern Peninsula) and the Miners Castle

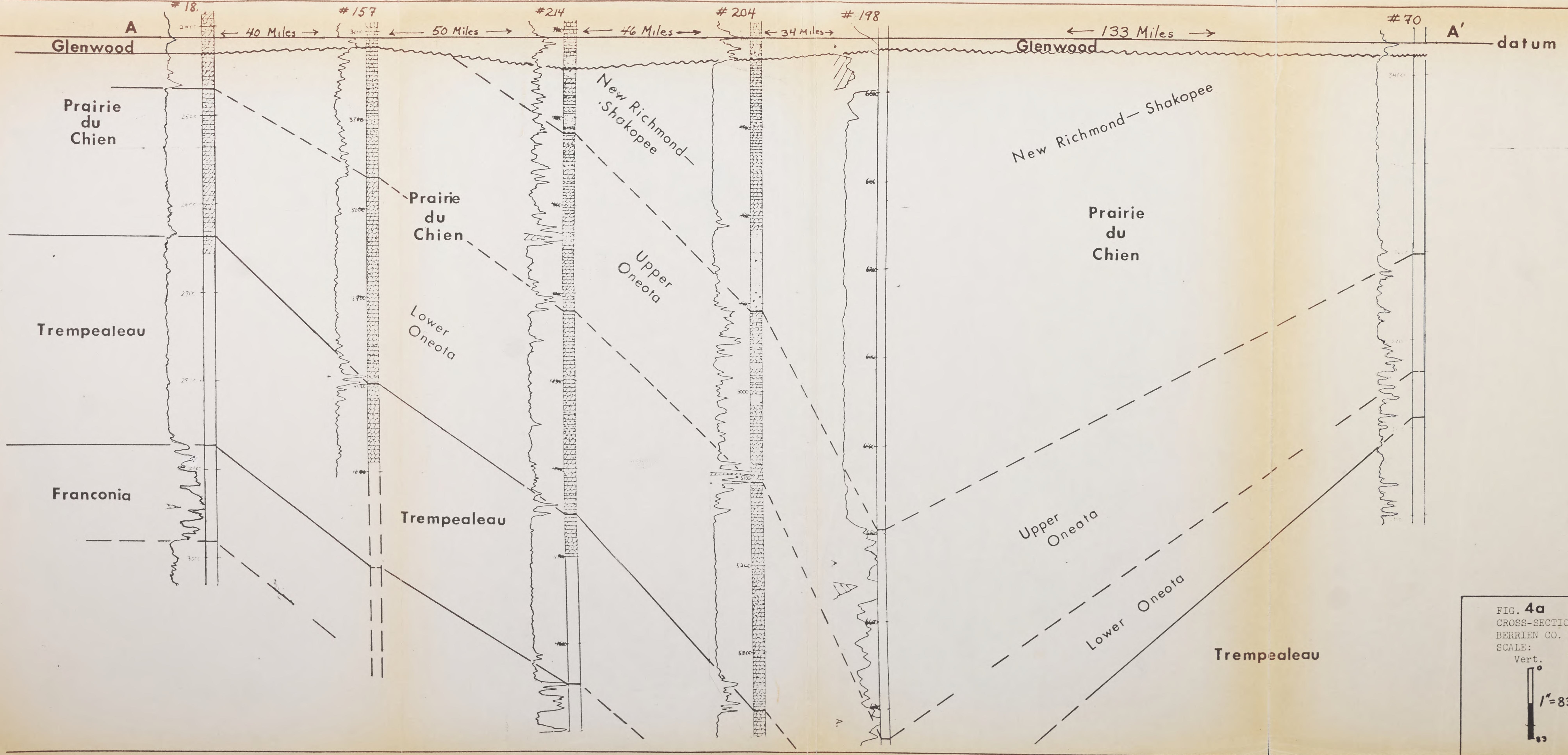
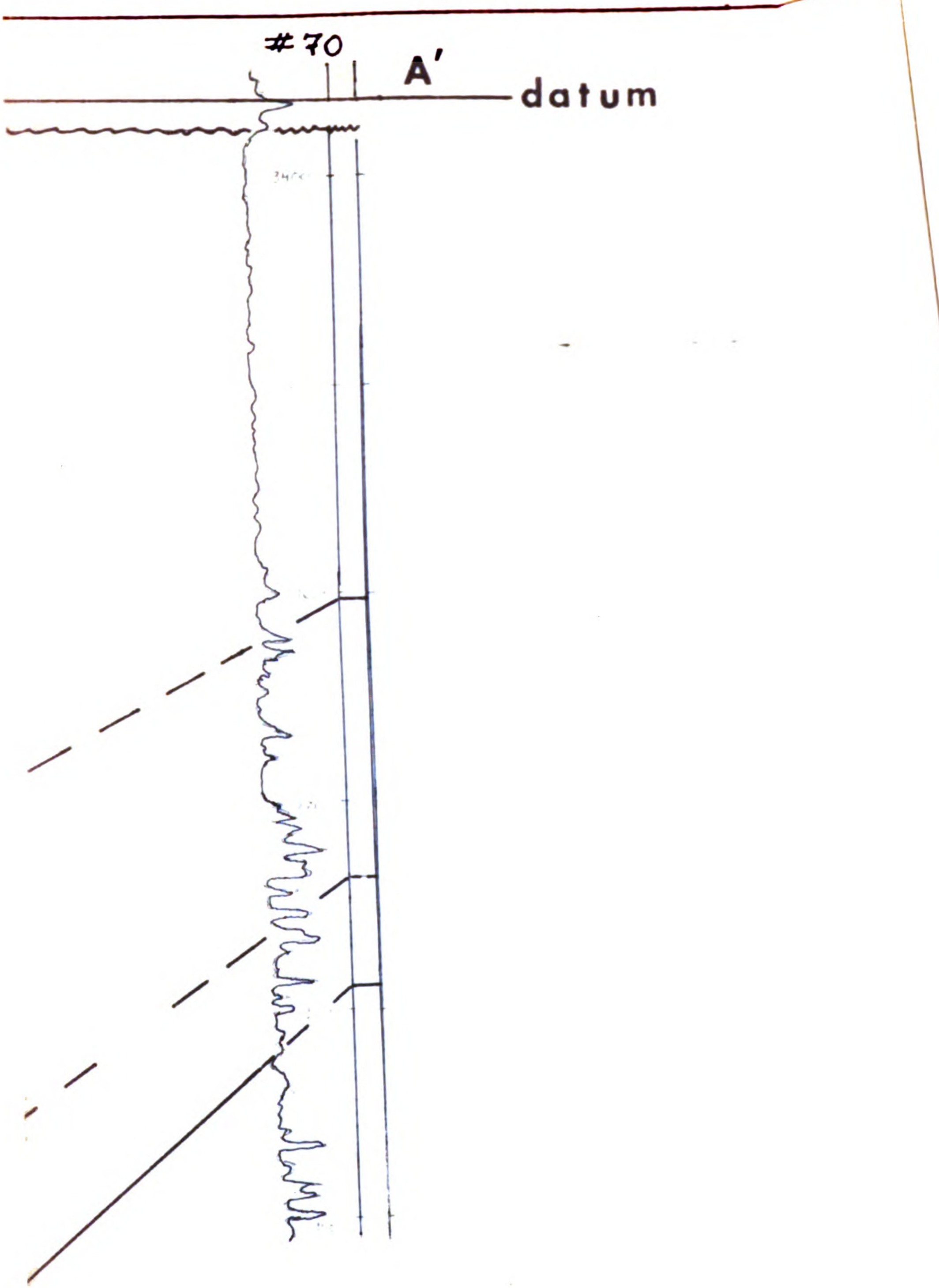


FIG. 4a
CROSS-SECTION A - A'
BERRIEN CO. to CHARLEVOIX CO.
SCALE:
Vert. Horz.
1" = 83'
1" = 18 Miles

RMS 1977



ealeau

FIG. 4a
CROSS-SECTION A - A'
BERRIEN CO. to CHARLEVOIX CO.
SCALE:
Vert. Horz.
1"=83' 1" = 18 M

RMS

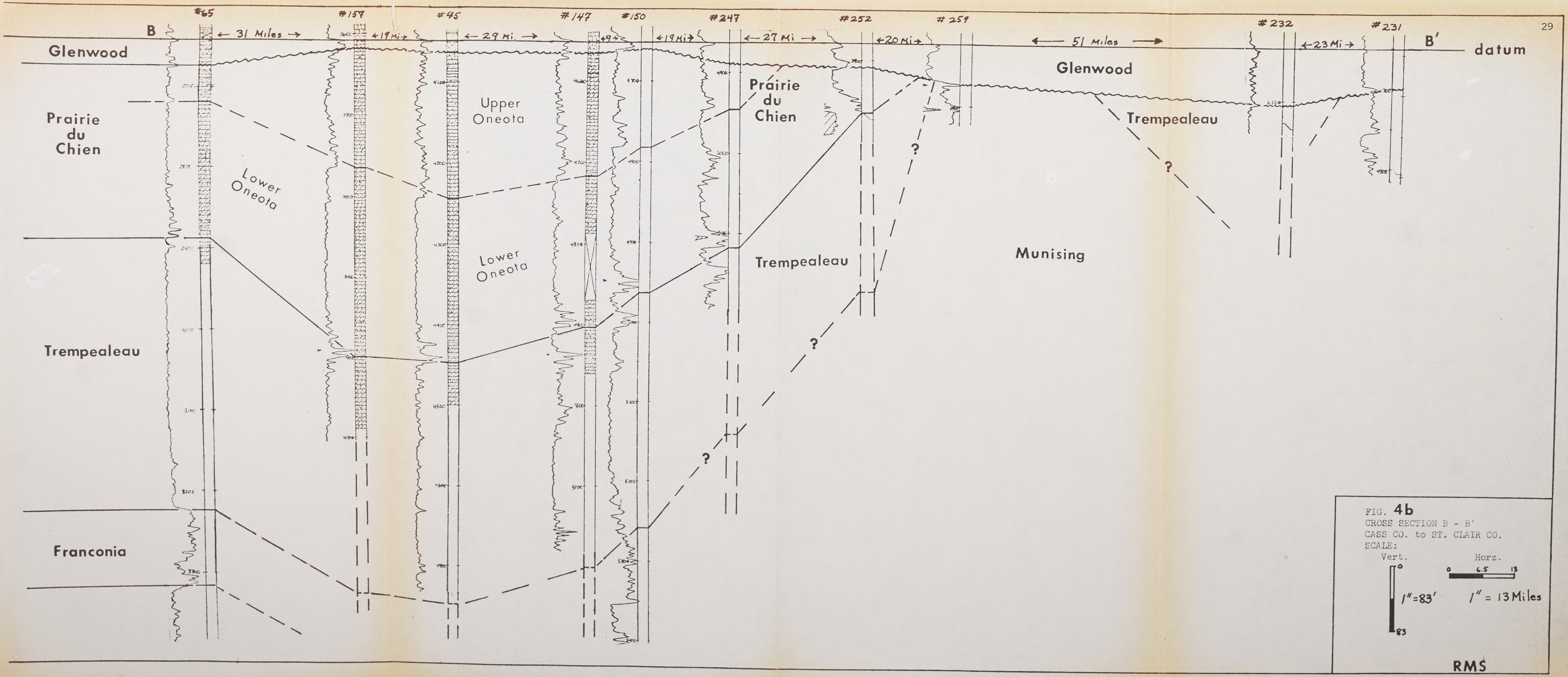


FIG. 4b
CROSS SECTION B - B'
CASS CO. to ST. CLAIR CO.
SCALE:
Vert. 1"=83'
Horz. 1" = 13 Miles

RMS

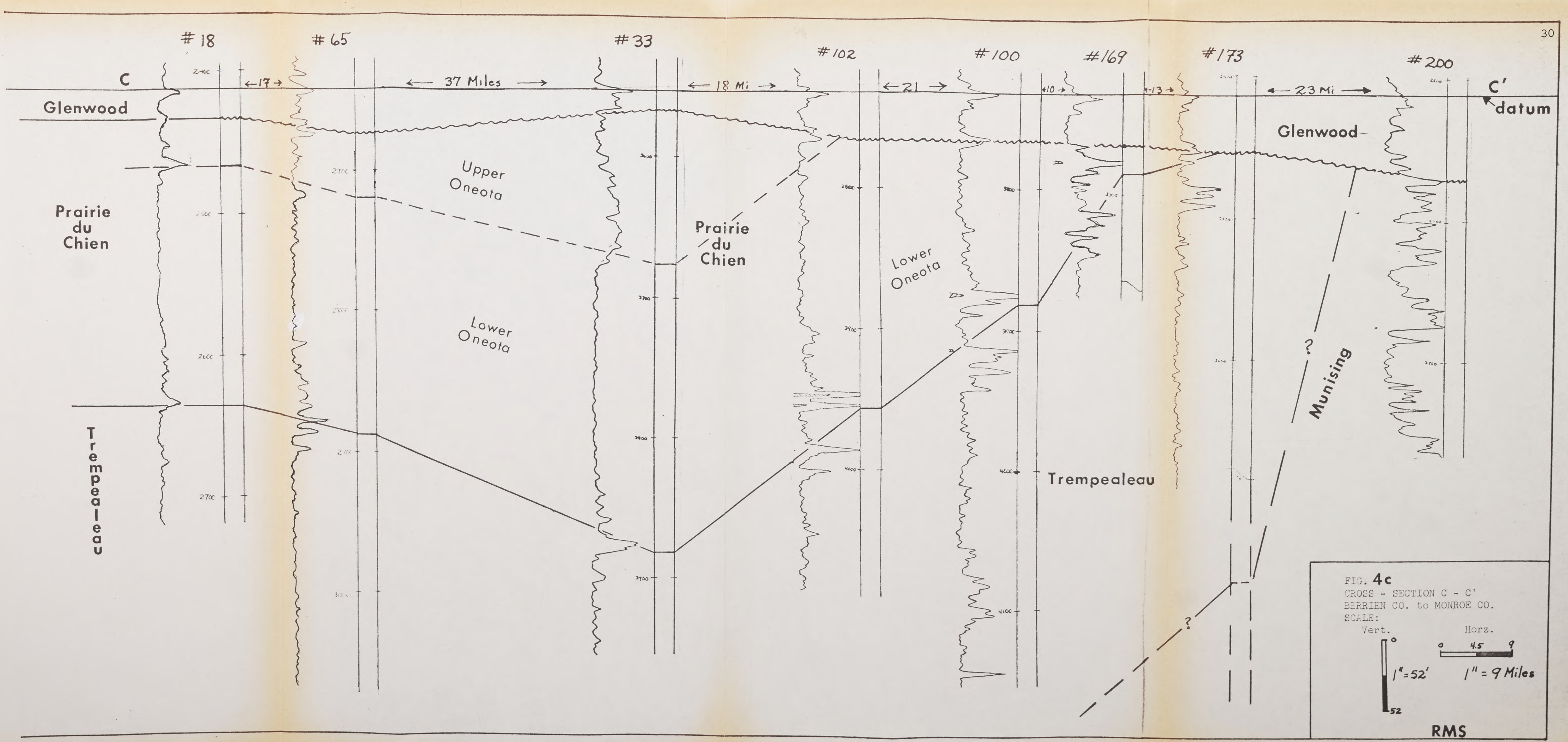
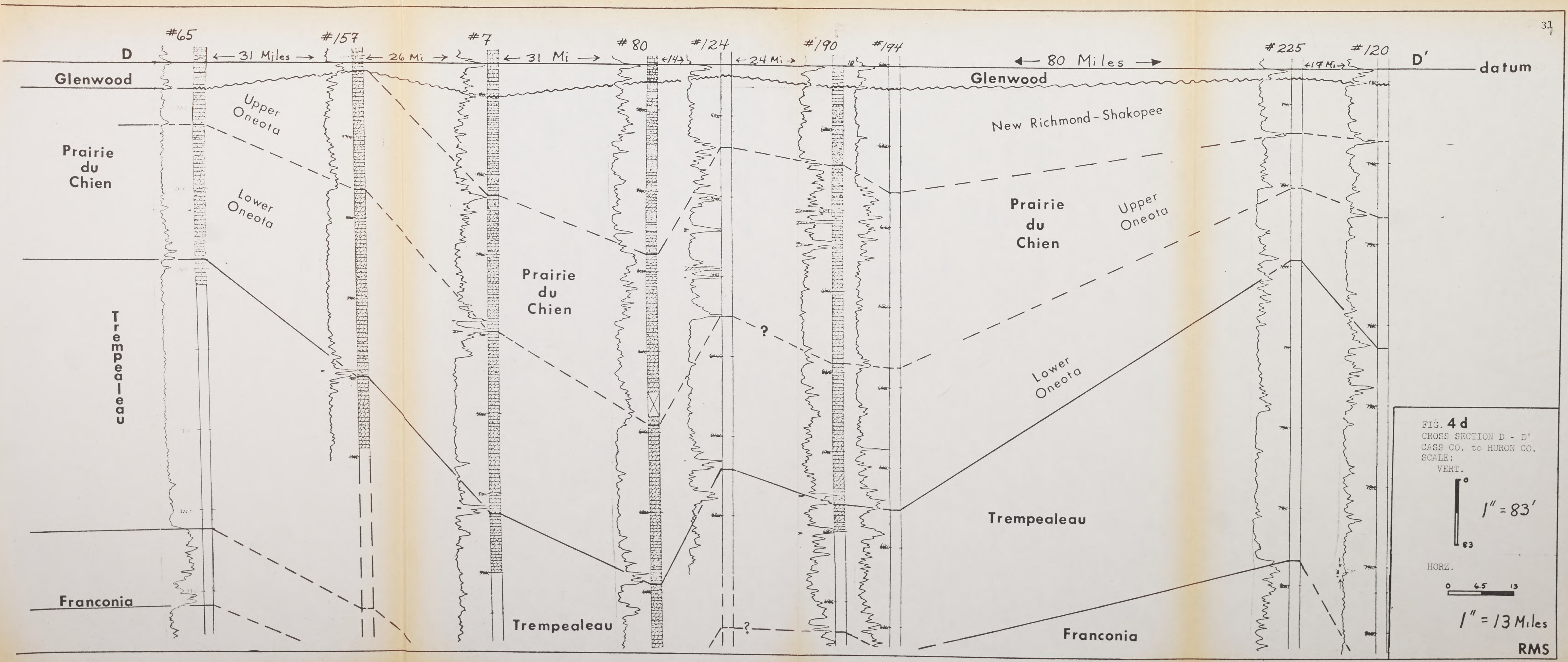


FIG. 4c
CROSS - SECTION C - C'
BERRIEN CO. to MONROE CO.
SCALE:
Vert. 1" = 52'
Horz. 1" = 9 Miles


#65
#157
#7
#80
#124
#190
#194
#225
#120
D
D'
← 31 Miles →
← 26 Mi →
← 31 Mi →
←14→
← 24 Mi →
← 80 Miles →
←17 Mi→
datum
Glenwood
Glenwood
Upper Oneota
Prairie du Chien
Lower Oneota
Trempealeau
Prairie du Chien
?
New Richmond - Shakopee
Prairie du Chien
Upper Oneota
Lower Oneota
Trempealeau
Trempealeau
Franconia
Franconia
FIG. 4 d
CROSS SECTION D - D'
CASS CO. to HURON CO.
SCALE:
VERT.
1" = 83'
HORZ.
0 6.5 13
1" = 13 Miles
RMS

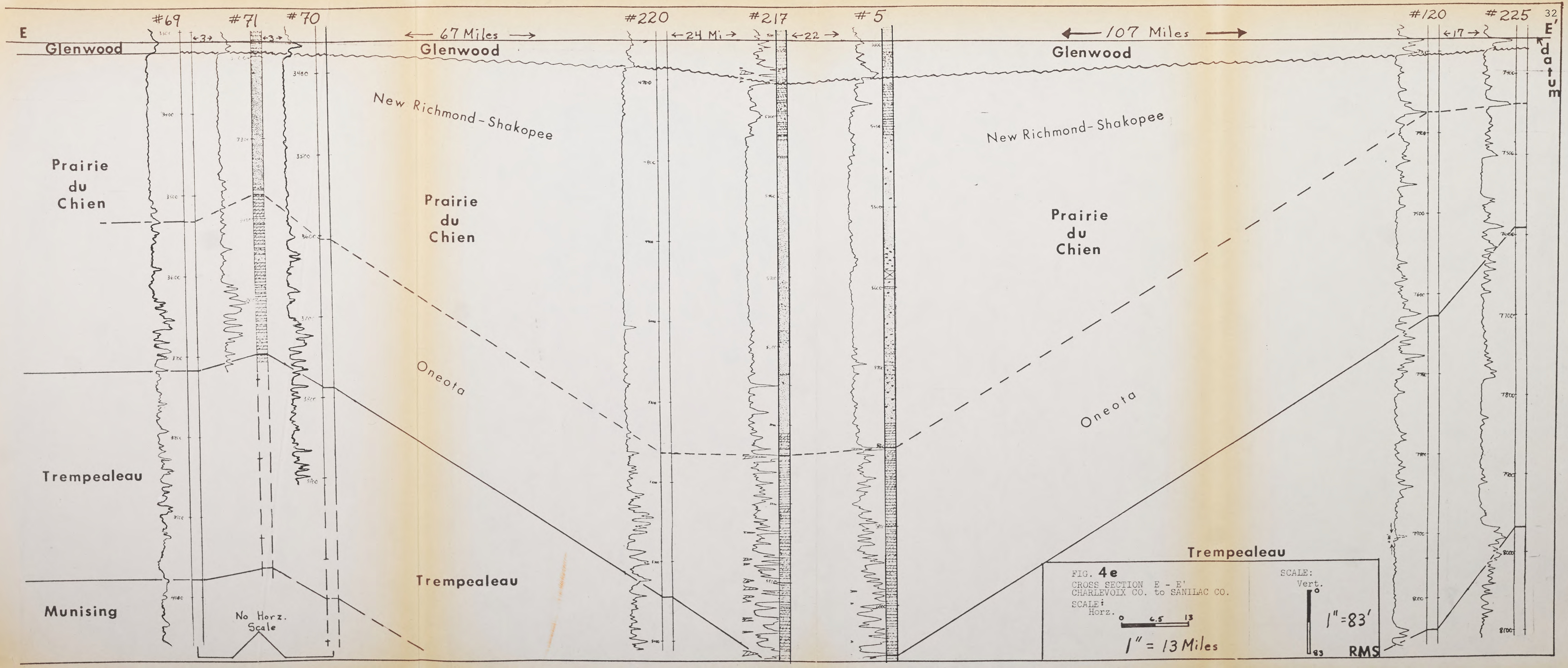


FIG. 4e
CROSS SECTION E - E'
CHARLEVOIX CO. to SANILAC CO.

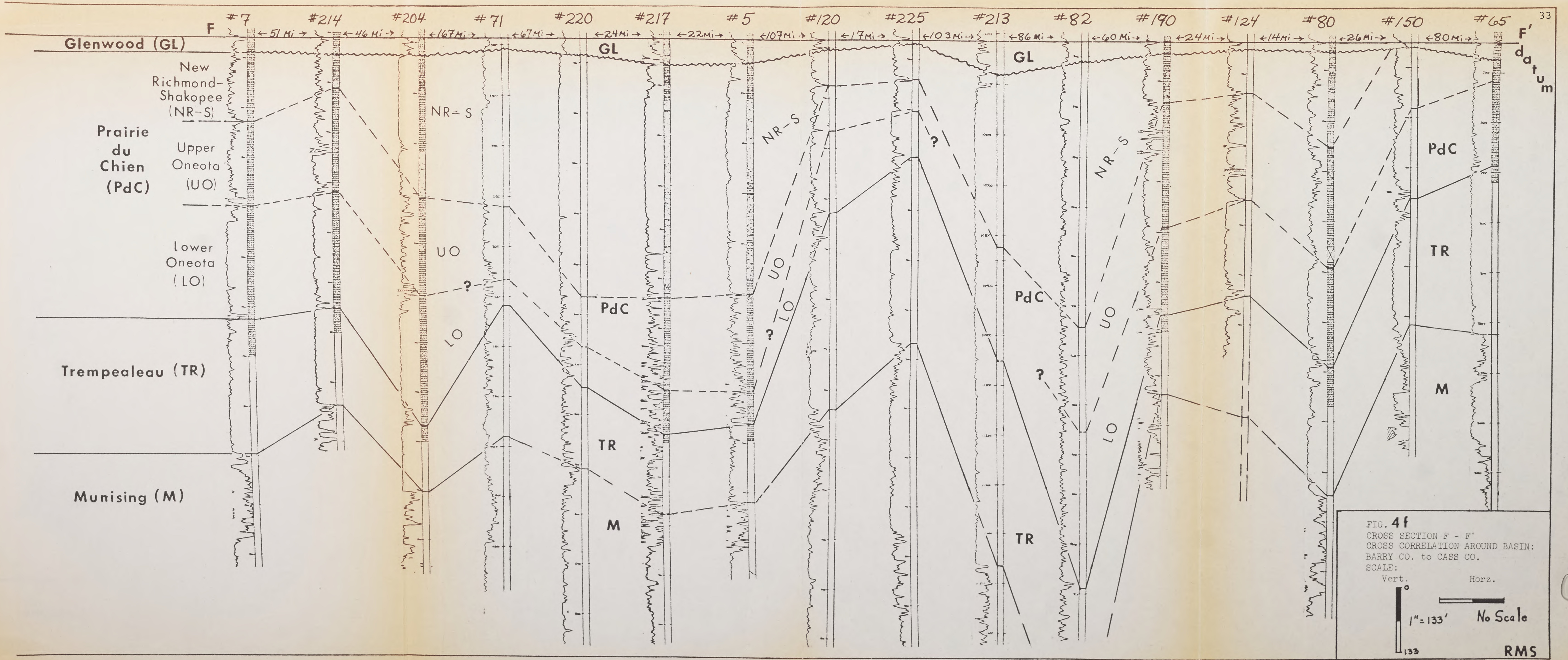


FIG. 4f
CROSS SECTION F - F'
CROSS CORRELATION AROUND BASIN:
BARRY CO. to CASS CO.
SCALE:

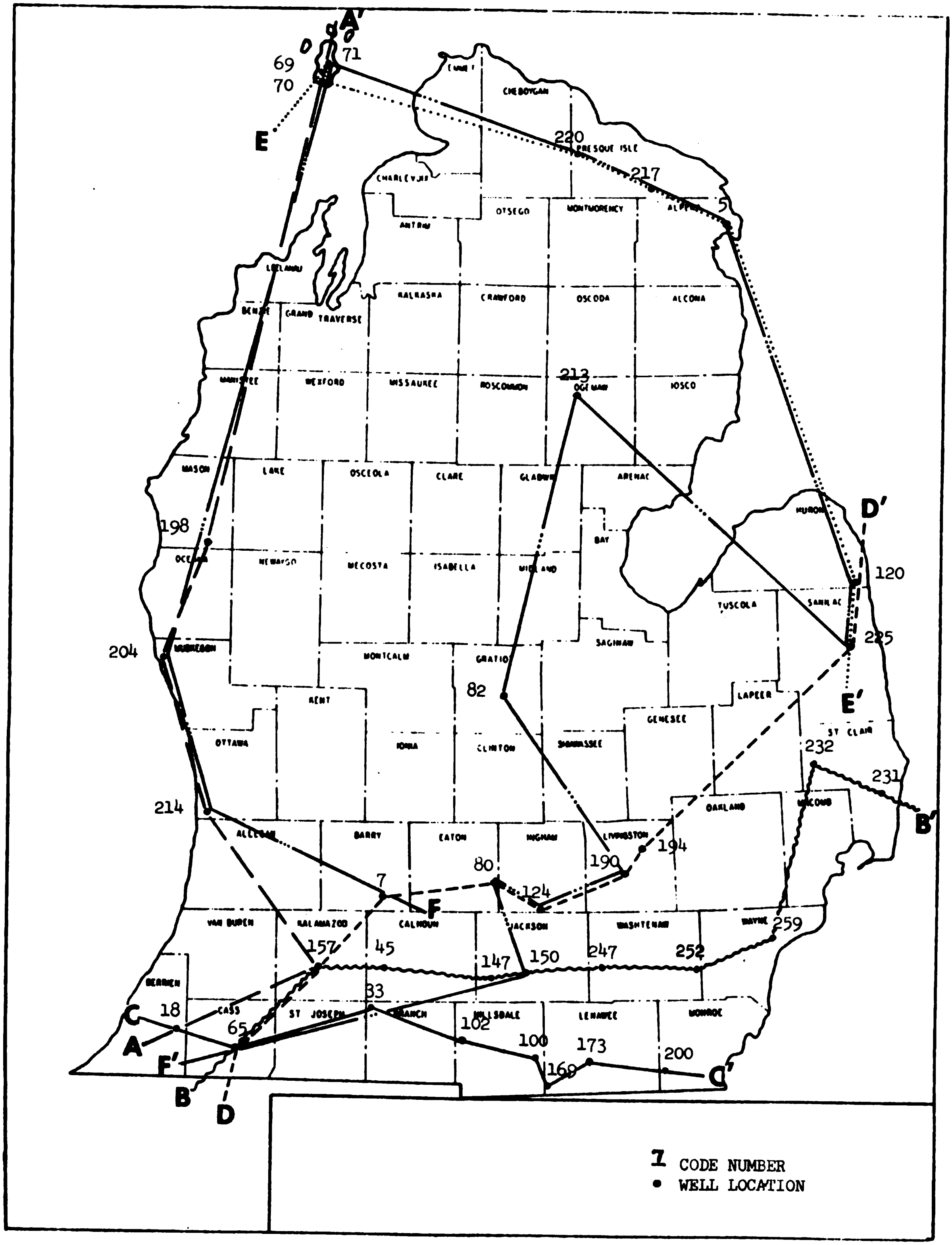


Figure 5

Regional Map of Lower Michigan Showing Stratigraphic Correlation Lines A - A' thru F - F'

Table 1

Wells Used in Stratigraphic Correlation

Code No.	Operator-Farm	Location	County
5	PEPC-Ford Motor Co. #1-5	31N 9E 5	Alpena
7	Battle Creek Gas Co.-BD #2	1N 8W 14	Barry
18	Security-Thalmann #1	6S 17W 10	Berrien
33	C.P.C. & Quintana-Clark #1	5S 8W 8	Branch
45	Bernloehr-Poole #1	3S 8W 13	Calhoun
65	Perry-Wooden #1	7S 14W 8	Cass
69	McClure-St. Beaver #2	37N 10W 6	Charlevoix
70	McClure-Goddard #1	37N 10W 19	Charlevoix
71	McClure-St. Beaver #1	38N 10W 27	Charlevoix
80	Mobil-Kelly #1	2N 3W 24	Eaton
82	McClure-Sparks et al. #1-8	10N 2W 8	Gratiot
100	Perry-Rymal #1	7S 1W 15	Hillsdale
102	Houseknecht-Price, Stafford #1	6S 4W 20	Hillsdale
120	Mobil-Volmering #1	15N 15E 26	Huron
124	Mobil-Reeve #1	1N 1W 36	Ingham
147	Rousek-McFarlane #1	3S 3W 35	Jackson
150	Collins & Black-Dancer #1	eS 1W 29	Jackson
157	Upjohn-Upjohn #3	3S 11W 14	Kalamazoo
169	Moco-Flint Comm #1	8S 1E 31	Lenawee
173	Horizon-Meech & Griffith #1	7S 3E 30	Lenawee
190	Brazos-Kizer #1	2N 4E 14	Livingston
194	Mobil-Messmore #1	3N 5E 11	Livingston
198	Superior-Sippy #17	17N 16W 25	Mason
200	Ashland-Nichols #1	8S 6E 5	Monroe
204	DuPont-DuPont Disposal #1	12N 18W 36	Muskegon
213	Brazos-St. Foster #1	24N 2E 28	Ogemaw
214	Holland Suco-Suco D.W. #1	5N 15W 30	Ottawa

Table 1.--Continued.

Code No.	Operator-Farm	Location	County
217	Shell-Shell Taratuta #1-13	33N 5E 13	Presque Isle
220	Pan Am-Dreysey #1	35N 2E 29	Presque Isle
225	McClure & M.N.R.-Hewitt & Shedd #1-20	12N 15E 20	Sanilac
231	C.P.C.-Roney #1	5N 16E 11	St. Clair
232	Lanphor O & G-Lyle #1	7N 13E 28	St. Clair
247	N.Y. Petromineral-Widmayer #1	3S 3E 21	Washtenaw
252	Rousek-Wabash R.R. #1	3S 7E 24	Washtenaw
259	PEPC-Ford Motor Co. #1	2S 11E 19	Wayne

sandstone (comparable to the Dresbach and Franconia formations of Southern Michigan).

The Mt. Simon (Figure 7) was named by Ulrich for exposures at Mt. Simon near Eau Claire, Wisconsin (in Walcott, 1914). In southeastern Michigan, Cohee (1948) described the sandstone as 300 feet of medium to coarse grained sandstone with angular to rounded grains, and a few thin beds of dolomite and sandy dolomite occurring in the upper part of the sandstone.

Wooster (1882) first used the term Eau Claire for exposures along the Eau Claire River in Eau Claire County, Wisconsin. In northern Michigan it is entirely sandstone while in southeast Michigan it consists of around 250 feet of sandstone, shale, and dolomite that is shaly, sandy and glauconitic. The dolomite beds may be gray to dark gray, pink, purple, and red to brown in color; and the shale also is variously hued (Cohee, 1948). Catacosinos (~~1974)~~ 1973 recognized the "bi partite" character of the Eau Claire, describing the lower portion as a sandstone, finer grained than the underlying Mt. Simon, often light gray with dolomite cement and glauconite, and the upper zone comprised of dolomitic sandstones, sandy and silty dolomites and often dark grey shale, which locally are glauconitic. The Eau Claire becomes increasingly sandy in western Michigan.

The term Dresbach was proposed by Winchell (1886) for beds of grey micaceous sandstone of Upper Cambrian age at Dresbach, Minnesota. In Michigan, Cohee (1947, 1948) lithologically describes it as a fine to medium grained sandstone with angular to rounded, frosted and pitted quartz grains. Thin beds of white to buff dolomite are found in parts of the sandstone, which is 100 feet thick in southeastern Michigan.

Berkey (1897) named the Franconia Sandstone after the section at the village of Franconia, Minnesota. The Franconia is comprised of fine to medium grained, angular to well rounded, frosted and pitted sandstone (possibly derived in part from reworked Dresbach). Thin beds of dolomite occur with the sandstones in places and both the dolomite and especially the sandstones are glauconitic. In southeastern Michigan it is from 10 to 20 feet thick (Cohee, 1947, 1948). Pennington (1967) described the Franconia of the Perry-Wooden #1 well in Cass County as a sandy and glauconitic, dolomitic siltstone.

The Trempealeau Formation, proposed by Ulrich (1924) is named for exposures at Trempealeau, Trempealeau County, Wisconsin. It is a distinct lithologic unit predominantly of dolomite, somewhat sandy in part, and also shaly dolomite, with dolomitic shale at the base. Small amounts of oolitic chert is found, as well as glauconite (Cohee, 1948). The Trempealeau is divided into three members, the St. Lawrence, the Lodi and the Jordan Sandstone, in ascending order.

The St. Lawrence was named by Winchell (1874) for outcroppings at St. Lawrence, Scott County, Minnesota. The basal St. Lawrence consists of gray, sandy, very glauconitic dolomite overlain by dark gray to black dolomitic shale and dolomite in southeast Michigan (Cohee, 1948).

Ulrich (1924) proposed the term Lodi for those rocks found at Lodi, Columbia County, Wisconsin. In Michigan they are described as a white to buff dolomite that may be glauconitic and sandy in part. Some dolomite is gray to dark gray, pink to purple and argillaceous with the pink dolomite occurring locally (Cohee, 1948).

Exposures at Sand Creek near the town of Jordan, Scott County, Minnesota were termed the Jordan Sandstone by Winchell (1874). According to Cohee (1948) it consists of well rounded, frosted and pitted quartz grains from 5 to 30 feet thick and is not present in southeastern Michigan. Thwaites (1943) indicated that the Jordan Sandstone was missing from the Northern Peninsula and that the Cambro-Ordovician contact occurred at the top of the prevailing red or pink, noncherty sandy dolomite (Upper Cambrian) which was overlain by a gray cherty dolomite (Lower Ordovician).

Lower Ordovician

The Prairie du Chien Group (Figure 7) was classified as Lower Ordovician by the United States Geological Survey and included the Oneota Dolomite, the New Richmond Sandstone and the Shakopee Dolomite, in ascending order. It was named for exposures in the vicinity of Prairie du Chien, Crawford County, Wisconsin by Bain in 1906.

The Oneota Dolomite (Figure 7) was named by McGee (1891) for outcroppings on the Oneota River (Upper Iowa River), Allamakee County, Iowa. Cohee (1948) described the Oneota in Upper and Lower Michigan as a buff to brown dolomite, very sandy and cherty in part, with the chert commonly oolitic. Green shale also occurs locally.

Wooster (1878) named the New Richmond Sandstone after the section at New Richmond, St. Croix County, Wisconsin. This formation is present in southwest Michigan as a thin sandstone unit overlying the Oneota and underlying the Shakopee (Cohee, 1948). Thwaites (1943) reported that in the Northern Peninsula there were at least two fairly persistent sandstones in the Prairie du Chien and that a three-fold subdivision should not be attempted.

The Shakopee Dolomite was named for rocks at Shakopee, Scott County, Minnesota by Winchell (1874). In southwestern Michigan it is a buff, brown and gray dolomite, sandy in part with thin beds of green shale and small amounts of chert (Cohee, 1948). The Shakopee

Formation has not been recognized in the Northern Peninsula of Michigan except by Dixon (1961).

Middle Ordovician

The St. Peter Sandstone (Figure 7) of Lower Middle Ordovician age was named by Owen (1947) for exposures along the Minnesota River (formerly the St. Peter River) in southern Minnesota. It consists of a fine to medium grained, white, friable sandstone locally stained brown, orange or yellow. It is subrounded to well rounded, frosted and pitted (most evident on larger grains), loose and often loosely cemented with dolomite, silica or calcite. It is commonly associated with chert and pyrite at the base, and recognized by its properties of high quartz content (99%+), uniform grain size distribution, and high degree of rounding. The extent of the St. Peter has been generally restricted to western Michigan, although various authors have placed a more easternly boundary to the sands (Dapples, 1955; Horowitz, 1961) or totally eliminated it from the Michigan Basin (Catacosinos, 19~~74~~72).

The Glenwood was named for Glenwood Township, Winneshick County, Iowa and was described by Calvin (1906). In southwestern Michigan the Glenwood was described as a fine grained sandstone and shaly dolomite ranging from 10 to 100 feet thick. In southeastern Michigan it was described as a green, brown or gray shale, sandy and pyritic in places. At the contact with the underlying dolomite the shale is commonly sandy (Cohee, 1948). Seyler (1974) characterizes the Glenwood in Michigan as:

> an interval of green gray and black sandy shale and limestone and dolomite . . . representing deposits derived from the erosion of Upper Cambrian and Lower Ordovician sediments and the marine transgression of the Middle Ordovician sea."

Vanuxem (1838) named the Black River Formation (Figure 7) from exposures along the Black River in New York State. The Black River is a brown to gray, lithographic to crystalline, fossiliferous limestone and dolomite. The basal beds are often dark gray to black, argillaceous limestone, or limestone, dolomite and shale. Secondary dolomitization occurs locally, with the Black River becoming generally more dolomitic to the west.

Prairie du Chien Group

In this study, one of the major problems encountered was the determination of the contact of the Prairie du Chien with the overlying St. Peter Sandstone and Glenwood Shale (considered together as the Glenwood in this report). From the gamma ray-neutron log (Figure 6) the top of the Glenwood is obvious and characteristic. The basal contact, however, often is difficult to choose, especially where the St. Peter is developed, for there is no apparent characteristic St. Peter kick on gamma ray-neutron logs (Balombin, 1974). It is only when used in conjunction with lithologic information that the logs can be used with some degree of accuracy.

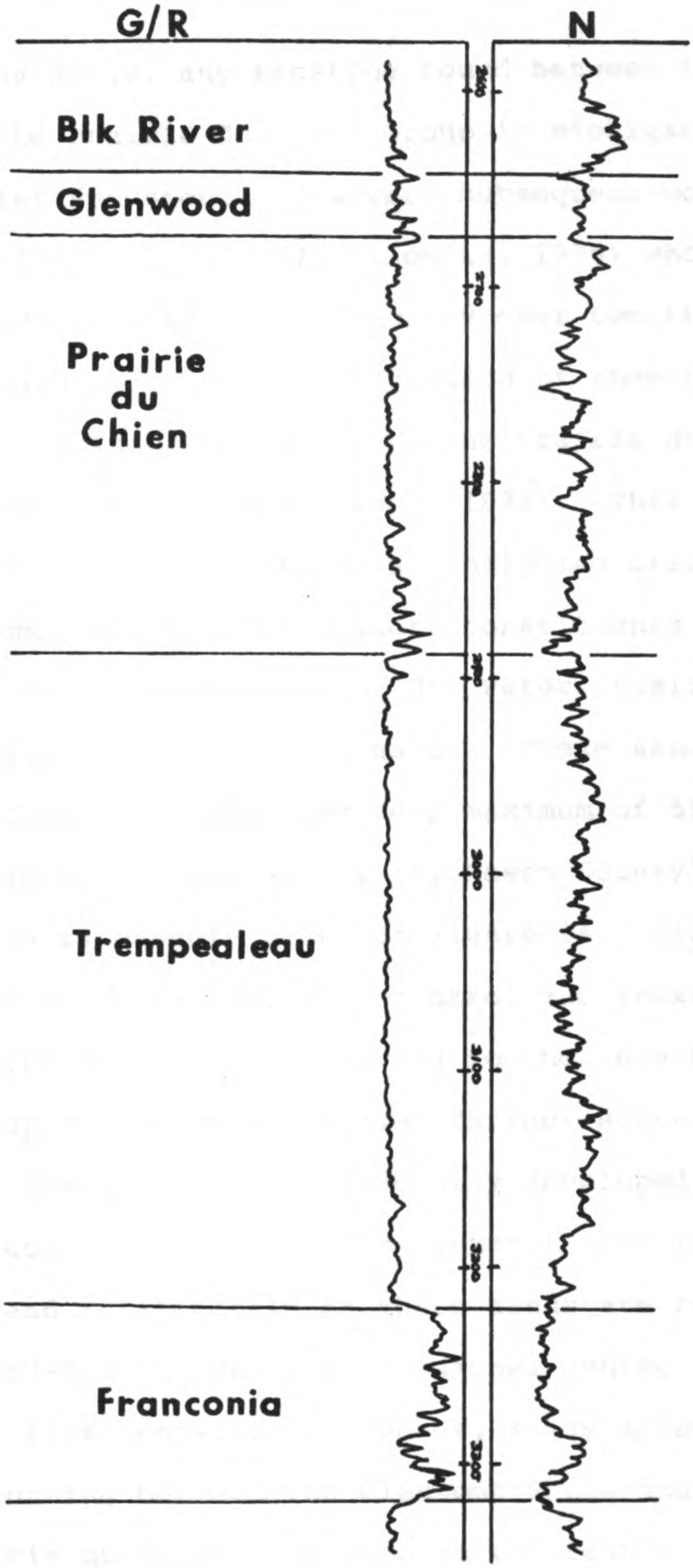


Figure 6

Typical Gamma Ray-Neutron Well Log

Previously, any sanstone found between the Glenwood Shale and the Prairie du Chien Group in Michigan was termed the St. Peter Sandstone. However, subsequent workers (Horowitz, 1961; Ells, 1967; Balombin, 1974) who have investigated these sands that occupy over two-thirds of the state have assigned only a portion of them to the St. Peter, the remainder belonging to the Prairie du Chien Group, or the Jordan (Catacosinos, 19~~74~~72). This subdivision was based on lithologic criteria, including grain shape, sorting, cementation and accessory constituents (chert, etc.), due to the similarity of St. Peter, Prairie du Chien and some Upper Cambrian sands. These sands range from a thickness of zero feet to a maximum of 590 feet in Well #199 (Dow, Brazos-Taggert #1, Mason County) and their distribution is roughly shown in Figure 14. Difficulties result from both the poor well control and inexact stratigraphic correlation of these sands to the interbedded sands, sandy dolomites and shales farther south and east; as well as the erosional unconformity developed upon its surface. Cognizant of this, the general distribution, thickness and relationship of these sands are related to the Glenwood-Prairie du Chien erosional contact. It would be best to first consider the sands, sandy dolomites and shales occurring between the Glenwood Shale and the underlying Prairie du Chien dolomites as the result of some combination of factors, including:

(1) the thick sands and sandy dolomites suggest exposure or uplift of the Wisconsin Arch or environs in upper Lower Ordovician time, with deposition occurring in foredeeps offshore, and facies changes across the Basin;

(2) that the section in some areas may be Glenwood containing reworked St. Peter, Prairie du Chien and Upper Cambrian sands;

(3) that in areas the St. Peter is part or all of the section;

(4) the section may be in part a clastic zone at the top of the Prairie du Chien where sand and silt filled solution joints and vugs developed on a karst terrain (as in the Sandhill Deep Well, Wood County, West Virginia where the thickness of the zone was 122 feet (Woodward, 1959)); and/or

(5) where the lithologies of the rocks below the sands are questionable, the section could possibly be an Upper Cambrian sand exposed by the erosional unconformity.

The Cambro-Ordovician boundary is not easily identified by lithology in the Michigan Basin because of the gradational nature of the contact between the basal Prairie du Chien Group and Trempealeau Formation. Therefore, the contact was established utilizing the gamma ray curve on the radioactivity log in conjunction with lithologic information (Figures 4a to 4f). Using two reference wells where the Cambro-Ordovician boundary had previously been determined (Well #18, Security-Thalmann #1, Berrien County and Well #65, Perry-Wooden #1, Cass County) stratigraphic correlations were carried out for the Michigan Basin. Ells (1967), Pennington (1967) and Yettaw (1967) correlated the underlying Cambrian formations of the Security Thalman #1 and Perry-Wooden #1 wells with established wells in Indiana and northwest Illinois closer to the type sections on the basis of gamma ray logs and similar lithologies to establish the Trempealeau-Prairie du Chien contact in southwest Michigan. It was noted by Pennington (1967) that the Trempealeau has a lower gamma radiation than the Oneota due to the shale content of the Oneota. In southwestern and southern Michigan the writer recognizes that this contact is often characterized by the presence of green, red and mottled shales that become increasingly grey to black basinward. While these shales are more indicative of environmental conditions the position of these shales coincide with equivalent stratigraphic positions on the gamma ray logs. The variability of the gamma ray contact basinwide is on the order of plus or minus 10 to 15 feet with a maximum of thirty-five feet and was subjectively established.

The Prairie du Chien Group (Figure 13) ranges in thickness from zero feet in southeast Michigan to a maximum thickness of 1080 feet in west central Michigan (Well #207, Thunder Hollow-Thompson #1, Newaygo County). A subdivision of the Prairie du Chien, while difficult, was attempted at the gradational boundary between the thick sands and underlying dolomite (Figures 4a, d, e, f). Both Cohee (1948) and Ells (1967) placed these sands in the Oneota formation, Cohee believing the Oneota becomes increasingly sandy to the north from southwest Michigan. On the basis of gross lithology and stratigraphic position the writer deems it advisable to classify these sands and associated sandy dolomites as equivalent to the New Richmond (and possibly Shakopee) formation(s). The thick sands are often fine to medium grained, frosted to slightly frosted, subrounded to rounded and contain numerous overgrowths, similar to the descriptions of the New Richmond in Wisconsin (Kay, 1935) and Illinois (Willman and Templeton, 1952; Buschbach, 1964). The appearance of the sand coincides with a marked decrease in gamma radiation on the logs owing to the decreased shale content and the increased sand content. Again, the boundary was subjectively picked on the basis of: similar lithology with surrounding areas; the appearance of the thick sands and/or interbedded sands, shales and dolomites, over a well developed Oneota Formation (in areas) at stratigraphically equivalent positions on gamma ray logs basinwide; and the absence of any well developed sand in the Oneota in surrounding states.

The variability of the exact contact is plus or minus twenty to a maximum of 50 feet toward the center of the Basin. From the gamma ray logs and lithologies a two-fold subdivision (discussed below) of the Oneota also occurs, similar in nature to the two members of the Chepultepec Dolomite as proposed by Calvert (1962) for northwest Ohio.

Oneota

Lithology.--The Oneota in the Michigan Basin is a buff to brown, gray and tan, fine to coarsely crystalline dolomite, locally stained pink to red. It is often sandy to silty, anhydritic and oolitic in part, containing chert, thin beds of sandstone and traces of glauconite, anhydrite and gypsum. The chert is predominantly white, dense to tripolitic, dolocastic and oolitic, and sandy in part; but may be orange to red with sandy and oolitic chert. Where argillaceous the dolomite is often interbedded with thin beds of green, gray, red and black shale (Appendix II, A-D).

The lower unit of the Oneota is a buff to brown, fine to coarsely crystalline dolomite containing white chert, floating sand grains (and some silt) becoming increasingly argillaceous and sandy at the base where it often is interbedded with green, red and gray, mottled shales and sandstones. The dolomites are buff-gray to tan, fine to medium crystalline, sandy and cherty, and locally stained pink to red. The chert is white to red, dense to tripolitic, and sandy and oolitic in part. The shales are variously colored red, green, black and gray, and mottled at times.

In the Upper Mississippi Valley and Wisconsin the Oneota consists predominantly of fine to medium crystalline, light brown, gray to buff, compact to vuggy, thin bedded to massive dolomite (Heller, 1956). The lower part of the member is commonly arenaceous with the basal few feet grading into sandy dolomite and dolomitic sandstone. White, porcelainous, oolitic, often fossiliferous chert nodules are a common constituent of the Oneota; as are greenish-gray shales containing algae (stromatolites). Sandstone, glauconite and goethite are locally common (Kay, 1935; Workman, 1935; Heller, 1956; Davis, 1969). The Oneota of northeast Illinois is made up of a basal, light gray to brown, medium to coarsely crystalline dolomite that is slightly glauconitic and very cherty, the chert being white to yellow and partly oolitic. It is overlain by a gray to pinkish gray, fine to medium crystalline, slightly glauconitic, partly sandy dolomite with small amounts of oolitic chert and thin beds of green shale (Buschbach, 1964). In northwest Indiana, Gutstadt (1958) described the Oneota as a light tan to gray, saccharoidal dolomite containing large amounts of chert of assorted colors and textures but commonly oolitic and some rounded and frosted sand. The Chepultepec Dolomite of northwest Ohio (Calvert, 1962) is the equivalent of the Oneota and consists of two members, a lower sandy member and an upper argillaceous unit. The lower sandy member is a light brown to light gray, sucrosic dolomite with interbedded dolomitic sandstone and argillaceous dolomite. The sandstones are white to gray, dolomitic, fine to medium grained, partly feldspathic with scattered gray and green shale and siltstone zones. The upper argillaceous member is a white to gray to light brown, fine to very fine crystalline dolomite. The upper member has more argillaceous dolomite and less chert than the lower member and both contain embedded, rounded, frosted quartz grains, oolitic chert and free silicious oolites.

An irregularly distributed basal sandstone has been found in the Upper Mississippi Valley, western Wisconsin, and northeast Illinois and northwest Indiana called the Kasota Sandstone, the Hickory Ridge member and the Gunter Sandstones, respectively (Buschbach, 1964). The Gunter was described by Buschbach (1964) as a medium grained, frosted, subrounded sandstone containing beds of light gray, fine crystalline dolomite and minor amounts of light green shale. The irregular distribution and sharp contacts suggest minor disconformities at the base and top of the Gunter.

Correlation.--The Oneota Formation of the Michigan Basin (Figure 7) is essentially equivalent (on the basis of stratigraphic position, lithologic similarities and an identifiable sequence of Cambrian and Middle Ordovician formations) to the Oneota Formation of the Upper Mississippi Valley, Wisconsin, northeast Illinois and northwest Indiana; the Chepultepec Dolomite of northwest Ohio, the Van Buren and Gasconade Formations of Missouri; the Little Falls of New York; and the Tanyard Formation of central Texas. Between areas of questionable correlation equivalent sections should be ascertained at the Series or Group level. Thus, the Prairie du Chien Group of the Michigan Basin is equivalent to the Upper Knox Dolomite of eastern Kentucky, the Chepultepec, Nittany, Kingsport and Mascot Formations of southwestern Virginia and eastern Tennessee, and the Beekmantown of West Virginia, Virginia, Pennsylvania and New York on the bases of stratigraphic position and similar lithologies.

Distribution and Thickness.--The Prairie du Chien Group crops out in northern Michigan, east and southwest Wisconsin, southeast Minnesota and northeast Iowa, often as the Oneota Formation. At the type area in southeast Allamakee County, Iowa the Oneota is about 170 feet thick, thinning northward to about 120 feet east of Minneapolis, Minnesota. In Wisconsin the dissected Oneota varies from zero to 150 feet thick and thickens to the southwest.

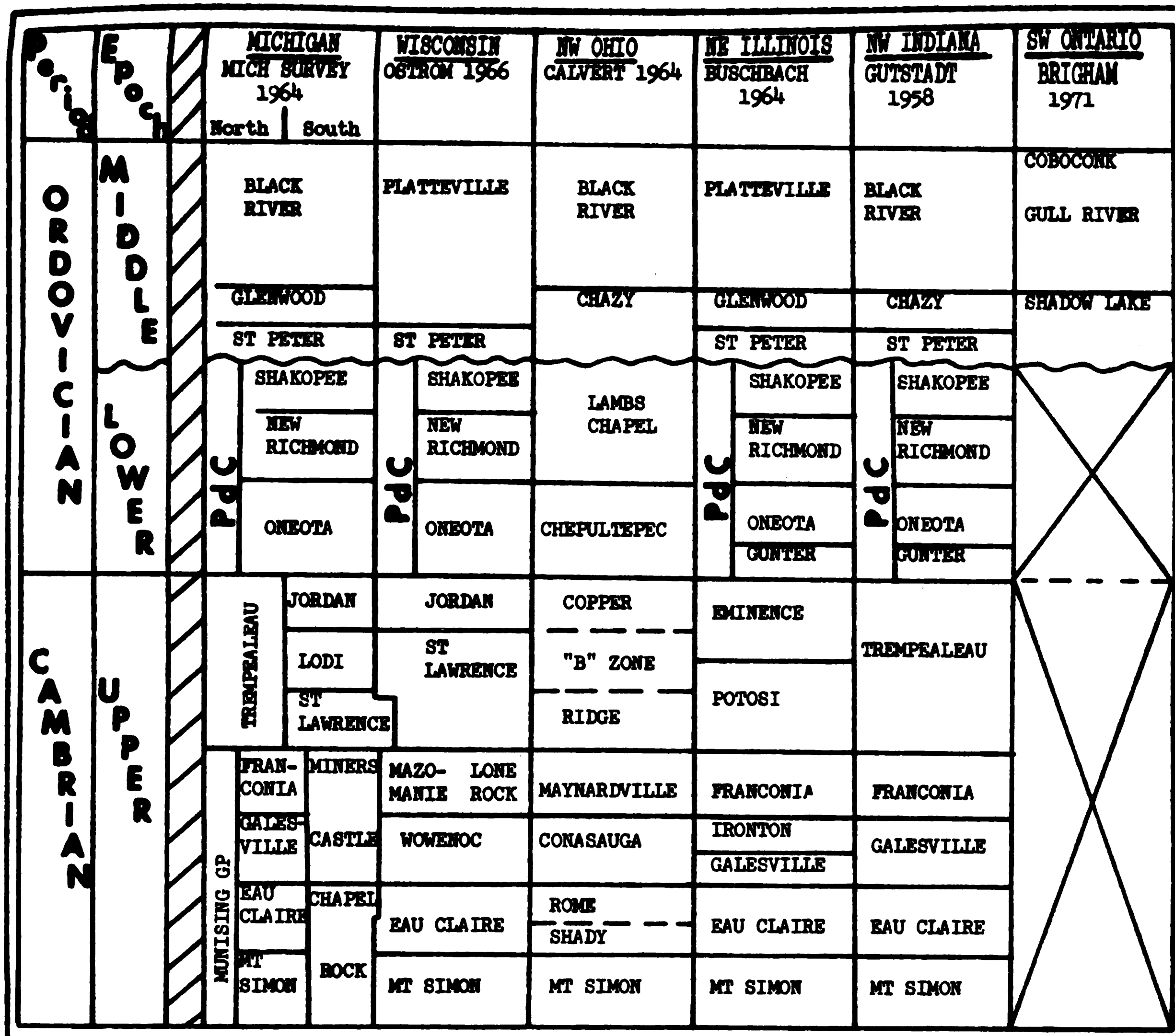


FIG. 7

GENERALIZED COLUMN AND STRATIGRAPHIC CORRELATION CHART OF OTHER AREAS.

PdC = PRAIRIE du CHIEN

In northeast Illinois the Prairie du Chien is missing by erosion from the northern corner but underlies most of the southern portion, increasing regularly southward into southeast Illinois and southwest Indiana to a thickness in excess of 400 feet. At Fayette County, central south Illinois, the Oneota (Chepultepec) is 596 feet thick, thinning to 116 feet northward to north central Illinois. The Oneota of Indiana thickens from a few hundred feet in northeast Indiana to 640 feet in south central Indiana to 960 feet at Lawrence County in central south Indiana.
In Ohio the thickness of the Chepultepec varies off of structures (Northern Ohio Platform) and is not recognized in central, north central and northeast Ohio where it was truncated by erosion. In northwest Ohio the Chepultepec Dolomite thickens from 120 feet to the south where it is present as a 700 foot interval. The Chepultepec of Ohio thickens to the east, south and west and attains thicknesses of 797 feet in northwest West Virginia and 1210 feet in south central Kentucky. In southwest Ontario there is no Oneota, having been eroded away with much of the Upper Cambrian prior to Middle Ordovician time.

Within the Michigan Basin the Oneota varies from zero feet in the southeast to 615 feet in west central Michigan (Well #207, Thunder Hollow-Thompson #1, Newaygo County). The Oneota reflects a gradual thickening into the Basin off of the shelf areas with the depocenter located in west central Michigan (Figure 4a-f). The criteria utilized was gamma ray-neutron logs.

New Richmond-Shakopee Interval

Lithology.--The New Richmond Sandstone in the Michigan Basin consists of a fine to medium grained, subrounded to rounded, frosted to slightly frosted to clear gray sandstone, often stained pink in part, with silica and dolomite cement. Overgrowths commonly occur and at some levels are abundant but decrease with depth as the amount of dolomite cement increases. The sandstones are best developed in northwest Michigan and basinwide are often associated with white, tripolitic chert (oolitic in part), green to gray shale, buff to tan siltstone, limestone and dolomite. The dolomites are commonly buff to brown, very fine to finely crystalline and sandy, and alternate with sandstones and thin beds of shale. Whether these alternating dolomites and sandstones are New Richmond or Shakopee is as yet unclear and here will be included in the New Richmond-Shakopee Interval. Some brown to tan, very finely crystalline, silty and argillaceous limestone is found basinward and also to the east alternating with dolomites, sandstones and shales but are too limited to be accurately mapped (Appendix II, A-D).

In Wisconsin and the Upper Mississippi Valley the New Richmond is a fine to medium grained, buff, gray and white well bedded sandstone with interbedded dolomite and Cryptozoon structures (stromatolites). The dolomites are light brown, gray to buff, fine to medium crystalline, arenaceous and cherty. Secondary enlargement of sand grains is very prominent and where the sandstones are well developed ripple marks and cross bedding are often found. The overlying Shakopee Formation (previously called Willow River Formation) is often completely truncated by erosion in this area and is typically described as a fine to medium crystalline, light brown-gray to buff, thin to thick bedded dolomite. When the New Richmond is mission th the Shakopee is difficult to tell from the Oneota. The dolomites of the Shakopee are usually more arenaceous and oolitic, but the chert less common, as in the Oneota. In the Shakopee thin beds of fine to medium sandstone and green to gray shale are often interbedded with the dolomite (Kay, 1935; Workman, 1935; Heller, 1956; Davis, 1969). In northeast Illinois (Buschbach, 1964) the New Richmond sandstone is composed of medium grained, moderately sorted, rounded sandstone with some interbedded sandy dolomites and shales. The dolomites are light colored, very finely crystalline, sandy and cherty carbonate with the chert white to gray and oolitic, and the shales gray, red and blue. The New Richmond resembles the St. Peter Sandstone but differs in being composed of more angular, less frosted, thinner bedded, better cemented grains with more overgrowths and containing free silicious oolites, chert, and a higher proportion of heavy minerals. The Shakopee is comprised of very finely crystalline, light gray to light brown dolomite containing oolitic chert, some thin beds of medium grained, rounded dolomitic sandstones and some green to light gray shales. The Shakopee in northwest Illinois is characterized by its highly variable beds of argillaceous and pure dolomite distorted by lenses of massive algae reef structures as much as 10 feet thick. When the New Richmond is absent the Shakopee can often be distinguished from the Oneota by the sandiness and fine grain size of the Shakopee dolomite. In Ohio the Lambs Chapel Dolomite is equivalent to both the New Richmond and the Shakopee (Calvert, 1962). The Lambs Chapel is composed of light colored, fine to coarsely crystalline, partly saccharoidal dolomite containing beds and lenses of light gray, banded chert, white oolitic chert, sand-centered oolitic chert and thin chert matrix sandstones. Thin green shale beds are common. Minor unconformities and intraformational conglomerates containing rounded and frosted quartz grains are present, as are zones of scattered embedded sand grains. The Lambs Chapel may be equivalent to the New Richmond-Shakopee Interval of the Michigan Basin but it is inadvisable to use Calvert's terminology at this time. In Indiana the New Richmond Sandstone is a medium to coarse grained, rounded and frosted sandstone containing interbedded tan to white, finely crystalline to saccharoidal dolomite, and white to brown, sandy and oolitic chert. The Shakopee is composed of tan to white, saccharoidal to finely crystalline, partly sandy dolomite containing white to blue, smooth to porous, oolitic and sandy chert. Thin beds of sandstone and grayish green shale are also found interbedded with this dolomite (Gutstadt, 1958). The New Richmond and Shakopee Formations, like the Oneota, are missing from southwest Ontario.

Correlation.--The New Richmond and Shakopee formations of the Michigan Basin (Figure 7) is equivalent on the bases of stratigraphic position and similar lithologies to the: New Richmond and Shakopee Formations of the Upper Mississippi Valley, Wisconsin, northwest Illinois and northwest Indiana; the Lambs Chapel of northwest Ohio; the Roubidoux, and the Jefferson City and Cotter Dolomite of Missouri, respectively; the Tribes Hill and Beekmantown of New York; and the Gorman and Honeycut Formations, respectively, of central Texas. Again, the Prairie du Chien must be compared as a Group or a Series (Canadian) to surrounding areas where the correlations are questionable, as in central Pennsylvania where the Prairie du Chien Group is equivalent to the Stonehenge, Nittany, Axemann and Bellefont Formations.

Distribution and Thickness.--When considering the distribution and thickness of the New Richmond-Shakopee Interval, two important points must be taken into account: (1) the Shakopee, by virtue of its superposition, was subjected to more pre-St. Peter erosion than the middle and lower formations of the Prairie du Chien Group; and (2) nondeposition or nonrecognition of a facies change of the New Richmond occurred locally on the Upper Mississippi Valley and in north Illinois, resulting in the Shakopee overlying or appearing to overly the Oneota Dolomite (Heller, 1956; Buschbach, 1964). The consensus of opinion today is that the highly dissected topography underlying the St. Peter Sandstone marks the contact of an erosional disconformity. The evidence includes: (1) the high relief at the contact; (2) the common occurrence of the basal St. Peter unit, the Kress member, which is composed of a chert conglomerate and sandstone. The appearance and occurrence of the Kress suggests that it is a relatively insoluble residuum developed on a karst surface and concentrated in local depressions by the transgressing St. Peter seas (Buschbach, 1964); (3) the St. Peter Sandstone is usually thickest where the Prairie du Chien is thinnest, and conversely so; (4) the top of the St. Peter Sandstone does not reflect the relief on top of the Prairie du Chien; and (5) the St. Peter sometimes unconformably (usually disconformably) overlies the Upper Cambrian formations.

However, Flint (in Heller, 1956) studied the contact in southwest Wisconsin and concluded the irregularity that marks the contact is due to an initial irregularity caused by the compaction of lime muds over relatively rigid masses, probably biogenic, that form domal structures in the Shakopee Dolomite. The preponderance of evidence indicates a major erosional unconformity.

The irregular distribution and variable thickness of the New Richmond and Shakopee Formations in the Upper Mississippi Valley and Wisconsin reflect the effects of erosion. The New Richmond Sandstone varies from zero feet to 45 feet thick at Lanesboro, Minnesota, and thickens southward continuously into southeast Iowa. The New Richmond is generally very thin in Wisconsin, ranging from zero feet to 25 feet. The only angular unconformity (at the base of this formation) occurs near Eastman in Crawford County, Wisconsin where the arched Oneota Formation is truncated and a flat pebble conglomerate is present in the basal New Richmond Sandstone. The arching was the result of either mild tectonic movements or compaction over a biohermal structure. The Shakopee Dolomite also reflects this trend of thickening toward the southeast, when it is present. Post-Shakopee erosion and the slumping of overlying St. Peter Sandstones make for few complete sections. At Shakopee, Minnesota, the dolomite is around 50 feet thick while in Grant and Iowa Counties, Wisconsin, the

Shakopee varies from 28 to 65 feet thick. In northeast Illinois the New Richmond and Shakopee Formations are missing from the northern section but increase to the southwest. In LaSalle County in north central Illinois the New Richmond attains a thickness of 147+ feet, thinning in all directions except to the south where in southwest Illinois it is a 190 foot section. The Shakopee too is absent to the northeast and thickens to the south. It is a 600 foot interval in south central Illinois and increases somewhat to the southwest. In north Indiana the New Richmond and Shakopee Formations are thinner and more reflect the effects of erosion. In Johnson County, south central Indiana, the New Richmond is 47 feet thick while the Shakopee is a 154 foot interval. In Lawrence County, central south Indiana, the equivalent Lambs Cahpel Dolomite is only 105 feet thick. The Lambs Chapel is absent from south central through north central, and northeast Ohio but thickens to the east and southeast (into Appalachian Basin) and to the southwest. In northwest West Virginia the Lambs Chapel equivalent is 233 feet in thickness while in west central Kentucky the Roubidoux (New Richmond) is 138 feet thick and the Jefferson City-Cotter Formations (Shakopee) interval is 405 feet thick. The Roubidoux of south central Kentucky is 190 feet thick and the Jefferson City-Cotter interval is 680 feet. No New Richmond or Shakopee is found in southwest Ontario.

In the Michigan Basin the New Richmond-Shakopee Interval was arbitrarily defined as the thick sands, sandy dolomites and limestones overlying the Oneota Formation and underlying the Glenwood (Figure 4a, d, e, f). On gamma ray logs the contact is distinguished as a marked decrease in gamma radiation accompanying the appearance of a thick sand. The Shakopee Formation, if present, was included in this interval, due to problems of correlation. Since it is not known that a complete, original thickness of the Shakopee has ever been measured it would be extremely difficult (or impossible) to try to assign a few, scattered, isolated sections to this formation at this time.

The New Richmond-Shakopee Interval varies from zero feet in southeast Michigan to 590 feet in northwest Michigan (Well #199, Dow, Brazos-Taggert #1, Mason County).

INTERPRETATION

The evolution of the Michigan Basin has probably been episodic through time. Prouty (1970) believed that the basic structural pattern of the Basin was inherited from the Precambrian. Catacosinos (1974) stated that a precursor to the present Basin existed in Late Cambrian time. Fisher (1969) and Seyler (1974) attributed the Michigan Basin to a Middle Ordovician origin. Most workers agree that the major deformations of the Basin occurred in Salina (Silurian) time (Cohee, 1948) and late Mississippian time (Kilbourne, 1947).

Structural Framework

From Figures 8, 9 and 10, the structure contours at the tops of the Glenwood, the Prairie du Chien and the Trempealeau, respectively, the broad structural form of the Basin is obvious. Equally prominent are the three major structural features of southern Lower Michigan, the Howell Anticline, the Lucas-Monroe Monocline and its northwest extension, and the slight folding in the region of the Albion Scipio trend.

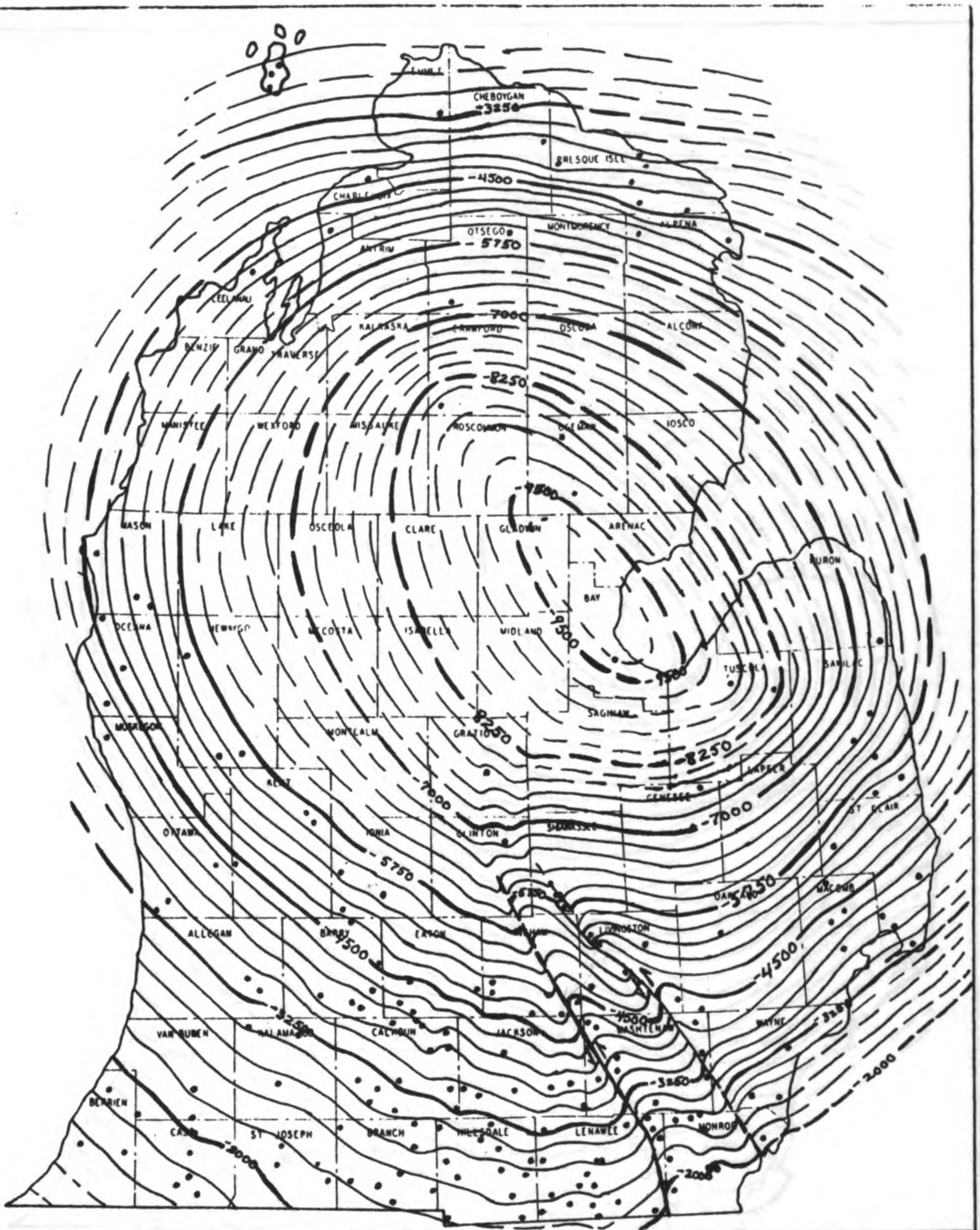


FIGURE 8
STRUCTURE CONTOUR OF THE MICHIGAN BASIN
ON TOP OF THE GLENWOOD

Contour Interval = 250 feet
Scale: 1" = 32 miles 0 16 32

RMS 1977

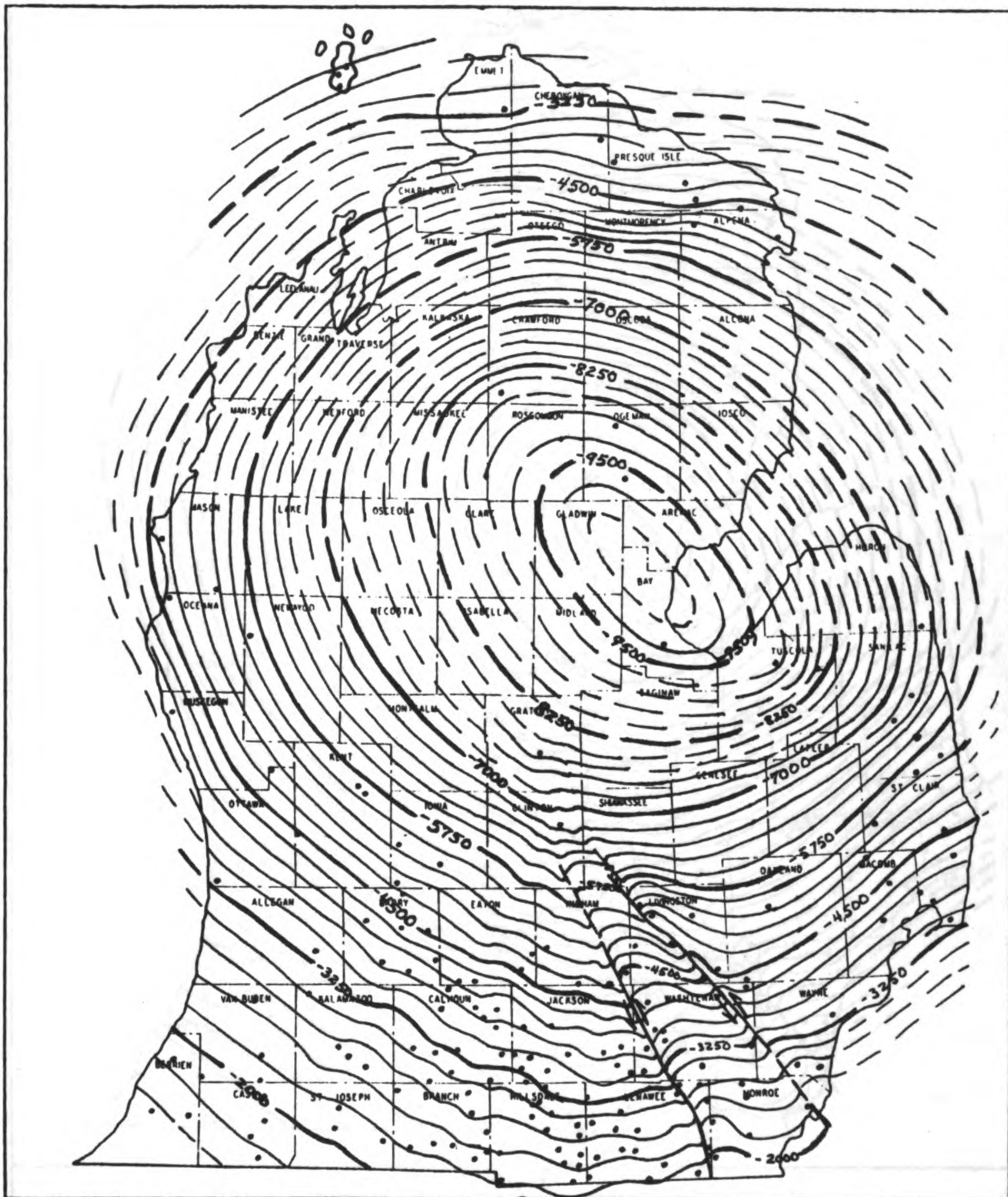


FIGURE 9
STRUCTURE CONTOUR OF THE MICHIGAN BASIN
ON TOP OF THE PRAIRIE du CHIEN

Contour Interval = 250 feet
Scale: 1" = 32 miles

RMS 1977

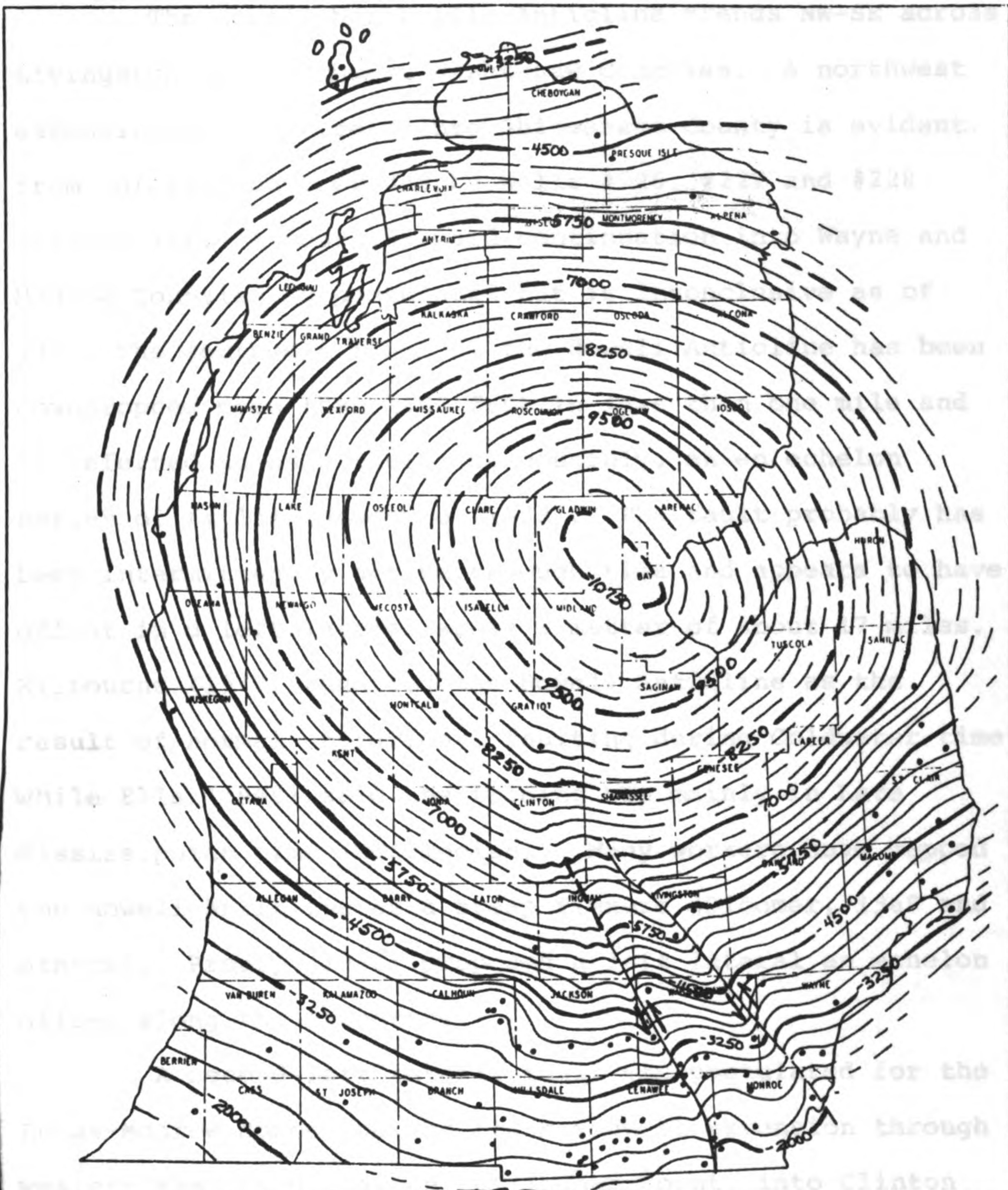


FIGURE 10

STRUCTURE CONTOUR OF THE MICHIGAN BASIN
ON TOP OF THE TREMPEALEAU

Contour Interval = 250 feet
Scale: 1" = 32 miles 0 16 32 MI. RMS 1977

The Howell-Northville Anticline trends NW-SE across Livingston and northwest Washtenaw Counties. A northwest extension of this trend into Shiawassee County is evident from information provided by Wells #226, #227 and #228 (Figure 11). A southeastward continuation into Wayne and Monroe Counties is postulated but is inconclusive as of yet. The southwest flank of the Howell Anticline has been downdropped more than 1000 feet in less than one mile and is referred to as a fault, or possibly, an en echelon series of faults (Newcombe, 1933). The fault probably has been intermittently active through time and appears to have offset in a left lateral sense a matter of about 17 miles. Kilbourne (1947) regarded the Howell Anticline as the result of normal, rotational faulting during Coldwater time while Ells (1969) said the folding was mainly in Late Mississippian time (Meremecian). Many workers have mapped the Howell Anticline as a steep flexure (Bloomer, 1969 and others). Prouty (1976) proposed a left lateral en echelon offset along the structure.

A second left lateral fault was postulated for the Lucas-Monroe Monocline and its northwest extension through western Washtenaw and central Ingham County into Clinton County. Again the downdropped side appears to be to the west with a maximum displacement of about 10 miles. The amount of displacement in both cases may be deceiving due to the poor well control on either side of the fault and

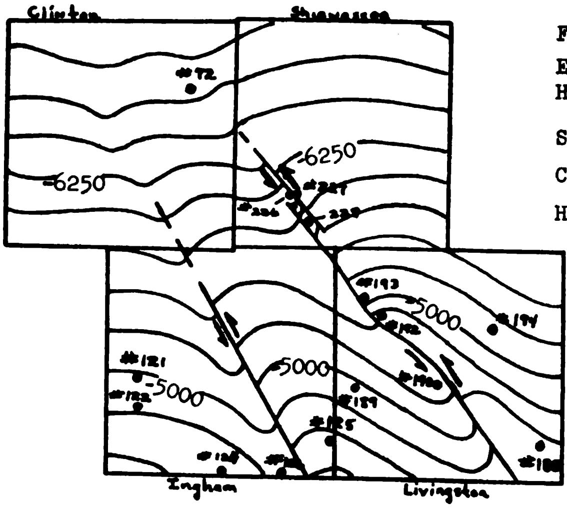


FIGURE 11

EXAMPLE of EN ECHELON FAULTING along the HOWELL ANTICLINE in SHIAWASSEE COUNTY

STRUCTURE CONTOUR on top of the GLENWOOD

CONTOUR INTERVAL = 250 feet

HORIZONTAL SCALE:
1" = 16 miles

0 8 16 mi

● WELL LOCATION

FAULT

QUESTIONABLE FAULTING

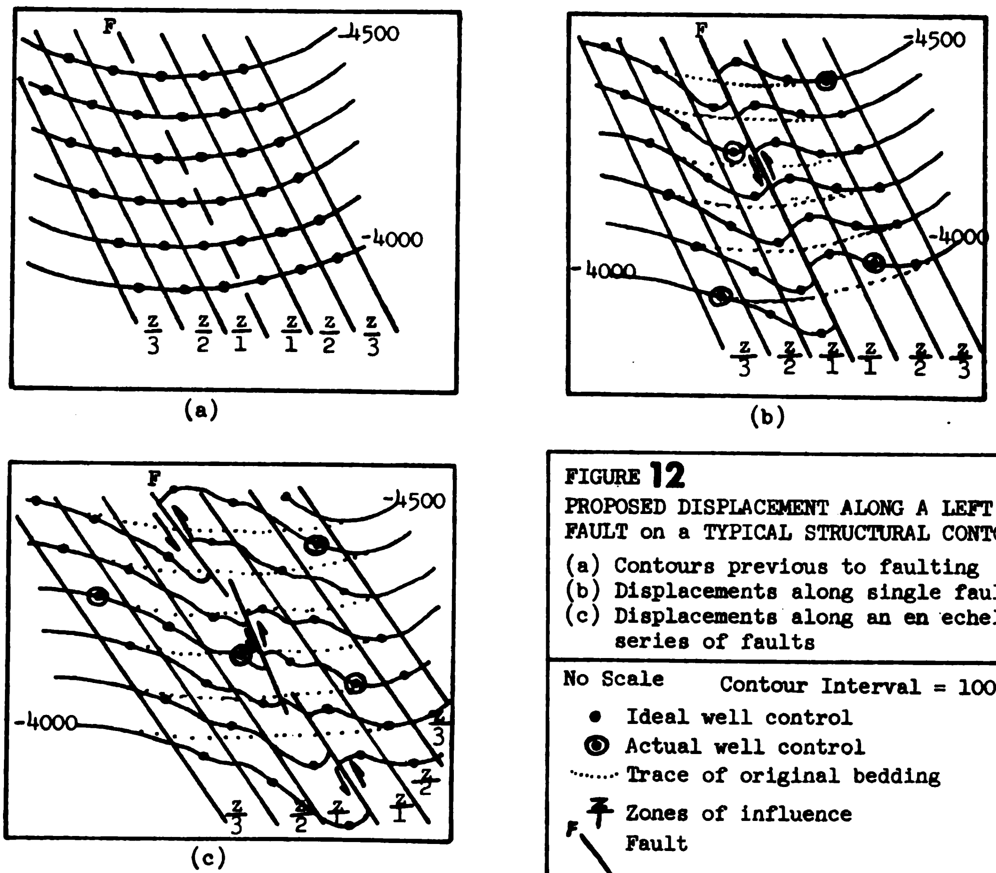


FIGURE 12

PROPOSED DISPLACEMENT ALONG A LEFT LATERAL FAULT on a TYPICAL STRUCTURAL CONTOUR MAP

(a) Contours previous to faulting
(b) Displacements along single fault
(c) Displacements along an en echelon series of faults

No Scale   Contour Interval = 100 feet

● Ideal well control
Actual well control
Trace of original bedding
Zones of influence
Fault

may represent a minimum rather than a maximum value. A hypothesized, idealized model is presented in Figure 12a through Figure 12c. The drag on each side of the fault would be most pronounced closer to the fault and reflected in zone 1, and lessen outward to zone 3. As well control is poor at the depth involved the problems of trying to exactly deduce displacements, as well as the approximate position of the fault itself, are extremely difficult. When dealing with an en echelon series of faults (Figure 12c) the displacements would be further complicated by differential movements and distortions along each fault.

A slight fold is observed in eastern Calhoun County that correlates to the Albion-Scipio trend. This trend is again believed to be fault controlled and, as in the cases of the Howell Anticline and the Lucas-Monroe Monocline and its northwest extension, may represent reactivated Pre-cambrian weaknesses. Hinze and Merritt (1969) hypothesized a basement fault-line scarp running from Hillsdale County northwestward through Calhoun County that diminishes in Barry County. Harding (1974) proposed "deep seated, slight, left lateral strike-slip displacements along a pre-existing basement fault" to account for the structure. The unique sag overlying and following Middle Ordovician production was attributed to contraction of the rocks during dolomitization and subsidence of the overlying rock. The

Albion-Scipio area was contoured as a fold due to the poor well control in the region.

To the north in Presque Isle County a slight flexure is noted that may correspond to the Middle Ordovician (Trenton) right lateral wrench faulting proposed by Seyler (1974) for the area. Fisher (1969) stated that the anomalous thinning of the Ordovician rocks in Alpena and Presque Isle Counties, as well as its northwest trend, conforms to the dominant northwest trend of major faults and folds of the Lower Peninsula. Newhart (1976) showed that "structural" dolomitization occurred in the area of the proposed faulting within Middle Ordovician rocks.

Stratigraphic Framework

The Prairie du Chien Group was divided into the Oneota Formation and the New Richmond-Shakopee Interval on the basis of lithology and stratigraphic position. Excellent correlations can be made throughout southern and western Michigan by the utilization of gamma ray logs in conjunction with lithology. In the northern eastern and central portions of Lower Michigan, however, the correlations become increasingly difficult (and sometimes obscure) owing to the questionable nature of the Cambrian topography, the poor well control and extreme distances between wells, and the anomalous thicknesses of the gamma ray intervals often found between correlatable points within and between some wells. Therefore, the

Cambro-Ordovician contacts were ascertained from the stratigraphic and lithologic results of this study in conjunction with those tops determined by the Michigan State Geological Survey in Lansing.

The Oneota Formation was divided into two members or units, a lower basal sandy dolomite (LO) and an upper argillaceous dolomite (UO) as shown in cross-sections A-A' through F-F', Figures 4a-f. The correlation lines across the Basin are shown in Figure 5 and the well locations are given in Table 1.

Cross section A-A', from Berrien to Charlevoix County, illustrates the overall distribution of the two Oneota members as well as that of the New Richmond-Shakopee Interval. The basal (sandy) dolomite unit (LO) and upper argillaceous dolomite unit (UO) exhibit a slight thickening into the Basin (Well #198, Superior-Sippy #17, Mason County) that appears to be associated with basin subsidence. To the north in Charlevoix County (Well #70, McClure-Goddard #1) the units have markedly thinned and reflect convergence more toward the northern limits of the Basin (perhaps on the stable shelf). The thin upper Oneota unit exhibited to the south (Well #18, Security-Thalmann #1, Berrien County) is more likely the result of erosion and nondeposition on a stable shelf, rather than the complete Prairie du Chien Group proposed by Yettaw (1967). The New Richmond-Shakopee Interval also reflects a marked basinal subsidence on the west side of the Basin. This Interval becomes increasingly sandy to the north while to the south it is an alternating sequence of sandy dolomites, dolomites, sandstones and shales. Thus there appears to be a definite facies change associated with the Interval across the Michigan Basin.

Cross section B-B', from Cass to St. Clair County, shows again a slight thickening of the Oneota units basinward. These units thin slightly to the east and contain an increasing amount of sandstones sands and silts (Well #247, N.Y. Petromineral-Widmayer #1, Washtenaw County) that may reflect the nearby eastern shoreline of the Basin, reworked sands from Cambrian formations exposed by sea level fluctuations or convergence onto the Findlay Arch. The truncation of the units in Well #247 and Well #252 (Rousek-Wabash R.R. #1, Washtenaw County) can best be explained by an erosional unconformity probably in post-Shakopee time. The truncation may be demonstrated by: (1) the similarity of gamma ray sections at the base of the Prairie du Chien as well as the similarity of lithologies between wells; (2) the thicknesses of the sections remain rather uniform between wells, and (3) progressively older formations become exposed beneath the unconformity to the southeast. No New Richmond-Shakopee Interval is present.

Cross section C-C' from Berrien to Monroe County, is taken along the southern shelf of the Michigan Basin and reflects again the erosional truncation of the Prairie du Chien and older rocks. The Findlay Arch was intermittently active during Upper Cambrian and probably Lower Ordovician time as well. From all indications the Prairie du Chien sediments were laid down in relatively shallow waters, as inferred from the presence of angular to rounded clasts, oolites and red shales. Minor fluctuations in sea level would expose large areas of land to subaerial erosion. and may have deposited the pebbles of dolomite, limestone, chert and conglomerate sometimes found randomly scattered along the edge of the Basin. It could be argued that the thinning exhibited in different wells along C-C' could be convergence onto the Findlay Arch or near-shore thinning off the eastern shoreline of the Basin. Evidence, however, indicates that the thinning or missing Prairie du Chien formations are mainly the result of major erosional processes, as seen from a comparison of Well #100 (Perry-Rymal #1, Hillsdale County) and Well #173 (Horizon-Meech & Griffith #1, Lenawee County). Both wells, as do those wells nearby, exhibit: similar lithologies of stratigraphically equivalent sections; similar gamma ray logs above and below the Cambro-Ordovician contact in regards to thickness and characteristic curves of the individual formations; abrupt truncations of the Prairie du Chien formations to the southeast with no evidence of convergence; and to the southeast the Upper Cambrian formations present immediately below the unconformity occupy structurally higher positions (not necessarily the result of basinal subsidence but of uplift of the Findlay Arch). No New Richmond-Shakopee Interval is present due to erosion or nondeposition.

Cross section D-D', from Cass to Huron County, illustrates that subsidence of the Michigan Basin was occurring in at least late Prairie du Chien time. The thickened sequence of Well #80 (Mobil-Kelly #1, Eaton County) is mainly the result of an increased New Richmond-Shakopee Interval (NR-S). The Prairie du Chien Group thins eastward into Sanilac County (Well #225, McClure & MNR-Hewitt & Shedd #1-20) and Huron County (Well #120, Mobil-Volmering #1). This convergence is accompanied by a facies change in Sanilac County where the entire sequence is sandstone interbedded with a few shales and dolomites, indicating an environment close to the eastern shoreline of the Basin and subject to intermittent erosion with minor sea level fluctuations. In Livingston County (Well #190, Brazos-Kizer #1; Well #194 Mobil-Messmore #1) the thinned Upper Cambrian formations reflect a structurally high area until Middle-Trempealeau time. The overlying Prairie du Chien Group's thickness coincides with the regional thickness of the Oneota Formation and the New Richmond-Shakopee Interval. The New Richmond-Shakopee

Interval is an alternating sequence of sands, dolomites and shales that thicken into the Basin.

Cross section E-E', from Charlevoix to Sanilac County, features an undifferentiated Oneota Formation overlain by a New Richmond-Shakopee Interval of varying thicknesses. The Oneota is an alternating sequence of dolomites, shales and sandstones in Charlevoix County (Well #69, McClure-St. Beaver #2; Well #70, McClure-Goddard #1; Well #71, McClure-St. Beaver #1) that thickens into an interbedded sequence of sandy and argillaceous dolomites and shales in Presque Isle County (Well #217, Shell-Taratuta #1-13; Well #220, Pan Am-Dreysey #1) and Alpena County (Well #5, P.E.P.C.-Ford Motor Co. #1-5). The New Richmond-Shakopee Interval consists predominantly of thick sands with interbedded dolomites at the base and limestones at the top. This Interval may reflect a combination of basinal subsidence and isostatic sinking of the sediments, as interpreted from Wells #220 and #217. The Oneota thickens from Well #220 to Well #217 but the New Richmond-Shakopee Interval remains the same between wells and even slightly thickens in Well #220. Several alternate interpretations exist, especially when the distance between wells is considered (24 miles), but isostatic sinking due to the accumulation of thick clastics in northern and northwest Michigan is the most logical explanation to date.

Cross section F-F' is a correlation encompassing, in a roughly circular manner, the entire Michigan Basin from Barry to Cass County. The purpose of this correlation was to illustrate: the regional distribution of the Prairie du Chien Group; the thickening and thinning of the individual formations; the available lithologies across the Basin; and the correlation between wells, especially with the two deep wells in Gratiot and Ogemaw Counties. In Gratiot County (Well #82, McClure-Sparks et al. #1-8) 1073 feet of Prairie du Chien rock was penetrated, while in Ogemaw County (Well #213, Brazos-St. Foster #1) 570 feet of alternating dolomite, sandstone, siltstone, shale and halite (at the base) were correlated with the Prairie du Chien Group on the basis of gamma ray log comparisons with Sanilac and Huron Counties (Wells #225 and #120) as well as Barry and Eaton Counties (Wells #7 and #80).

Distribution Related to the Structural Framework

The Total Isopach Map of the Prairie du Chien Group (Figure 13) reveals a somewhat anomalous distribution of Prairie du Chien rocks in the Michigan Basin. Diagrammatic evidence for left lateral faulting along both the Howell Anticline and the Lucas-Monroe Monocline and its northwest extension is presented. The activation of the faults, while episodic, were probably post Prairie du Chien and most likely of Middle-Late Mississippian age--the time

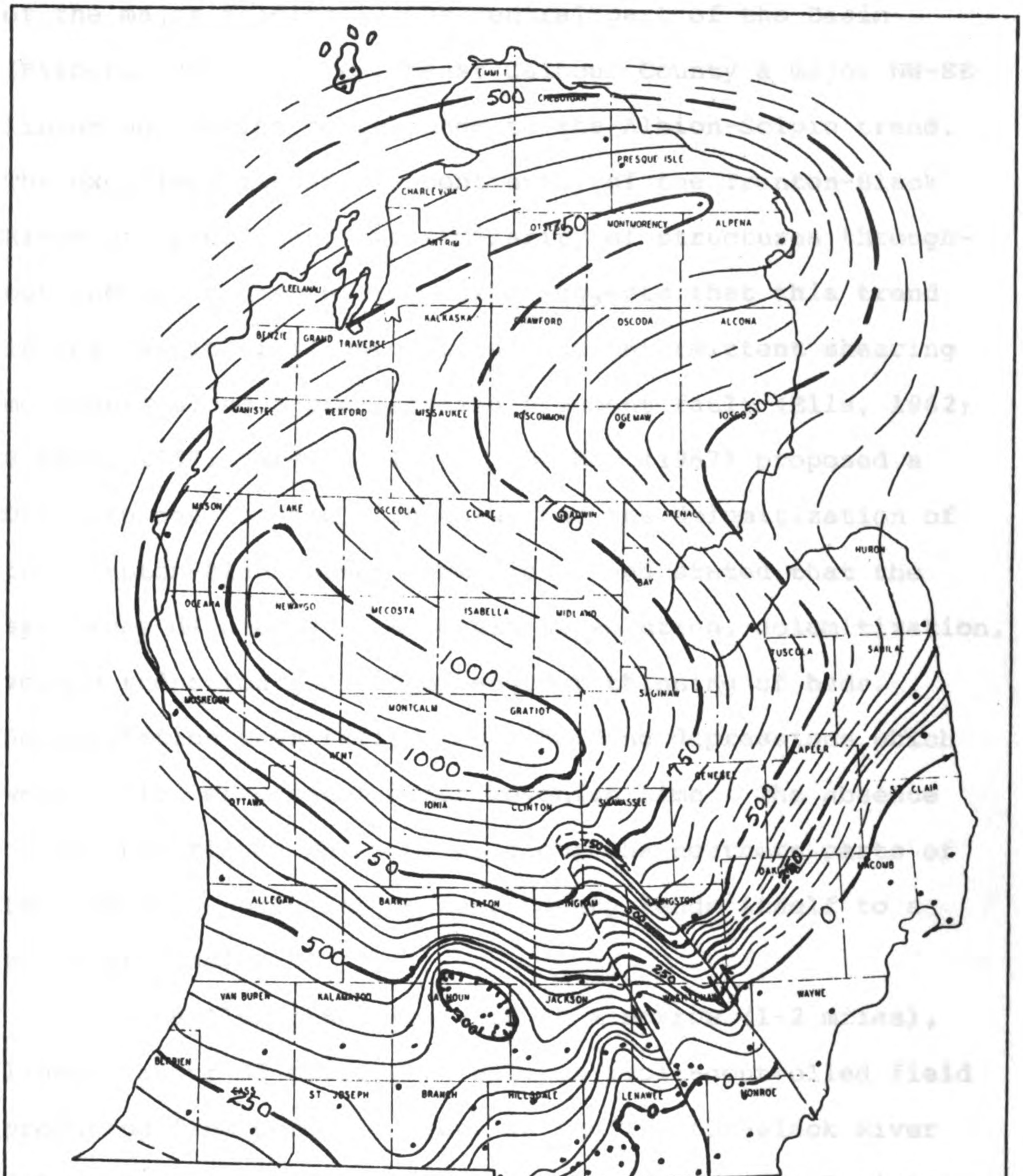


FIGURE 13

TOTAL ISOPACH OF THE PRAIRIE du CHIEN GROUP

Contour Interval = 50 feet
Contour Interval of NE Calhoun County = 300 feet
Scale: 1" = 32 miles   0   16   32 MI   RMS 1977

of the major folding in the central part of the Basin (Fisher, 1969). In northeast Calhoun County a major NW-SE linear depression corresponds to the Albion-Scipio trend. The excellent lineation, continuity of the Trenton-Black River oil pools, and the similarity of structures throughout the major part of the trend suggests that this trend is the result of slight lateral and intermittent shearing movements along a pre-existing basement fault (Ells, 1962; Bishop, 1967; Harding, 1974). Bishop (1967) proposed a Devonian age for the structures and the dolomitization of the Trenton-Black River formations, and stated that the synclines developed as a result of solution, dolomitization, volume reduction and the subsequent thinning of beds. Sedimentation then filled the subsiding depressions which were no longer present after Devonian time. The absence of the Prairie du Chien Group along the northern parts of the trend in northeast Calhoun County lends itself to a brief discussion.

The Albion-Scipio trend is a narrow (1-2 miles), linear (about 35 miles), en echelon fault-controlled field producing from porosity traps in the Trenton-Black River dolomites. Assuming normal sedimentation of the Prairie du Chien formations ($\sim$ 350 to 500 feet of Prairie du Chien rock on the Total Isopach Map for the region) over 350 feet of rock was selectively removed at depth. Overlying formations, from the Glenwood up to the Sunbury (Early

Mississippian), exhibit a slight thickening over synclines and a thinning over anticlines, generally assumed to be the result of solution activity, dolomitization, and volume reductions of 8-9% for the Trenton-Black River dolomites (Bishop, 1967). The selective removal of the Prairie du Chien Group probably originated in post Shakopee time. A karst topography developed at the unconformity surface may have created a cavernous region along the trace of a pre-existing fault but the study of Glenwood and Black River isopachs precludes the possibility of total erosion of the Prairie du Chien interval, as only a slight thickening in the region is noted. The overlying formations were laid down on a partially eroded Prairie du Chien surface that had previously undergone dolomitization diagenetically, or epigenetically (Kirschke, 1962) but prior to Glenwood deposition owing to the total dolomitization of the Prairie du Chien Group while the Glenwood may be dolomite, limestone, shale, or some combination. Reactivation of the fault and dolomitization of the Middle Ordovician formations occurred in Devonian time previous to which time the Prairie du Chien Group had been continually eroded by sub-surface solutions operating along the fault system. Cross faulting (shear coupling), as evidenced in T3S, R4W, Section 10, Calhoun County (at N 31° E), further fractured the rocks and increased activity on the Prairie du Chien formations. The selectivity of erosion for the Prairie du Chien Group may be the result of: (1) the Canadian rocks had previously been eroded at the unconformity surface (and developed a karst topography); (2) the unconformity surface (and/or the Glenwood Shale) may have been a crust of dense, erosional residuum preventing solutions from penetrating overlying formations (until Devonian time); (3) the Prairie du Chien was fractured (and vugular due to the karst terrain) and had a high amount of solution activity; and (4) the lithographic texture of the Black River Formation also may have offered a partial seal to ascending waters until fracturing occurred. The Prairie du Chien dolomites even may have acted as a source of magnesium for the dolomitization of the overlying formations, as may have the underlying Upper Cambrian formations. The synclines, therefore, may have developed primarily as a result of subsidence onto the continually eroding Prairie du Chien surface, as well as from volume reductions accompanying dolomitization of the Trenton and Black River Formations. The Prairie du Chien Group was thinned or eroded away as a result of: erosional processes at the unconformity surface; differential compaction accompanying dolomitization; and subsurface solution activity.

The Total Isopach map (Figure 13) exhibits a regular thickening of sediments into the Michigan Basin, the general distribution resembling a crescent open to the east. The thickest Prairie du Chien interval is located in west central Michigan (Newaygo County) from which two elongate troughs radiate outward, one to the southeast into Gratiot County and the other to the northeast into Presque Isle and Alpena Counties. The Prairie du Chien Group is missing from southeast Michigan because of erosion along the Findlay Arch.

A comparison of Figure 13 with Figure 14, the Regional Isopach of the New Richmond-Shakopee Interval, demonstrates the same sweeping distribution of rocks within the deeper portions of the Michigan Basin. The similarity is striking, considering that the top of the New Richmond-Shakopee Interval was the erosional surface. This suggests that the general distribution of the Prairie du Chien Group was greatly determined by New Richmond-Shakopee Interval sedimentation, by Cambrian topography and by later erosion. The absence of the Interval from the southern margin of the Michigan Basin implies erosion and/or nondeposition in the area. A comparison of the New Richmond-Shakopee Interval lithologies reveals a change of facies across the Basin. In northwestern Michigan, from Newaygo to Charlevoix County, the interval is almost totally sandstone but of varying thicknesses. In northeastern Michigan, from Cheboygan to Alpena County, the lithology while predominantly sandstone contains interbedded dolomites at the base and limestones at the top of the section. In Muskegon County (Well #204, Dupont-Dupont Disposal #1) the lower 90

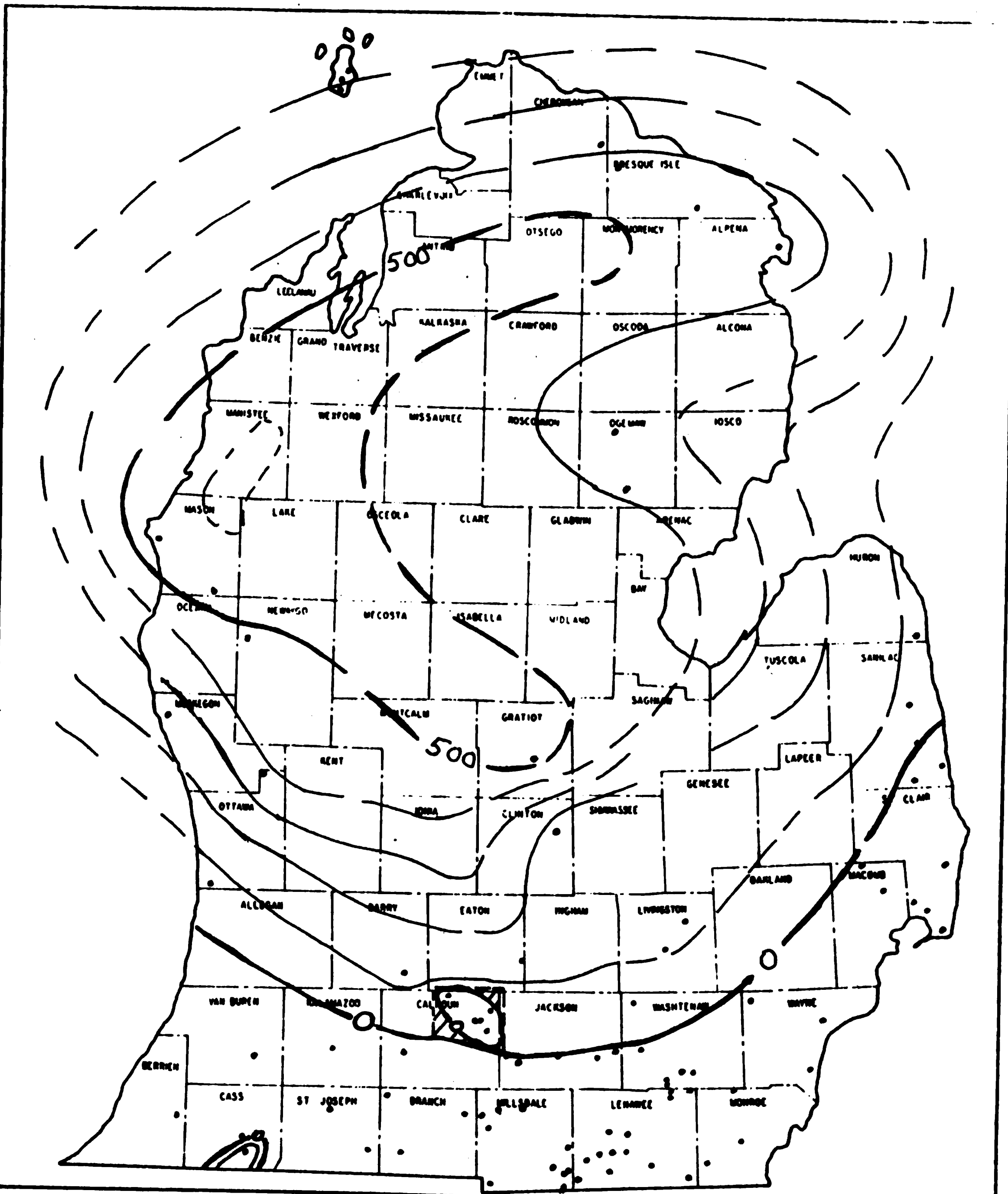


FIGURE 14

ISOPACH OF THE NEW RICHMOND-SHAKOPEE INTERVAL

Contour Interval = 100 feet
NE Calhoun county
Scale: 1" = 32 miles 0 16 32mi

RMS 1977

feet of sandstone is overlain by 187 feet of sandy dolomites, dolomites and a few interbedded sandstone units. From Ottawa County (Well #214, Holland Suco-Suco D.W. #1) southeast and eastward into Livingston County the New Richmond-Shakopee Interval becomes an alternating sequence of dolomites, sandstones and shales of decreasing proportions. In central Michigan (Gratiot County Well #82 and Ogemaw County, Well #213) the lithology is an interval of interbedded sandstones, dolomites, siltstones, shales, and minor limestone near the top of the formations. Halite is found at the base of the Interval in the State Foster #1 well in Ogemaw County, and small amounts of gypsum, anhydrite and glauconite are found scattered throughout the interior of the Basin.

It appears that the overall distribution of the Prairie du Chien Group in the Michigan Basin reflects many factors acting in conjunction, including:

(1) the underlying Cambrian topography;

(2) gradual subsidence of the Basin centered more toward central or west central Michigan;

(3) isostatic sinking associated with the thick sands more in the western and northern portions of the Lower Peninsula;

(4) the Post-Knox Unconformity;

(5) subsurface solution along pre-existing basement faults;

(6) differential compaction accompanying dolomitization; and

(7) major and minor fluctuations of the shallow seas resulting in alternate erosion and deposition in the same areas.

Lithology

Because of the poor well control and the almost 100% dolomitization of the Prairie du Chien carbonates no facies maps were attempted. A few scattered limestones were noted in the central and northeast portions of the Basin at the top of the New Richmond-Shakopee Interval but could not be accurately mapped.

The fine to coarsely crystalline, interlocking dolomites contain scattered sand grains, silts, anhydritic and argillaceous material, and in some cases, oolites and oolite ghosts. No structures were found other than stylolites and the only identifiable fossils discovered were dolomitized crinoid stems. The oolites were usually dolomitized and the crystal size remains constant from oolites to matrix. Only a color variation outlines the oolite ghosts. Based upon this criteria and the fact that the dolomite crystals cut across oolitic boundaries, Kirschke (1962) called the Prairie du Chien dolomites epigenetic. Based upon the widespread, massive dolomitization, and the fine to coarsely crystalline nature of the dolomite, the main body is believed diagenetic in this study. The chert is commonly oolitic and sandy, dolocastic, and dense to tripolitic. In some cases the chert acted as a sandstone matrix. Chalcedony, vein quartz and quartz crystals were sometimes associated with the chert but in small amounts.

Sandstones were commonly fine to medium grained, coarse grained, subrounded to rounded, frosted to clear (with some iron staining) and cemented. Overgrowths were common, and in some cases the sand grains were pyrite coated. "Floating" sand grains in the dolomite indicate possible wind transport to an offshore carbonate environment. The thin to thickly bedded sandstones were indicative of subaqueous deposition, as near beaches and in foredeeps. The source of the sand was primarily from the northwest off of the craton and the Wisconsin Arch area as well as from reworked Upper Cambrian deposits (and positive structures) surrounding the Basin.

Vari-colored shales occurring toward the center of the Basin may indicate alternating oxidizing and reducing conditions associated with sea level fluctuations.

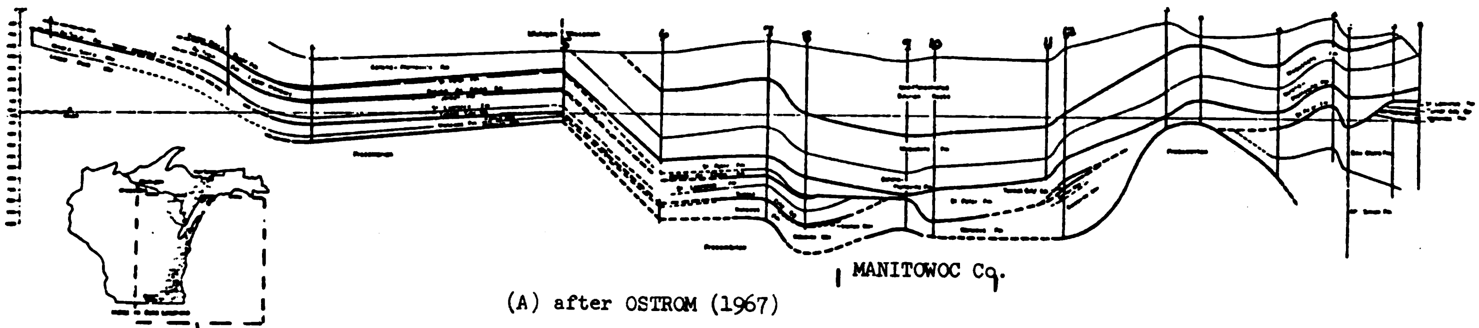
The presence of anhydrite was usually associated with the dolomite in the deeper reducing waters of the Basin. Some anhydrite, gypsum and halite were present in samples toward the center of the Michigan Basin (Wells #212 and #213, Ogemaw County) and may indicate:

(1) pockets of poor circulation on the Basin floor (resulting from Cambrian topography) in which supersaline conditions existed;
(2) a lagoonal or areally restricted bay characterized by shallow water and restricted circulation in which high evaporation caused high concentrations of brines, and thus precipitation of evaporites; and
(3) sinking of the Basin in conjunction with (1) (Kashfi, 1967).

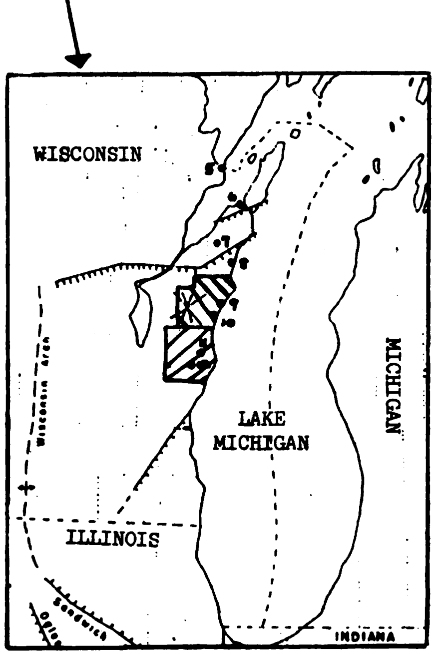
Model for Prairie du Chien Deposition

In the Lower Peninsula the transition from Upper Cambrian to Lower Ordovician time was one of continuous deposition marked by a slight regression of the sea as evidenced by the increased clastic content in the upper Trempealeau-lower Oneota formations. In Northern Michigan, Delta County, Dixon (1961) regarded the clastics as a reworking or interfingering of Upper Cambrian sediments with the basal Prairie du Chien units. A slight transgression of the sea followed in which the basal dolomite unit of the Oneota was deposited in a relatively shallow sea (presence of clasts in dolomite and traces of glauconite throughout the interval in areas). The transgression of the Prairie du Chien sea continued with the possible exposure or uplift of surrounding regions in upper Oneota time. Increasingly argillaceous dolomite was deposited throughout the Basin while along the shelf a thinning of sedimentary deposits is apparent (Well #199, Dow, Brazos-Taggert #1, Mason County; Well #225, McClure and M.N.R.-Hewitt, Shedd #1-20, Sanilac County). During this period the Michigan Basin had been subsiding as gleaned from the regular thickening of sediments basinward.

Regression of the sea continued into New Richmond-Shakopee time in an episodic manner resulting in the initial deposition of thick sands in northwest Michigan. These sands indicate a northwesternly source areas off of the craton or the Wisconsin Arch which would have been further exposed by the regression. Exposed Cambrian sediments would also have contributed sands to the thick accumulation in northwest Michigan. It is interesting to note that along the length of eastern Wisconsin from Manitowoc County south to Walworth County (Figure 15) the Prairie du Chien Group is missing along with several Upper Cambrian formations as a result of erosion (Ostrom, 1967). The thickening and thinning of pre-St. Peter formations over the irregular Precambrian surface indicates that the basement was intermittently uplifted by faulting or other tectonic uplift. In Manitowoc County the St. Peter Formation thickens from 40 feet to 280 feet in five miles. The rather linear nature of this eastern Wisconsin belt has a geometry suggestive of fault control. Subsequent drainage along fault traces may have developed channels near linear highs. The formations overlying the St. Peter Formation show no anomalous change in thickness inferring that the St. Peter may have been deposited off of a slightly positive arch into a subsequent stream channel



(A) after OSTROM (1967)



(B) after PROUTY (1974)

FIGURE 15

GEOLOGICAL CROSS SECTION: ALGER COUNTY, MICH. - WALWORTH COUNTY, WISC.
(A) THICKENED ST PETER FORMATION IN MANITOWOC COUNTY, WISCONSIN
(B) STRUCTURAL TRENDS IN EASTERN WISCONSIN

(A) SCALE: VERTICAL - 1" = 1300 feet (650' – 0 – 650') HORIZONTAL - 1" = 32 mi (0 – 16 – 32 mi)

(B) SCALE: VERTICAL - None HORIZONTAL - 1" = 72 mi (0 – 36 – 72 mi)

LEGEND

- AXIS OF WISCONSIN ARCH
- FAULT, hatchers on downthrown side
- JOINT SETS
- MANITOWOC COUNTY
- SHEBOYGAN COUNTY

which acted as a sediment trap. Manitowoc County is roughly adjacent to Mason County, Michigan, across Lake Michigan, where the greatest interval of New Richmond-Shakopee sandstone is encountered (590 feet in Well #199). Uplift or faulting may have occurred in late Upper Cambrian or early Lower Ordovician time. By New Richmond-Shakopee time, and as a result of sea level fluctuations (regressions) the earlier Prairie du Chien and Upper Cambrian sediments may have been undergoing erosion and transportation to the northeast into a shallow sea where the sediments (sands) were being deposited by currents into foredeeps. While it is more logical to consider the main source of these sands as the craton and/or a positive Wisconsin Arch, this nearer eastern Wisconsin area may have a partial source.

The New Richmond-Shakopee Interval in the Michigan Basin suggests an important source of sediments to the northwest. It appears that the initial deposition of this Interval was concentrated in a foredeep and that the sandy phase migrated outwards with time. As the Wisconsin Arch or craton weathered down and the amount of clastics diminished the sands again became more restricted to the northwestern part of the state. Adjacent areas previously receiving sands now were the depositional sites of dolomite, sandy dolomite and a few thin beds of sand and shale. The center of the Basin continued as a site of deeper water sedimentation. During this Interval the slow subsidence of the Basin was augmented to the north and northwest by isostatic sinking in response to the weight of the thick sands. Whether the Shakopee is present in the Basin cannot be ascertained directly. It may well be that in the Michigan Basin the Shakopee cannot be distinguished from the New Richmond because of the anomalously high quartz sand incursion during Shakopee time in this area. After the New Richmond-Shakopee Interval a major regression of the sea occurred resulting in one of the most widespread erosion periods of the Paleozoic Era. It is often referred to as the Post-Knox Unconformity and is not only a widespread stratigraphic break throughout the eastern United States but over many other parts of the world as well. This erosional event has obscured the relationship of the New Richmond-Shakopee Formations in the Michigan Basin and whether it is a facies relationship as proposed by Buschbach (1964) for northeast Illinois cannot be determined at this time. Likewise, the effects of the Findlay Arch as well as its activity at this time are a matter of conjecture owing to the total erosion of the Prairie du Chien Group in southeast Michigan and adjacent areas. The absence of the New Richmond-Shakopee Interval from most of the Northern Peninsula and from the southern portions of the Lower Peninsula connotes a major erosional event especially in the shelve areas of the Michigan Basin.

Thus it appears that the distribution of the Prairie du Chien Group in the Michigan Basin is generally the result of basinal subsidence, isostatic sinking and erosional events. A restored section of the Prairie du Chien Group prior to deposition of the Glenwood Formation is presented in Figure 16.

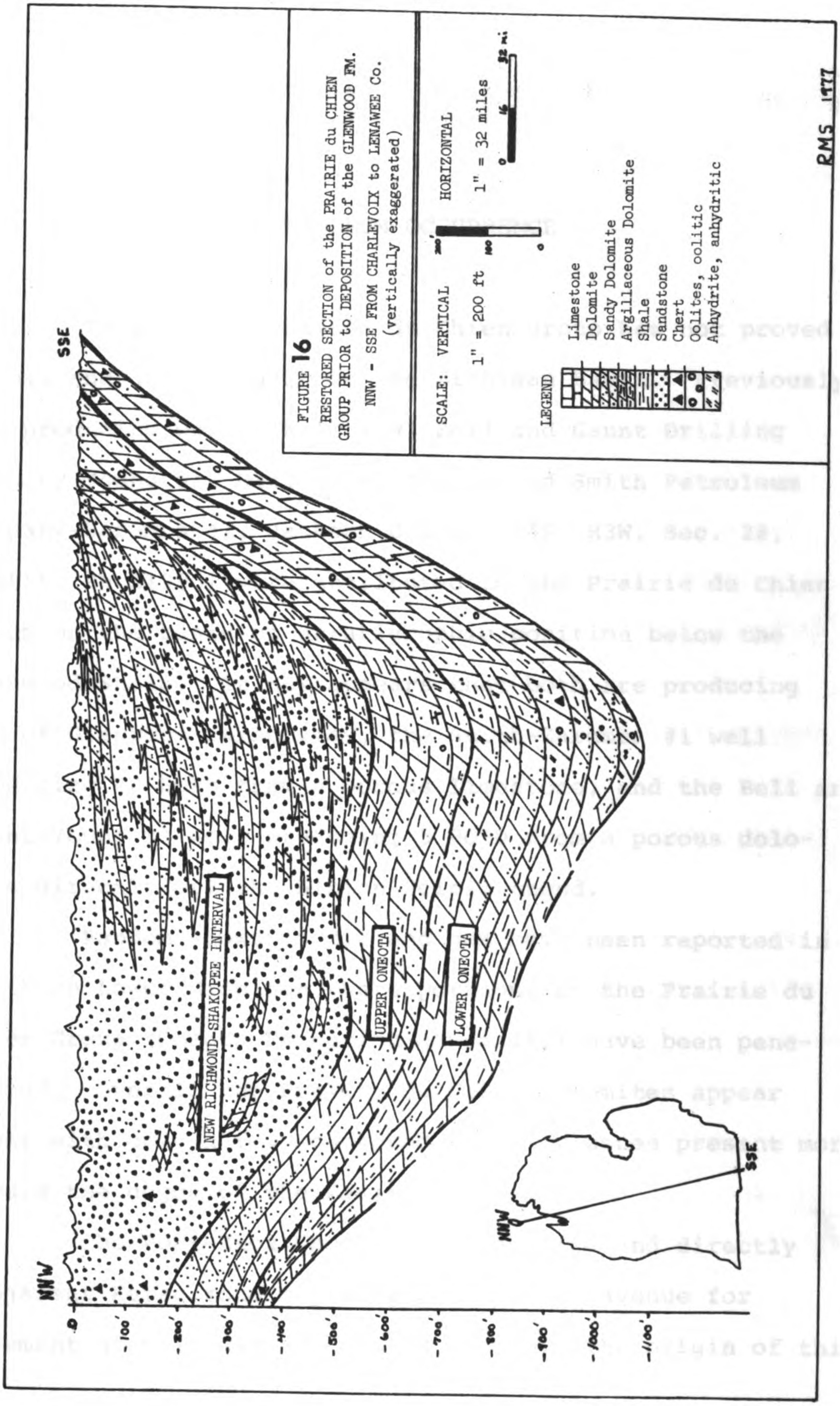


FIGURE 16
RESTORED SECTION of the PRAIRIE du CHIEN GROUP PRIOR to DEPOSITION of the GLENWOOD FM.
NNW - SSE FROM CHARLEVOIX to LENAWEE Co.
(vertically exaggerated)

SCALE: VERTICAL 1" = 200 ft (0, 100, 200)
HORIZONTAL 1" = 32 miles (0, 16, 32 mi)

LEGEND
Limestone
Dolomite
Sandy Dolomite
Argillaceous Dolomite
Shale
Sandstone
Chert
Oolites, oolitic
Anhydrite, anhydritic

PETROLEUM OCCURRENCE

To date the Prairie du Chien Group has not proved an oil and gas producer in the Michigan Basin. Previously, two producing wells (Well #89, Bell and Gaunt Drilling Company-Young #1, Hillsdale County; and Smith Petroleum Company-Zaremba #1, Jackson County, T4S, R3W, Sec. 28, SESENE, Ph 21985) were attributed to the Prairie du Chien Group on the basis of stratigraphic position below the Glenwood Shale. It now appears that both are producing out of Glenwood carbonates, the Smith-Zaremba #1 well producing 40 BOPD from a porous limestone, and the Bell and Gaunt-Young #1 well producing 5 BOPD from a porous dolomite directly off the Albion-Scipio trend.

Random shows of oil and gas have been reported in southern Lower Michigan where portions of the Prairie du Chien Group (Oneota Formation generally) have been penetrated. Overall the Prairie du Chien dolomites appear tight with only a few scattered porosity zones present more toward the edges of the Basin.

The Post-Knox Unconformity surface and directly subjacent karst zone may have acted as an avenue for movement of oil, gas and fluids up dip. The origin of this gas and oil is problematical. Geologists have often looked to the carbonaceous shales of the Utica as a potential source. While the Utica shale is stratigraphically higher than the Prairie du Chien Group it is structurally lower basinward and oil and gas may have migrated generally up dip passing stratigraphically lower along faults to trap beneath the erosional surface and the overlying Glenwood shale. A couple of possible mechanisms for this movement might be:

(1) the water migrated up dip upon lithification and compaction of structurally deeper formations flushing the hydrocarbons up dip until trapped by tight and impermeable beds; and

(2) the water was also of artesian origin off of the Wisconsin and Algonquin Arches that flowed down the bedding planes and became trapped under the unconformity along with connate waters.

The activation or uplift of the arches, basinal sinking, and the pressure of compaction increased the lithostatic pressures and hydraulic head of the waters, flushing hydrocarbons up dip. The high magnesium rich waters of the Lower Ordovician and Upper Cambrian formations may have been forced upwards through fracture systems dolomitizing Middle Ordovician rocks and later emplacing some oil within these porosity traps.

The up dip migration of oil along the unconformity may have continued into Ohio and Indiana and resulted in the vast Lima-Indiana Field. This field produces from erosional highs in the Copper Ridge Dolomite (Upper Cambrian) and from secondary porosity associated with dolomitization of the Trenton Limestone. It is interesting to note that the field: is associated with faulting and fracture zones and produces a relatively heavy oil containing a large amount of sulfur compounds. The formations beneath the unconformity in southern Lower Michigan are usually filled with salt water or, as nearer the Ohio-Michigan border, sulphuric waters.

Future petroleum possibilities seem limited for the Prairie du Chien Group in Michigan at this time because of the general lack of vugular porosity in the dolomites and lack of exploration drilling and resulting data at this depth in the Basin. The most likely places for potential production would be: (1) porosity traps associated with faulted structures in the Basin; (2) porous erosional remnants underlying impermeable seals (unconformity surface and Glenwood shale); and (3) wedge outs along the margins of the Basin (porous sands or dolomites).

LANDSAT imagery showing the trends of lineaments may be a major means of locating prospective areas of petroleum production in the near future. Prouty (1976) has plotted nearly 700 lineaments in the Basin, indicating faulting. He (1976) has also noted the presence of cross-lineaments in such producing structures as the Howell Anticline and Albion-Scipio trend. Lineaments may play an important role in the accumulation and distribution of oil in the Michigan Basin and in the exploration of linear fault traps of the Albion-Scipio type.

SUMMARY AND CONCLUSIONS

The Prairie du Chien Group in the Michigan Basin is a far more extensive sequence of rocks than was previously believed. The thickness varies from zero feet in southeastern Michigan to a maximum interval of 1,080 feet in Newaygo County. The distribution of the Prairie du Chien isopach highs is somewhat crescent shaped with the two elongate troughs extending northeast into Presque Isle and Alpena Counties, and southeast into Gratiot County. The gradual thickening of the sediments basinward indicates basinal subsidence in Lower Ordovician time. It appears that general basinal subsidence was complicated by the somewhat eccentric isostatic sinking caused by the loading of the thick sands of the New Richmond-Shakopee Interval.

Faulting in the major structures of the southern Lower Peninsula has been interpreted as left lateral in nature with each of the major structures (the Howell Anticline, the Lucas-Monroe Monocline and its northwest extension and the Albion-Scipio trend) being a basement controlled, en echelon series of faults. Major movements of the faults are believed of Devonian and Mississippian age. Evidence for earlier episodes of faulting is not presented because of the lack of deep well control, except as pointed out in Calhoun County.

The Prairie du Chien Group presents identifiable, characteristic curves on gamma ray logs for southern Lower Michigan. When used in conjunction with lithologic information correlations can be made over the entire Basin. Again, well control is a major problem but can be overcome by detailed studies. The Prairie du Chien Group was divided into the Oneota Formation and the New Richmond-Shakopee Interval on the basis of gamma ray logs and lithologic criteria. The Oneota Formation can be further subdivided into a lower sandy dolomite and an upper argillaceous dolomite unit. It is inadvisable to try to subdivide the New Richmond-Shakopee Interval at this time. The lithologies reveal the gradational nature of the Trempealeau-Oneota-New Richmond-Shakopee Interval contacts in the Michigan Basin. The New Richmond-Shakopee Interval-Glenwood contact is marked by a major unconformity--the Post-Knox Unconformity, that has truncated not only the Prairie du Chien Group in Michigan but also parts of the Upper Cambrian formations as well, as evidenced in southeast Michigan.

Lithologic information reveals that the Lower Ordovician was a time of alternating transgressions and regressions of the inland seas in Michigan. Following a slight regression in Trempealeau time the lower Oneota sea transgressed, depositing dolomites and reworked sands into the shallow marine waters. The argillaceous dolomites of the upper Oneota indicate a transgression possibly accompanied by the exposure of surrounding land masses during this time. The deposition of thick clastics in northwestern Michigan during the New Richmond-Shakopee Interval connotes either a continued regression from upper Oneota time or an uplift to the northwest (the Wisconsin Arch or the craton) or possibly both. As the source of these sands wore down the seas stabilized or may have slightly transgressed allowing for the continued deposition of the Shakopee dolomites. There is no reason to believe that the Shakopee was not deposited in the Michigan Basin. The problem of differentiating the New Richmond and Shakopee formations in the Basin may reflect the transitional relationship between the two formations. A major regression followed this Interval during which time the sea retreated from most of the Michigan Basin and the Prairie du Chien topography was subjected to a long period of subaerial erosion entirely removing the upper formations from the shelves of the Basin. The extent of the erosion is unknown but judging from the absence of the New Richmond-Shakopee Interval from most of northern and southern Lower Michigan, the total absence of the Prairie du Chien Group in southeast Michigan, and the highly dissected nature of the Prairie du Chien Group in adjacent areas, must have been of considerable magnitude. The severity of the truncation varies but is probably greatest over the positive areas or the regional Precambrian "highs" that frame the Michigan Basin.

Dolomitization of the Prairie du Chien Group in the Basin appears to have been stratigraphic and primarily penecontemporaneous with sedimentation although some minor epigenetic dolomite was noted in southern Lower Michigan (Kirschke, 1962). As in Ohio it is likely that the Prairie du Chien surface was suitable for the formation of a karst topography, at least in areas along the rim of the Basin. The soluble carbonate rock, probably fault and joint patterns, possible channeling, and the long exposure to subaerial erosion processes would facilitate the development of a karst terrain.

Whether or not the Wisconsin and Findlay Arches were active structures in Lower Ordovician time cannot be determined with certainty. The presence of thick sands in northwestern Michigan, and the absence of both Prairie du Chien Group and several Upper Cambrian formations in southeast Michigan indicates either uplifting structures or positive features exposed to erosion by the regressions of the Prairie du Chien seas.

Future petroleum possibilities for the Prairie du Chien Group seem limited at this time.

This preliminary study of the Prairie du Chien Group of the Michigan Basin was limited by the distribution and number of wells that have penetrated the Group. It is hoped that the information gleaned from this study will enhance an understanding of the distribution, lithology, history and relationships of the Canadian Series to that of the surrounding areas.

RECOMMENDATIONS FOR FUTURE STUDY

(1) A petrographic analysis and comparison of New Richmond-Shakopee interval sands within Michigan to the New Richmond Sandstones of surrounding states to determine the lateral relationship of the Michigan Basin New Richmond-Shakopee Interval.

(2) A detailed petrologic examination to differentiate lithologically (if possible) the Oneota dolomite from the Trempealeau dolomite.

(3) A detailed petrologic examination of well samples to gain a better understanding of the major deflections on the gamma ray logs.

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APPENDICES

APPENDIX I

SUB-PRAIRIE DU CHIEN WELL LOCATION MAP

APPENDIX 1

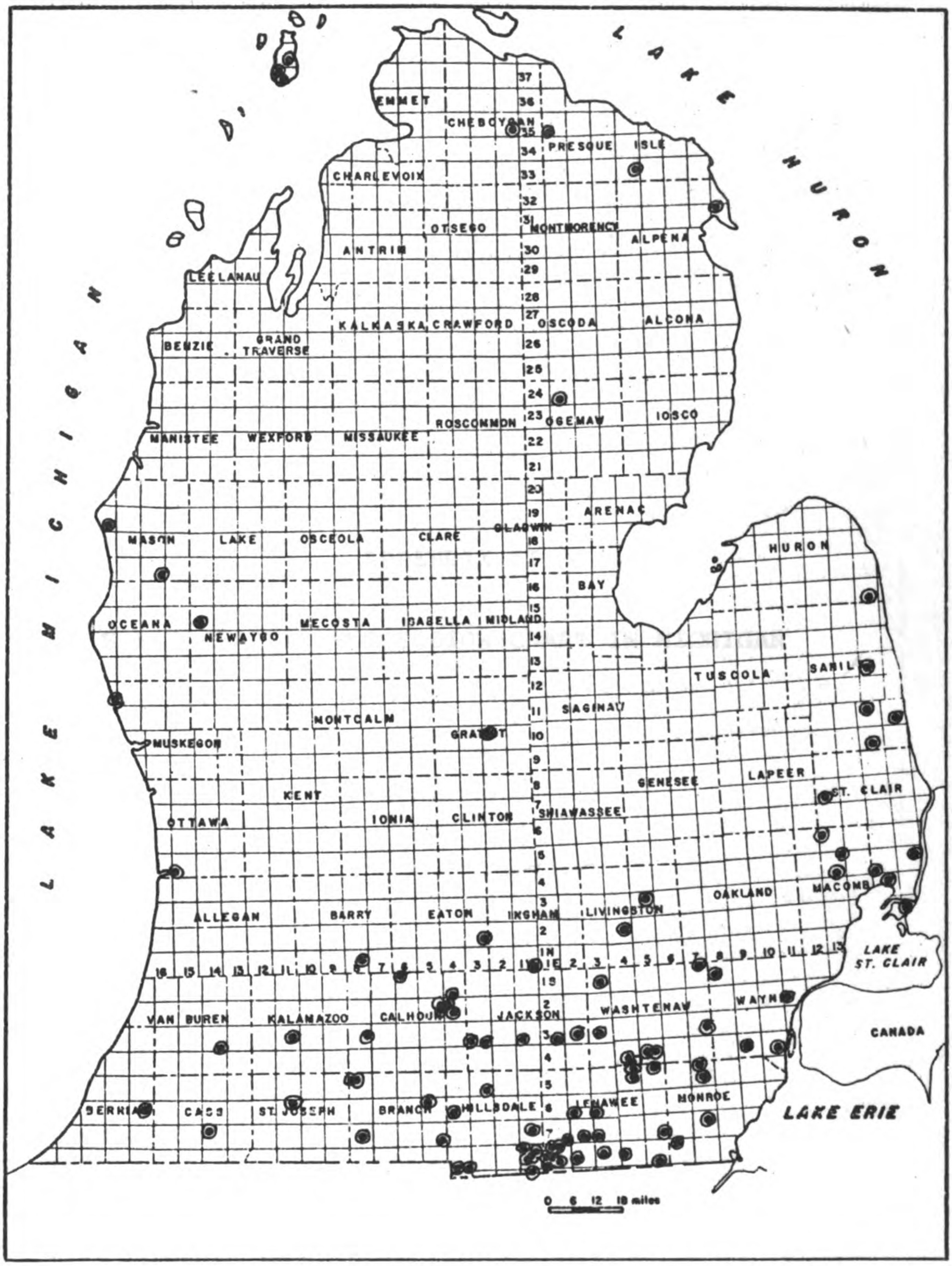

Figure 17

Sub-Prairie du Chien Well Location Map

APPENDIX II

STRATIGRAPHIC SUCCESSION CHART IN MICHIGAN

APPENDIX II

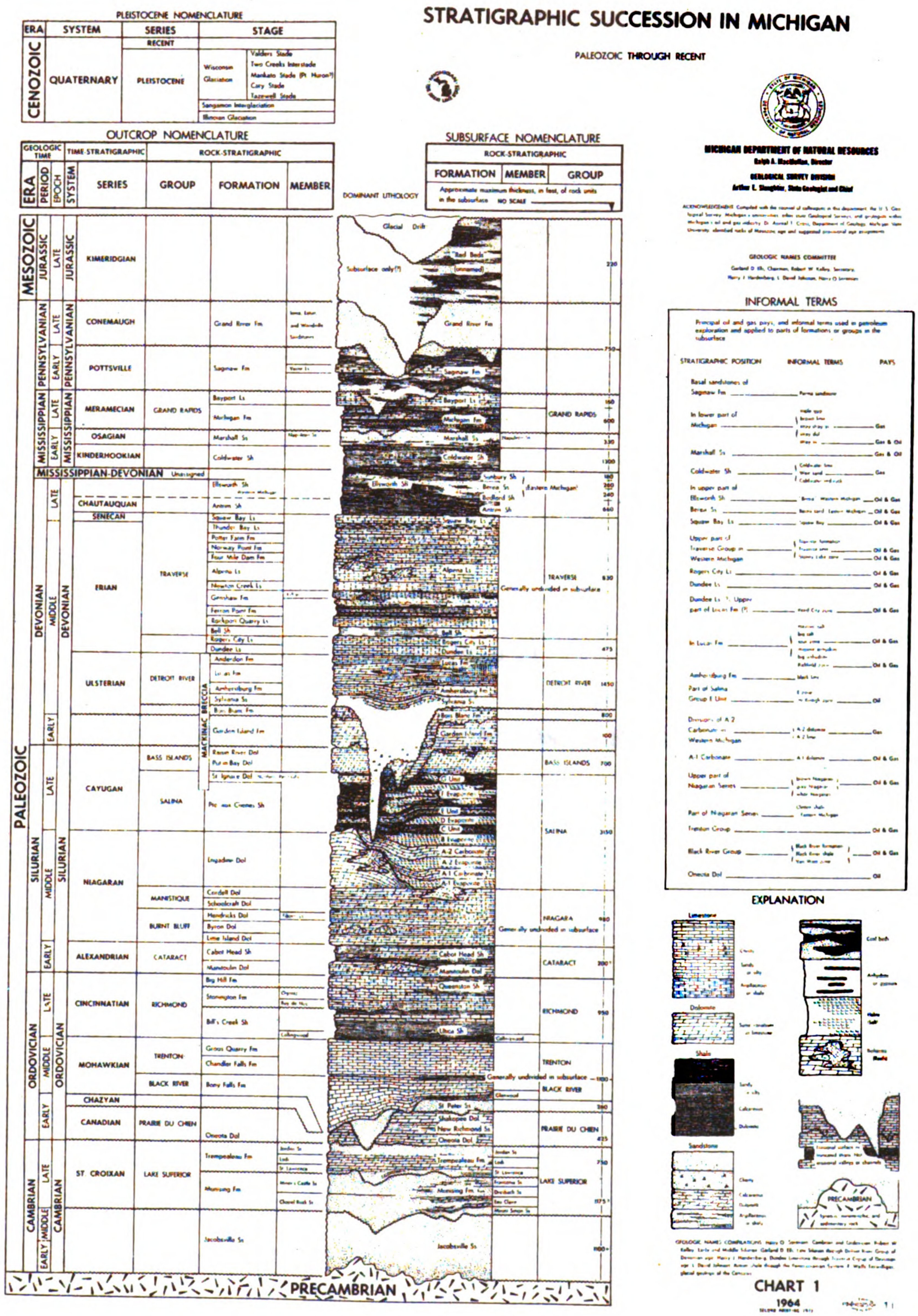

Figure 18

Stratigraphic Succession Chart in Michigan

APPENDIX III

WELL LISTINGS, LOCATIONS, FOOTAGE

APPENDIX III

Table 2.--Well Listings, Locations, Footage.

County Code Number	Operator-Farm	Location	Permit #	Log: KB	Top GW	Top PdC	Top Tremp
Allegan							
1.	Republic Oil Co.-Green #1	2N 11W 30	23361	836	4189	-	-
2.	Continental Oil Co.-Simpson #1	2N 12W 10	23685	827	4257	-	-
3.	Smith-Marshall #1	2N 12W 24	24323	836	4197	4202?	-
4.	Strake-Bass #1	2N 12W 25	21684	849	4214	4244?	-
Alpena							
5.	P.E.P.C.-Ford Motor Co. #1-5	31N 9E 5	25690	684	5292	5348	6064
6.	Shell-Sheldon-State Wellington #1-34	32N 5E 34	29571	756	5853	5917	-
Barry							
7.	Battle Creek Gas Co.-BD #2	1N 8W 14	BD#153	930	4756	4804	5327
8.	Miller Bros.-Willison #1	1N 9W 23	27731	963	4591	4614?	-
9.	Moran Drlg. Co.-Schantz #1	2N 7W 22	21999	979	5152	-	-
10.	Peninsular O & G-Kopf #1	2N 7W 36	29082	959	5085	5114?	-
11.	McClure-Hibbard #1	2N 9W 34	20732	925	4746	4753?	-
12.	Benedum-Trees Oil Co.-Bahs #1	3N 7W 22	21987	908	5434	5444?	-
13.	Amoco-Kennedy #1-14	3N 8W 14		927	5314	5361	-
14.	Sun Oil-Afman #1	3N 10W 12	24504	776	4859	4904	-
15.	McClure-Schaibly #1	4N 7W 20	23572	882	5634	5693	-
16.	McClure-McClellan #1	4N 8W 3	23366	882	5618	5651	-
Bay							
17.	Gulf-Bateson #1	14N 4E 2	10447	599	10364	10409	-

Table 2.--Continued.

County Code Number	Operator-Farm	Location	Permit #	Log: KB	Top GW	Top PdC	Top Tremp
Berrien							
18.	Security Oil-Thalmann #1	6S 17W 10	26112	804	2413	2430	2634
19.	C.P.C.-Schlutt #1-1	6S 19W 7	24369	654	2136	2142	-
20.	PEPC-Carter #8-1	3S 18W 36	24368	732	2558	2573	-
Branch							
21.	Occidental Petrol. Corp.-Voorhis #1	8S 5W 4	28536	1051	3462	3497	-
22. E. Log.	Ambass. Oil-Schlentman #1	7S 8W 15	20685	910	3196	3210	3538
23.	M.I.O.-Nearpass #1	7S 7W 1	27694	1034	3476	3509	-
24.	Hanner Oil Co.-Pierce #1	7S 7W 10	21893	956	3347	3394	-
25.	M.I.O.-Claar #1	7S 7W 12	27844	1026	3457	3491	-
26.	Hudson O & G-Brown #1	7S 7W 14	23308	989	3363	3403	-
27.	McClure-Armstrong #1	7S 6W 15	23564	1022	3473	3513	-
28.	Algonquin Petrol.-March #1	7S 5W 25	25758	1102	3568	3604	3747
29.	Perry & Son, Inc.-Meadows #1	7S 5W 32	23860	1017	3425	3460	-
30.	Mobil-Ransborg #1	6S 5W 36	26478	1075	3679	3716	-
31.	Houseknecht-Liskey #1	6S 5W 5	26719	1033	3812	3842	4090
32.	C.P.C. Quintana-Hostetter	5S 8W 7	29779	890	3517	3547	3847
33.	C.P.C. & Quintana-Clerk #1	5S 8W 8	29969	889	3553	3574	3885
34.	M.I.O.-Adolph-Bartlett #1	5S 7W 15	27853	909	3648	3672	-
35.	Union Oil of Calif.-King #1	5S 5W 8	27650	994	3924	3948	-
36.	Ohio Oil-Wilson #1	5S 5W 31		989	3766	3790	-
Calhoun							
37.	M.I.O.-Hyatt #1	4S 7W 33	28321	904	3779	3794	-
38.	McClure-Spires #1	4S 6W 21	22476	938	3953	3963	-
39.	McClure-Davis #1	4S 6W 17	23563	990	4019	3931	-

Table 2.--Continued.

County Code Number	Operator-Farm	Location	Permit #	Log: KB	Top GW	Top PdC	Top Tremp
Calhoun (continued)							
40.	C.P.C.-Quintana-Taylor	4S 5W 31	29630	975	3968	3987	-
41.	Jackson-Trader #1	4S 4W 1		1030	4409	4436?	-
42.	Trolz-Trader #1	4S 4W 1	23608	1038	4415	4438?	-
43.	Fulk-Horn #1	4S 4W 13	22807	999	4302	4323	-
44.	Turtle Drlg. Co.-Littlebrandt-Smith-Schaffer #1	4S 4W 22	23551	1026	4249	4266	-
45.	Bernloehr-Poole #1	3S 8W 13	22352	952	4048	4073	4448
46.	Hathcock-Engelhard #1	3S 8W 16	23038	958	3984	3994	-
47.	Citgo-Spooner #1	3S 7W 23	23292	925	4093	4106	-
48.	Petrosonic-Maynard #1	3S 6W 15	23389	963	4260	4283	-
49.	Trolz & Assoc.-Kinney #1	3S 4W 26	23576	1042	4484	4518?	-
50.	Cummings-Fountain #1	2S 5W 12	23680	923	4694	4708	4708
51.	Cowen-Young #1	2S 5W 13	23983	933	4678	4692	4692
52.	Rudman-Cruse-Brandt #1	2S 4W 7	23553	932	4738	4742	4751
53.	Cowen-Masternak #1	2S 4W 21	23438	983	4691	4715	4727
54.	Cowen-Davis & Davis #1	2S 4W 21	26203	963	4710	4740	4740
55.	McClure-North Acres #1	2S 4W 29	23033	958	4644	4668	-
56.	Fulk-Mymochod Comm. #1	2S 4W 34	22053	981	4632	4648	-
57.	Brazos & Dow Chem-Holden #1	1S 6W 5	24536	866	4747	4753	4760
58.	Hensley-Hensley #1	1S 5W 5	26737	944	4950	4960	-
59.	Trenton-Wood #1	1S 5W 9	22397	949	4962	4967	-
60.	Simpson-Walter #1	1S 5W 15	22578	936	4863	4906	-
61.	Sun Oil-Sundberg #1	1S 5W 26	22386	948	4848	4887	-
62.	Cowen-Lake Comm. #1	1S 4W 33	23427	986	4883	4894	4942

Table 2.--Continued.

County Code Number	Operator-Farm	Location	Permit #	Log: KB	Top GW	Top PdC	Top Tremp
Cass							
63.	Harris Oil-McClure Oil-Gordon #1	8S 14W 3	22047	846	2497	2505	-
64.	Perry & Sons Inc.-Kaminski #1	7S 15W 26	23290	846	2451	2476	-
65.	Perry & Sons-Wooden #1	7S 14W 8	23289	865	2641	2677	2888
66.	Van Raalte-Gemberling #1	7S 14W 36	17414	904	2588	2659	-
67.	Simpson-Kimmick #1	6S 14W 14	23698	920	2843	2871	-
68.	Kehlet-Hartsell #1	5S 14W 26	23959	954	2959	2963?	-
Charlevoix							
69.	McClure Oil-St. Beaver #2	37N 10W 6	23478	743	3310	3326	3717
70.	McClure-Goddard #1	37N 10W 19	23681	661	3364	3330	3787
71.	McClure-St. Beaver #1	38N 10W 27	23435	680	3183	3194	3569
Clinton							
72.	McClure-Fox #1	7N 1W 6	27811	773	7577	7618	-
Crawford							
73.	Union Oil-St. Beaver Cr. C-4	25N 4W 21	28110	1240	9884	9955	-
Cheboygan							
74.	Northern Mich. Exploration-St. Waverly #1-24	35N 1W 24	30682	801	4556	4598	5243
Eaton							
75.	Perry & Son-Koch #1	1N 6W 25	27628	921	5087	5107?	-
76.	Lawton & Hack Drlg. Co.-Black #1	1N 6W 17	22541	954	5033	5013?	-

Table 2.--Continued.

County Code Number	Operator-Farm	Location	Permit #	Log: KB	Top GW	Top PdC	Top Tremp
Eaton							
77.	Fulk-Palmer & Miller #1	1N 6W 2	22497	948	5161	5181?	-
78.	Fortuna-Snow #1-28	1N 5W 28	30291	910	5018	5040	-
79.	Trolz-Whittum #1	1N 3W 3	27766	907	5518	5555?	-
80.	Mobil-Kelly #1	2N 3W 24	29117	870	5745	5766	6389
Emmet							
81.	Atlantic Inland-White & Burns #1	37N 4W 35	28212	714	3845	3900	-
Gratiot							
82.	McClure-Sparks, Echelbarger Whightail #1-8	10N 2W 8	29739	762	8572	8614	9687
Hillsdale							
83.	Liberty-Fellows #1	9S 1W 3	26655	886	3222	3261	3283
84.	Liberty-Horwath #1	9S 1W 3	27024	882	3224	3269	3295
85.	B.B. & C Oil Co.-Crall #1	8S 4W 33	27045	1011	3269	3303	3430
86.	Whitmer-Ellison & Jones #1	8S 4W 36		979	3238	3274	-
87.	Whitmer-DePue #1	8S 4W 10	23973	1081	3445	3481	-
88.	Liberty-Frank #1	8S 1W 6	27517	980	3520	3553	3654
89.	Bell & Gault Drlg.-Young #1	8S 1W 11	22536	920	3437	3475	3560
90.	Bell & Gault Drlg.-Laser #1	8S 1W 15	27349	916	3468	3500	3573
91.	Liberty-Landel #1	8S 1W 20	26488	894	3327	3361	3425
92.	Clerici & Phillips-Cox #1	7S 4W 29	21856	1081	3576	3610	-
93.	Ohio Oil & McClure-Hoard #1	7S 4W 3	21910	1104	3737	3775	-
94.	Covey & Null-Crifton #1	7S 4W 7	23817	1082	3655	3690	-
95.	Liberty-Joughlin-Stuck #1	7S 2W 2	26788	1163	3908	3945	-

Table 2.--Continued.

County Code Number	Operator-Farm	Location	Permit #	Log: KB	Top GW	Top PdC	Top Tremp
Hillsdale (continued)							
96.	McClure-Lee #1	7S 2W 10	21770	1097	3802	3839	-
97.	Texaco-Edmonds #1	7S 2W 10	26078	1094	3796	3833	-
98.	D & I Drlg-Bailey & Sanders #A-1	7S 2W 24	22304	1062	3725	3757	-
99.	Eureka O & G-Crittenden #1	7S 1W 2	21951	1088	3907	3942	-
100.	Perry & Son-Rymal #1	7S 1W 15	25508	1029	3732	3768	3883
101.	McClure-Plum #1	7S 1W 35	23058	916	3495	3525	-
102.	Houseknecht-Price-Stafford #1	6S 4W 20	26500	1062	3732	3767	3956
103.	Collins Bros.-North, Sawyer #1	6S 2W 3	27716	1189	4167	4202	-
104.	R & H Development-Swager #1	6S 2W 6	24073	1146	4136	4163	-
105.	McClure-Barker #1	6S 2W 8	22510	1171	4130	4173	-
106.	Cassidy-Goodwin #1	6S 2W 9	25463	1150	4070	4110	-
107.	McClure-Post #1	6S 2W 16	22029	1133	4025	4060	-
108.	Houseknecht-Ebel #1	6S 7W 18	26252	1074	4020	4056	-
109.	Jenkins & Woodruff-Fuller #1	6S 2W 21	24657	1132	4013	4046	-
110.	Jenkins & Woodruff-Black #1	6S 2W 28		1172	4008	4040	-
111.	Frontier Petrol-Schmitt #1	6S 3W 12	23079	1121	4004	4042	-
112.	McClure-Adams #1	6S 1W 23	26370	1069	3987	4017	-
113.	Rousek-Shipman & Kobitz #1	5S 3W 13	24769	1159	4236	4263	-
114.	Jenkins & Woodruff-Chilson #1	5S 3W 24	24994	404	4133	4173	-
115.	Mason Petrol Prop.-Ramsey & Ellis #1	5S 3W 26		1109	4082	4115?	4345
116.	Davis Drlg. Co.-Spencer & Hergert #1	5S 3W 25	22164	1189	4191	4223	-
117.	Occidental-Rumsey & Emerson #1	5S 2W 4	28271	1081	4332	4360	-
118.	Fulk-Godfrey #1	5S 2W 19	22528	1177	4227	4257	-
119.	Glavin-Powell #1	5S 2W 33	22780	1177	4182	4213	-

Table 2.--Continued.

County Code Number	Operator-Farm	Location	Permit #	Log: KB	Top GW	Top PdC	Top Tremp
Huron							
120.	Mobil-Volmering #1	15N 15E 26	29191	711	7244	7305	7628
Ingham							
121.	Pure Oil-Harkness #1	2N 2W 16	24518	916	5912	5933?	-
122.	Hibbard Oil Co.-Seibly #1	2N 2W 33	23929	937	5707	5725?	-
123.	Mobil-Hasbrook #1	1N 1W 35		983	5631	5655?	-
124.	Mobil-Reeve #1	1N 1W 36	29672	977	5637	5651	6143
125.	Ketchum-Basore #1	1N 2E 13	22607	972	5430	5452?	-
126.	Ambassador Oil-Wild #1	1N 2E 31	24470	944	5771	5795	-
Ionia							
127.	Anson Corp. Dieterman #1	6N 8W 4	27021	684	6017	6040	-
128.	Ambassador Oil-Burtle #1	6N 8W 4	25025	718	6073	6100?	-
129.	Hunting Oil-Possehn #1	6N 6W 31	27700	873	6242	6275?	-
130.	McClure-Trayer #1	5N 8W 28	23482	816	5633	5673?	-
131.	McClure-Wildman #1	5N 7W 15	23574	870	5994	-	-
Jackson							
132.	Nanco-Hubbard Est. #1	4S 3W 3	25610	1053	4457	4479	-
133.	Rudman-Frank #1	4S 3W 6	22908	1028	4370	4409	-
134.	Sun Oil-Peterson-Howard #1	4S 3W 17	22013	1013	4325	4341	-
135.	Petromin-Day #1	4S 3W 19	23022	1011	4276	4291	-
136.	Lovitt-Dunham #1	4S 3W 24	23344	1038	4434	4450	-
137.	Davis Drlg.-Hancock & Loub #1	4S 3W 27	22664	1123	4373	4393	-
138.	Fulk-Heath #1	4S 3W 34	22951	1097	4296	4318	-
139.	McClure & Rudman-Dean #1	4S 3W 36	22691	1145	4382	4407	-
140.	Rousek & Volk-Dean Center #1	4S 2W 16	22934	1069	4476	4481	-

Table 2.--Continued.

County Code Number	Operator-Farm	Location	Permit #	Log: KB	Top GW	Top PdC	Top Tremp
Jackson (continued)							
141.	Perry & Son-Harris #1	4S 2W 34	25190	1111	4386	4412	-
142.	Otterbine & Donley-Baylis	4S 2E 9	22017	964	4608	4617	-
143.	Ohio Oil-Watkins Farms #1	4S 2E 24	23656	1051	4593	4624?	-
144.	Palmer & Cummings-Rhodes #1	3S 3W 22	22674	1035	4586	4614	-
145.	McClure-Smith #1	3S 3W 30	22351	998	4458	4482	-
146.	Nanco-Smith #2	3S 3W 30	27137	1018	4473	4498	4840
147.	Rousek-McFarlane #1	3S 3W 35	24840	1079	4548	4563	4903
148.	Rousek & Volk-Burnett #1	3S 2W 31	22950	1044	4570	4581	-
149.	Collins & Black-Hill #1	3S 1W 28	22442	970	4675	4700	-
150.	Collins & Black-Dancer #1	3S 1W 29	22275	987	4646	4661	4963
151.	Dart-Boone #1	3S 1E 26	21898	959	4761	4768	~4893
152.	American Hydrocarbon-Culbert #1	3S 2E 22	23397	962	4808	4823	~4925
153.	Miller Bros.-McConkey #1	2S 3W 26	21905	971	4783	4793	-
154.	M.I.O.-McDonald & Leh #1	2S 3W 27	27882	1010	4807	4814	-
155.	Texaco-Benn #1	2S 2W 16	26548	940	4954	4960	-
Kalamazoo							
156.	Alexander-Bowerman #1	4S 10W 11	23004	893	3578	3586	-
157.	Upjohn-Upjohn #3	3S 11W 14	MW 137-744-839	885	3607	3618	3999
158.	Ashland Oil-Hayward #1	3S 10W 31	27508	874	3522	3530	-
159.	Turtle Drlg. Co.-Rumsey #1	1S 12W 10	23035	790	3791	3796	-
160.	McClure-Todd #1	1S 10W 24	20972	916	4085	-	-
Kent							
161.	Producers Comm.-Riddering #1	7N 12W 30	9166	739	5105	5199?	-
162.	Ambassador Oil-Ten Have #1	8N 9W 6	24826	867	6479	6527?	-
163.	Anson Corp.-Parmeter #1	9N 10W 26	26908	911	6564	6618	-

Table 2.--Continued.

County Code Number	Operator-Farm	Location	Permit #	Log: KB	Top GW	Top PdC	Top Tremp
Leelanau							
164.	Lindsay-Kirt #1	30N 11W 6	22627	913	5693	-	-
Lenawee							
165.	N.A. Drlg. Co.-Seven Seas #1	8S 1E 3	24035	861	3399	3437	3470
166.	Baver Brost Basin-Beal #3	8S 1E 4	27046	867	3390	3425	3465
167.	MOCO-Walter #1	8S 1E 18	23652	872	3341	3383	3428
168.	Buck & Basin Oil Co.-Sly & Ferris #1	8S 1E 27	21916	-	3248	3291	3304
169.	MOCO-Flint Comm. #1	8S 1E 31	25931	840	3231	3267	3286
170.	Howard-Snyder #1	8S 2E 20	23718	790	3202	3240	3256?
171.	Hammer-Wellnitz #1	7S 1E 36	21822	857	3421	3458	3481
172.	Amer. Hydrocarbon-Emerson #1	7S 2E 27	23737	840	3390	3432	3452
173.	Horizon Oil-Meech & Griffith #1	7S 3E 30	26876	799	3414	3454	3454
174.	Buck & Basin-McClenathen #1	8S 4E 18	16693	717	3158	3192	3192
175.	Occidental-Schumacher #1	8S 5E 34	28543	713	2872	2910	2910
176.	Trolz Hawkins et al. #1	6S 1E 20	23838	979	3889	3922	-
177.	Anderson-Brooks #1	6S 2E 4	28168	1010	4020	4054	-
178.	Lawton-Drewyer #1	6S 2E 25	23751	864	3669	3708	-
179.	Occidental-Rupert #1	6S 2E 29	28529	930	3764	3796	3796?
180.	Seven Seas-Francover #1	6S 3E 18	22112	888	3793	3814?	?
181.	California Co.-Mohr #1	6S 3E 30	24515	872	3712	3741	3741?
182.	McClure & Ambassador-Sawyer #1	5S 1E 18	22010	1092	4354	4491	-
183.	McClure-Allen #1	5S 4E 14	22866	872	3916	3950	3955
184.	Cambridge-Service #1	5S 4E 2	28868	895	3810	3844	3852
185.	Good & Good-DeLodder #1	5S 5E 3	24304	760	3471	3521	3521
	Bernhardt O & G-Gerber #1	7S 5E 25	25016	687	2691	2726	2726
	Basin Oil-Snedicor & Under. #1	8S 3E 17	23527	749	3217	3281	3281

Table 2.--Continued.

County Code Number	Operator-Farm	Location	Permit #	Log: KB	Top GW	Top PdC	Top Tremp
Livingston							
186.	Strake-Lopez #1	1N 6E 14	24771	929	5488	5522	-
187.	Texaco-Amer. Aggregate #1	1N 6E 15	27720	910	5492	5522	-
188.	Texaco-Kish #1	1N 6E 14	26999	936	5387	5400?	-
189.	Patrick Petrol-Kleinschmidt #1	2N 3E 17	28752	960	5893	5928?	-
190.	Brazos O & G-Kizer #1	2N 4E 14	25868	938	6222	6247	6766
191.	Muskegon Dev., Rousek & Mutch-Ganton #1	3N 3E 1	29051	920	5655	5678?	-
192.	Humble Oil-Soule #1	3N 3E 2	23374	939	5600	5623?	-
193.	White-Scepka #1	4N 3E 28	22642	900	5955	5930?	-
194.	Mobil-Mess. #1	3N 5E 11	27986	980	6201	6229	6753
Macomb							
195.	C.P.C.-Halmich #1	4N 13E 1	26214	693	5113	5180	5180
196.	Cowen & Gordon-Pell. #1	4N 13E 29	29008	668	4988	-?	-
197.	P.E.P.C.-Heide #1	5N 13E 7	22439	785	5638	5694	5694
Mason							
198.	Superior-Sippy #17	17N 16W 25	18905	726	5938	∿5958	6956
199.	Dow, Brazos-Taggert #1	19N 18W 27	17789	647	5340	5350	6165
Monroe							
200.	Ashland-Nichols #1	8S 6E 5	26224	693	2512	2568	2568
201.	McClure-Williams #1	7S 7E 10	25062	650	2878	2919	2919
202.	Pell & Marks-Heath #1	5S 7E 4	23531	658	3335	3368	3368
203.	Simpson & Good & Good-Jennings #1	5S 7E 22	23532	662	3176	3227	3227

Table 2.--Continued.

County Code Number	Operator-Farm	Location	Permit #	Log: KB	Top GW	Top PdC	Top Tremp
Muskegon							
204.	DuPont-Dupont Disposal #1	12N 18W 36	BD	656	4595	4623	5368
Newaygo							
205.	Miller Inc.-Seaman #1	11N 13W 15	22918	817	6132	-	-
206.	Simpson-Harris-State Grant	11N 12W 10	23149	812	6498	-	-
207.	Thunder Hollow-Thompson #1	15N 14W 20	26662	829	6432	6495	7585
Oakland							
208.	Texaco-Huntoon #1	4N 8E 35	28258	1048	6315	6366	-
209.	Collin-Gowan #1	1N 7E 35	19055	1020	5328	5345	-
Oceana							
210.	Peake Petrol & Harvey-Skidmore #1	16N 16W 11	22801	984	6027	-	-
211.	Carter Oil-Lauber #12	16N 17W 6	17549	651	5233	5300?	-
Ogemaw							
212.	Ohio Oil-Reinhardt #1	22N 2E 35	12896	903	10418?	10475	-
213.	Brazos-Sun-Superior-St. Foster #1	24N 2E 28	25099	1477	10412	10480	11050?
Ottawa							
214.	Holland Suco-Suco D.W #1	5N 15W 30	BD	623	3907	3934	4455
215.	Dow Chem-Heinz WDW #3	5N 15W 30	BD	617	3875	3900	4413
216.	Michigan Petrol-Moe #1	9N 13W 6	537	704	5490	5640	-

Table 2.--Continued.

County Code Number	Operator-Farm	Location	Permit #	Log: KB	Top GW	Top PdC	Top Tremp
Presque Isle							
217.	Shell-Shell Taratuta #1-13	33N 5E 13	29372	761	5206	5258	6013
218.	Fain-Porter-Weide #1	33N 7E 33	24999	816	5310	5367	-
219.	Lindsay-Sellke #1	34N 5E 20	22638	844	5043	5087	-
220.	Pan Am.-Draysey #1	35N 2E 29	27199	809	4650	4685	5344
Sanilac							
221.	Hallwell G & O-Spencer #1	9N 15E 27	26480	759	6195	6264	6264
222.	Simpson-Hontar #1	10N 15E 9	25936	775	6609	6662	6683
223.	Phillips Petrol.-Long #1	10N 16E 27	24441	770	6252	6298	6298
224.	Amoco-Sheldon #1	11N 14E 21	29157	774	7430	7487	-
225.	McClure & M.N.R. et al. #1-20	12N 15E 20	30974	785	7314	7369	7593
Shiawassee							
226.	Lee-Ferris #1	5N 2E 5	22379	856	6718	6756?	-
227.	Mobil, Jelinek-Ferris #1	5N 2E 5	27907	843	6953	6992?	-
228.	Hadson O & G-Dysinger	5N 2E 22	23376	906	7227	7267?	-
St. Clair							
229.	Bernhardt-Puzzuoli #1	2N 16E 17	25780	581	3940	3995	3995
230.	C.P.C.-BD #139	4N 15E 31	BD139	616	4436	4486	4486
231.	C.P.C.-Roney #1	5N 16E 11	22002	629	4653	4700	4700
232.	Lanphor O & G-Lyle #1	7N 13E 28	25632	813	6237	6294	6294?
233.	Collin-Bidal, Fancher, Levrau #1	3N 15E 10	23796	595	4398	4446	4446

Table 2.--Continued.

County Code Number	Operator-Farm	Location	Permit #	Log: KB	Top GW	Top PdC	Top Tremp
St. Joseph							
234.	Mahnke-Mahnke #1	6S 11W 2	1244	833	3040	3065	3360
235.	National Industries-Cook #1	6S 11W 14	28005	830	3018	3060	-
236.	Grigg & Marshall-Thunder #1	6S 11W 27	21155	823	2961	2996	-
237.	Simpson-Reed #1	7S 9W 15	23839	864	3066	3096	-
Tuscola							
238.	Simpson & Sun Oil-Sattelberg #1	13N 9E 8	23890	678	9858	9944	-
239.	Simpson-Novesta Twp. #1	13N 11E 16	25609	738	9089	9176	-
Van Buren							
240.	McClure-Daly #1	4S 16W 30	27501	813	2672	2687	-
241.	Turtle Drlg.-Kern	4S 14W 34	23524	922	3040	3064	-
242.	Miller Bros.-Jolicoeur #1	1S 14W 16	28590	764	3396	3412?	-
243.	Tri County-Reed #1	3S 14W 35	25706	748	3020	3040?	3372
Washtenaw							
244.	Rousek-Bulman #1	1S 7E 2	25759	996	5253	5265?	5265
245.	Simpson & Gulf-Wagner & Slocum #1	1S 3E 22	24161	961	5088	5094	5194
246.	Peake Petrol-Goers #1	2S 3E 25	24396	939	4698	4718	-
247.	N.Y. Petromineral-Widmayer #1	3S 3E 21	28655	978	4863	4883	5117
248.	N.Y. Petromineral-Widmayer #1A	3S 3E 21	28990	980	4857	?	5107
249.	Rousek-Grau #1	3S 4E 8	27472	957	4556	4574	-
250.	Sun Oil-Meyer #1	3S 4E 16	25607	974	4458	4474	-
251.	Sun Oil-Hoener #1	3S 4E 21	27099	1002	4439	4463	-
252.	Reusek-Wabash R.R. #1	3S 7E 24	25482	694	3883	3910	3964?
253.	Trolz & Assoc.-Trolz #1	4S 3E 20	25950	1025	4563	4582	-

Table 2.--Continued.

County Code Number	Operator-Farm	Location	Permit #	Log: KB	Top GW	Top PdC	Top Tremp
Washtenaw (continued)							
254.	Besko Petrol-Allen #A-1	4S 4E 27	26204	864	3893	3920	3962
255.	Peake Petrol. & Harvey-Bohnenstiehl #1	4S 4E 34	23380	919	3870	3904	3926
256.	Good & Good-Marion #GG-1	4S 5E 14	23921	795	3760	3776	3788
257.	Good & Good-Schowacke #GG-1	4S 5E 16	24714	864	3776	3799	3825
258.	Leonard Oil-Schwocho #1	4S 5E 17	26856	861	3794	3812	3849
Wayne							
259.	PEPC-Ford Motor #1	2S 11E 19	25560	588	3824	3874	3874
260.	Marathon-BD #1	4S 10E 22	BD146	609	3194	3252	3252
261.	Colvin et al.-Theisen Est. #1	4S 9E 16	10430	625	3300	3340	3340
262.	Woodson Oil (C.P.C.)-#1	1S 8E 17	19496	900	~4782?	~4786	4786

APPENDIX IV

SAMPLE WELL DESCRIPTIONS

APPENDIX IV

Table 3.--Sample Well Descriptions.

(A)

C. A. Perry & Son, Inc. - Wooden #1, 7S 14W 8 SENENW
Cass Co., Calvin Twp. Rotary PN #23289

Blk. River

2625-30	Dol, brn-buff, f-m xtal, few sdy (60%); ss, vf-mgr, fr & pit to clr, dol cmt, arg, ss m-c gr rd-wrd, lse, frostpit (38%); sh gn & blk, some sdy (2%).
2630-35	Dol buff-brn, f xtal, arg, tr sdy (92%); ss, as above (3%); sh, gn-gn gy, brn, blk (5%).
2635-40	X

Glenwood (and St. Peter)

2640-45	Dol, buff-brn, f-m xtal, few sdy, some por, dol rhmb (xtals) (80%); ss, a.a. (10%); sh, a.a. (10%); tr LS.
2645-50	Dol, buff, brn, buff wh, f-m xtal, sdy, some por, poss cong? (90%); sh, a.a. (10%); tr Ls, buff-buff wh, fxtal, tr pyr.
2650-55	Dol, buff wh-brn, f-mxtal, sdy, rhmbs (80%), sh, a.a. (10%); ss, f gr, subang-subrd, clr, dol cement (10%).
2655-60	SS, f-m gr, few c gr, frostpit, lse, rd-wrd, dol cmt in pt, some arg, some overgrowths (90%); dol, a.a. (5%); sh, gy, blk, gn, brn (fis), (5%); tr Glau, gn.
2660-65	Dol, buff-brn, f xtal, sdy, por in pt, arg, tr ool, some pyr (85%); ss buff-wh to blk, dol cmt, arg in pt, f-c gr subrd-wrd, clr to fros & pit, some overgrowths, pyr in pt; some lse (10%); sh blk, gy (5%); tr anhy wh, sft.
2665-70	Dol, buff to tan, f.xtal to gran, sdy, s amt pyr, por (100%); tr sh, gy, blk gn.

Table 3.--Continued.

2670-75	Dol, a.a. (99%); sh gn, sdy, gy-blk (1%); tr ss, tr pyr.
2675-80	Dol, buff wh to tan, f gr, gran, por, sdy, some pyr (99%); sh a.a., tan, fiss (1%); tr ss; tr Cht, wh, trip.

Prairie du Chien at 2677 (G.R.)

2680-85	Dol, buff wh-buff, f xtal, por in pt, sdy, pyr (100%); tr sh; tr cht, wh, ool, chky, vug; tr Glau., gn on dol; pyr.
2685-90	Dol, a.a., (100%); tr sh; tr Cht, a.a.; tr Glauc, a.a.
2690-95	Dol, a.a., few lt gy-brn (98%); sh, a.a., gn sdy (2%); Cht wh, ool, sdy in pt; tr Glauc.; tr pyr; tr ss; dol, gn slty fgr.
2695-2700	Dol, a.a., rhmb, (99%); sh, a.a. (1%); tr Glauc.
2700-2705	Dol, a.a. (99%); sh gy, gn, brn (1%); tr Glauc; tr ss.
2705-10	Dol, buff-buff wh, lt gy, f xtal, por, rhmb, pyr (98%); cht, wh, ool, gy wh, porc (2%); sh, a.a.; tr ss; tr Glau.
2710-15	Dol, a.a. (100%); sh, a.a.; tr ss; tr Glauc.
2715-20	Dol, a.a. (100%); sh, a.a.; cht, wh, trip, gy, porc/incl of ool rhmbs.
2720-25	Dol, buff-tan, f-m xtal, por, pyr, rhmb (97%); cht, wh to buff, dnse to chk, sil/incl, cht sec, some pyr (3%); tr pyr, tr sh.
2725-30	Dol, tan, buff brn, f-m xtal, rhmb, pyr in pt (95%); cht, wh to buff, pore, dns, pt trip, dol xtal incl (5%).
2730-35	Dol, buff-tan, f xtal, por, tr pyr (100%); tr cht wh assoc/dol rhmbs, fill vug, tr sh, gy blk.
2735-40	Dol, a.a., dol, buff wh v f-f xtal por (80%); cht, wh (chky & trip) to buff (porc, dns), few vug, pt ool (20%); tr sh, a.a.; sh, gn, pyr; qtz xtals.
2740-45	Dol, buff-buff gy, f-md xtal, rhmb, int xtal por (98%); cht, chk, wh to buff, pt trip (wthrd) (2%); tr sh, a.a.; tr sd gr.
2745-50	Dol, buff-brn, f-m xtal, por, dol xtals (80%); cht wh to buff, vug, trip in pt, sm to chk, sil (17%); sh gy-blk (1%); tr vn qtz; ss, f-fm gr, subang-rd, clr, overgrowths, thn bd (1%); Anh, wh, sft, slky (1%).

Table 3.--Continued.

2750-55	Dol, buff-tan, f-m xtal, por in pt, rhombs, clr xtals (94%); Cht, wh to buff, porc, dns, relic ool, pyr, sil (6%); tr sh; tr Anhy.
2755-60	Dol, buff-tan, f xtal, gran xtal in pt, some por (90%); Cht buff to wh, porc to trip, sil, col mot, incl, some vug (10%); sh, a.a.; tr Anhy wh-tan.
2760-65	Dol, a.a. (95%); Cht, wh, assoc/dol, pt wthrd, pt Fe stn (reddish) (5%); sh, a.a.
2765-70	Dol, a.a. (80%); Cht wh-buff, vug rhmb dolocastic, sil, chk to porc, trip assoc/ rhmbs, geode, qtz xtals in vug (20%); sh a.a.
2770-75	Dol, buff wh-buff, f-m xtal, por in pt, rhmb (100%); sh high contamination.
2775-80	Dol, buff wh-gy, f-m xtal some por, rhmb (91%); Cht, wh-gy, ltl trip., porc, sil, mot, assoc/rhmb, qtz (4%); sh, gy, gn, assoc/dol (5%); pyr xtal.
2780-85	Dol, buff wh-gy, f-m xtal, rhmb, some clr xtal, por in pt, pyr in pt (100%); Cht, wh chk assoc/rhmb, sh gy, gn.
2785-90	Dol, a.a., inc rhmb, inc por (100%); Cht wh (chk) to brn (dns), a.a.; sh, a.a.
2790-95	Dol, buff-tan, m-c xtal, rhmb, int xtal por, qtz filling in some (100%); sh, a.a.; tr Cht, a.a.
2795-2800	Dol, tan, buff, brn, f-m xtal por in pt, few rhmb, qtz xtal on dol (100%); sh, gy gn, gy; tr sd.
2800-05	Dol, tan-buff wh, m-c xtal, por, rhmb, clr xtal, pyr (98%); sh, gn-gn gy spec (2%); cht wh chk; pyr.
2805-10	Dol buff-tan, m-c xtal por, looks jumbled like c rhmb in f mtx (100%); tr pyr.
2810-15	Dol buff, tan, lt brn, m-c xtal, por, rhmb, less jumbled (88%); Cht wh-brn, ool, dns to por between ool, clr mot (brn) (12%); sh gy-gn gy.
2815-20	Dol, buff wh, buff-tan, f xtal, some por, ool (ool surf pyr coated in pt) (100%); sh a.a.
2820-25	Dol, a.a., (100%); sh a.a.
2825-30	Dol tan to buff, brn, c xtal some por, (Fe stn or wthrd, tr arg on surf poor sample) (100%); sh gy-blk.
2830-35	Dol, buff-buff wh, f xtal, some por, (poor sample) (100%).
2835-40	Dol, buff-tan, brn, f-m xtal, rhmb some por, tr pyr, sl arg (100%).

Table 3.--Continued.

2840-45	Dol, buff-buff wh, brn, f-m xtal, some gran, some por, tr pyr (100%).
2845-50	Dol, buff wh, buff, gy, tan, f-m xtal, por, rhmb (100%); tr Cht, wh, trip, assoc w/dol rhmb.
2850-55	Dol, a.a. (100%); tr Cht, a.a.; tr Gyp, wh, sft.
2855-60	Dol, buff-buff wh, m-c xtal, g por, rhmb, pyr (100%); tr Cht.
2860-65	Dol buff, buff wh-tan, vf-c xtal, few rhmb, pyr (98%); sh gn, red (tr) (2%); tr sd, f gr, subrd, fr, pit; tr pyr.
2865-70	Dol, a.a. (97%); Cht, wh-buff, dns/few vug, tr ool (3%).
2870-75	Dol, buff-brn, f-c xtal, ltl por, few rhmb, sl arg (brn) (100%).
2875-80	Dol, buff, f-c xtal, few rhmb, some por, tr ool, sl sil (97%); Cht, wh to buff, ool, dns, mot ool (sl Fe stn) (1%); sh red-brn, dol, gry slty in pt (2%).
2880-85	Dol, buff, f-c xtal, por in pt, few rhmb, some sulfide (blk-silver) (95%); Cht, wh, ool, mot (2%); sh red-brn, gry, tr gn (3%).
2885-90	Dol, a.a., arg (82%); Cht, wh-orng tan, ool (3%); sh, red, brn gn brn (15%).

Trempealeau @ 2888 (G.R.)

2890-95	Dol, buff wh-buff, f-m xtal, some por (98%); sh, a.a. (2%); tr sd, f-c gr.
2895-2900	Dol, buff wh-wh, f-m xtal, no pyr, some por, rhmb (100%); tr sh, a.a.; tr sd.
2900-05	Dol, buff wh-wh, m-c xtal, some por, rhmb (100%).
2905-10	Dol, a.a. (100%).
2910-15	Dol, a.a. (100%).

Table 3.--Continued.

(B)

Mobil-Kelly Unit #1 2N 3W 24 W/2 NENW
Eaton Co., Eaton Rapids Twp. Rotary PN #29117

Blk River

5730-40	Ls, brn-buff, blk, arg shy (100%).
5740-50	Ls, as above, few sdy, inc arg, pyr (82%); sh, blk calc, pyr (15%); dol, calc, brn, f xtal arg in pt, sil (3%); tr ss, mgr, fr, subrd-rd.

Glenwood @ 5745 & St. Peter

5750-60	Dol, buff wh to gy, calc in pt, sl sil, sdy in pt, pyr (45%); Ls, wh v sdy (25%); ss, f-m gr, sub rd-rd, overgrowths give ang-subang look, clr to fr, tr ss m-c, stn yellow subrd (20%); sh, a.a. (10%); pyr.
5760-70	SS, a.a., dol cmt (70%); dol, wh-tan, gy, f xtal to gry sdy, pyr (30%).

Prairie du Chien @ 5766

5770-80	Dol, buff wh-gy, dns to f xtal, sdy (77%); ss, a.a. (20%); sh, gn, gy/sd, gn sl xtal (2%); Cht, wh, trip/dol rhmb & sd gr incl (1%).
5780-90	SS, a.a. (60%); dol, a.a. (38%); sh, gn, a.a. (2%); tr Cht, a.a.
5790-5800	Dol, buff wh, gy f xtal, few sd gr, tan sil ool, Cu stn (50%); ss, a.a., inc/se gr subrd-rd, fr (49%); Cht, a.a. (1%); tr Glau, gn; tr Cu stn blue.
5800-10	Dol, buff-gy, f xtal to gny, suc, sly (75%); ss, a.a. (25%); tr Cht trip wh; tr sh gn.
5810-20	Dol a.a. (71%); ss a.a., inc dol cmt wh-tan (25%); Cht, wh, dns to chky, trip, tr orange sil, dolocastic qtz replace (4%); tr sh, gn, sl xtal.
5820-30	Dol a.a., few gn sdy in pt (87%); ss a.a. (5%); Cht, wh, dns, sdy (4%); sh, gn-gy (4%).
5830-40	Dol, buff-tan dns-f xtal, gny, few sd gy (90%); ss inc lse gr, f-m gn fr-sl fr-clr, subrd-rd, dol cmt (10%); tr cht wh, chky, ool; tr Cu stn on sh.

Table 3.--Continued.

5840-50	Dol, buff-tan f xtal, few sd gr (8%); ss, a.a., inc overgrowths, sil cmt (90%); sh gn sl xtal (2%); tr pyr.
5850-60	SS, a.a., ang from overgrowths (70%); dol, a.a. (30%).
5860-70	SS, a.a., most lse gr, some pyr (90%); dol, a.a. (8%); cht, wh, trip (2%); tr sh, gy-gn, tr Cu stn.
5870-80	SS, a.a., dol cmt, pyr (65%); dol, buff wh to tan, xtal, sdy (33%); sh, gn, dol, xtal, sdy in pt (2%); tr pyr.
5880-90	Dol buff wh-tan, f xtal, few red, gran, sdy (82%); ss a.a. (15%); sh gn, mot red (3%).
5890-5900	SS, f-c gr, sl fr to fr, subrd-rd, uncons, few overgrowths (65%); dol, a.a. (30%); sh gn few sdy (5%); cht trip, wh.
5900-10	Dol, a.a. (65%); ss, a.a. (35%).
5910-20	Dol, a.a. (90%); ss, a.a. (10%), tr Cht wh.
5920-30	Dol, a.a. (40%); ss, a.a. (60%), tr sh.
5930-40	Dol, a.a., to suc (10%); ss, a.a. (90%); tr Cht, wh, trip; tr Glau, gn.
5940-50	SS, a.a., to w rd (95%); dol, a.a. (5%); tr cht, tr sh.
5950-60	Dol buff-tan, gy, f xtal, v sdy in pt (76%); ss, a.a.,/dol cmt, chty (15%); sh gn-gn mot/ red, gn sh, pyr & fis in pt (5%); cht, wh, wthrd, assoc/dol rhmbs sdy in pt, tr ool (4%).
5960-70	Dol, tan-buff, suc-f xtal, sdy, dol stn red (50%); ss a.a.,/dol cmt (5%); sh, a.a. (20%); cht, wh, trip, wh-buff, dns, tr ool, tan to orng, ool, sil (25%).
5970-80	Sh, blk, gy, purp, red gn, mot, dol in pt (90%); dol, a.a., (8%); cht, buff-orng, sil (2%).
5980-90	Sh, a.a., f gr sd in gn & blk sh (81%); dol a.a., arg (18%); cht a.a. (1%); tr Glau, gn.
5990-6000	Dol, a.a., few sd gr, few arg (50%); sh a.a., not sdy (30%); cht, wh, buff, orng, red, sil, dns (20%).
6000-10	Dol, a.a. (50%); sh, a.a. (49%); cht a.a., orng to wh dns, ool (1%); tr ss, m gr subrd-rd, fr, a.a.
6010-20	Dol, buff, gy, tan, suc-f xtal, gry few sd gr (50%); sh, a.a. (48%); Cht, a.a. (2%); tr Glau, gn.
6020-30	Dol, a.a. (65%); sh, red, gy, gn (30%); cht, orng to wh, sil, ool (4%); ss, m-c gr, subrd-rd, fr, Fe stn in pt (1%).

Table 3.--Continued.

6030-40	Dol, a.a. (78%); sh, gn, red, gy (15%); cht wh-tan, dns, ool, ool (7%); tr ss, f-m gr.
6040-50	Dol, buff, gy, vf xtal, to pink (63%); cht, wh, dns to trip, ool, tr embd sd gr (20%); sh, gn, red, mot, pyr (15%); ss m-c gr, fr, pt Fe stn red, subrd-w rd (2%).
6050-60	Dol, a.a., inc pink col (70%); cht, a.a.,/dol rhmb, some por, ool tr orng (25%); sh, red gn (5%); tr Glau on dol.
6060-70	Dol, buff-brn, f xtal, int xtal por (87%); cht wh to buff, trip to dns, ool, sdy in pt, dol rhmb, vug por (doloclas) tr orng, sil (12%); sh, red, blk (1%); tr Glauc; tr sd.
6070-80	Dol buff-brn, f-m xtal, gy dol ool, inc gy-brn (96%); cht a.a., mot brn no orng (4%); tr sd.
6080-90	Dol, a.a., arg in pt (83%); cht a.a. more dns, ool (15%); sh blk dol, gn & red mot (2%).
6090-6100	Dol, tan gy brn, suc-f-m xtal, few sil ool, some por (96%); cht, wh-tan, pt wth rd, ool, ss/dol rhmb (repl) vug (4%).
6100-10	Dol, a.a., vf-f xtal (100%).
6110-20	Dol, a.a. (100%).
6120-30	Dol, tan, lt gy, brn, f xtal, ltl arg (100%); tr sh, gy.
6130-40	Dol tan brn gy f-m xtal slty, sdy in pt (100%).
6140-50	Dol gy, buff, tan, vf-f xtal, few sdy slty, pyr, arg. ltl por (100%).
6150-80	X
6180-90	Dol, brn-gy, m xtal slty, few sd, ltl arg, tr pyr, tr suc (100%).
6190-6200	Dol, a.a., to c xtal, arg (100%).
6200-10	Dol, a.a., m xtal, arg, slty, clr rhmb (100%); tr cht wh trip to dns, ool in pt; tr Anh, clr, tab.
6210-20	Dol tan-brn, gy m xtal, few clr xtals, sl arg, tr ool (97%); cht, a.a. (3%); tr Anhy, a.a.
6220-30	Dol, a.a., rhmb clr to brn (95%); cht, a.a., dol rhmb (4%); sh blk, gn gy (1%); tr Anhy a.a.
6230-40	Dol, a.a. (98%); Cht, a.a., ool, sil (2%); tr Anhy.
6240-50	Dol, a.a., f-m xtal (100%); tr cht wh wthrd ool.
6250-60	Dol a.a. (99%); cht, a.a., (1%).
6260-70	Dol, tan-buff, gy, brn, f-m xtal, few ool, rhmb (100%); tr cht wh trip, to tr vug, sil ool in pt.

Table 3.--Continued.

6270-80	Dol, a.a., (100%).
6280-90	Dol, tan brn m xtal (98%); cht wh trip assoc/ dol rhmb, ool (2%).
6290-6300	Dol a.a., some arg (98%); cht, a.a. (1%); sh, blk (1%); tr Glau on cht.
6300-10	Dol, a.a. (99%); cht, a.a., to dns (1%); tr Glau, sh.
6310-20	Dol, a.a., ool in pt (98%); cht, a.a., wh qtz (2%).
6320-30	Dol, brn-tan, m-c xtal (100%); tr cht.
6330-40	Dol, a.a., ltl por, rhmb (100%); tr cht wh porc to trip/dol assoc.
6340-50	Dol, tan, brn, buff f-m xtal, c xtal in pt (100%); tr Cht, a.a.
6350-60	Dol, buff-brn, f xtal tr sd, tr ool, pyr (100%); tr cht; tr sh; tr sd.
6360-70	Dol, buff-tan f xtal to gry, few sdy, pyr, brn m-c xtal (93%); cht, wh trip ool, qtz, sil orng ool (3%); sh, gn, pyr, blk (4%); tr anhy.
6370-80	Dol a.a., dirty arg (79%); cht, a.a. (1%); sh, a.a., gy brn (20%).
6380-90	Dol, buff-tan brn, f xtal to gran, arg, sdy, rhmb dol clr (74%); cht, a.a., some dirty wh-tan, ool (1%), sh gy, gn, blk pyr orng (25%); tr sd, f gr, fr, sub rd.

Trempealeau @ 6389

6390-6400	Dol, buff, tan to brn, vf-f xtal, few sdy, pyr (84%); Cht wh-tan, gy dns, v ool, sil, wh cht/tan ool, milky some vn qtz (12%); sh, gy, gn (4%); tr sd.
6400-10	Dol tan-brn, buff, uf-f xtal, few ool, sdy in pt (96%); cht, a.a., (2%); sh, gn (2%); tr sd.
6410-20	Dol, a.a., few brn (98%); Cht, a.a., qtz (2%); sd, m gr, tr c gr, fr, subang-subrd; tr sh.
6420-30	Dol buff-gy, tan, f xtal, blk arg, sd in pt (83%); Cht, a.a., to trip wh (2%), sh, gy, blk, gn (15%), tr sd.
6440-50	Dol buff-brn, vf-m xtal, arg in pt, sdy, pyr, ool in pt (95%); sh, a.a. (2%); cht, a.a., not trip (2%); sd m-c gr, fr, subrd-rd (1%); tr pyr.

Table 3.--Continued.

(C)

E. I. duPont de Nemours and Co.-Montagne, Dupont #1
Muskegon Co., White River Twp.   12N 18W 36   NWSWNE
Rotary PN BD

Black River

4560-70	LS, brn-buff, dk brn arg, lith-f xtal (100%).
4570-80	LS, a.a. (100%).
4580-90	LS, a.a., foss (Brach), inc arg, tr sd (98%); sh, blk, gn-gy, gran in pt (2%); tr ss, f gr, fr subrd-rd LS cmt,/pyr xtal coating on sd; tr dol, wh-tan f xtal sdy.
4590-4600	LS, a.a., arg, v sdy in pt, Hl pyr (85%); dol, tan-buff f xtal, sdy in pt (5%); ss, f-c gr, rd-wrd, fr, dol cmt, pyr (5%); sh gy-blk, gry, jumbled (5%).

Glenwood @ 4595

4600-10	Sh, gr-gy, dol & calc, sdy, xtal (50%); ss f-m gr, fr, arg, few c gr, rd-wrd, dol & sil cmt, pyr (80%); Ls, a.a., arg (15%), dol a.a., sdy, arg in pt (5%); tr vn qtz, clr.
4610-20	Ss, a.a. (45%), sh gy, blk grainy, gn, pyr, dol (30%); dol, brn, arg sdy, dol rhombs, xtals clr (20%); Ls, a.a. (5%); halite, clr, ? contam (∿ 3%).
4620-30	Dol, buff-buff gy, gn, sil, tr sd, pyr (90%); sh, gn, gy, dol, sdy in pt, pyr (10%); tr salt; tr Glau on dol & sh.

Prairie du Chien @ 4623

4630-40	Dol, a.a., suc to f xtal, gn dol sil, sdy in pt (95%); sh dk gy gn (5%); tr salt.
4640-50	Dol, a.a., sdy in pt (93%); sh, a.a. (7%); tr salt; tr cht, wh, trip, tr ool.
4650-60	Dol, a.a. (100%); tr sh; tr salt; tr cht, all a.a.
4660-70	Dol, buff-tan, dns to vf xtal, sdy, ltl red (86%); sh, gn, gy, sdy (10%); ss, f gr, fr, subrd, dol cmt/sil ool (2%); cht, a.a., tr ool, few sd gr (2%); tr Glau; tr Anhy.
4670-80	Dol, a.a., pt sil (gn dol) sdy (82%); sh a.a., sil pyr (7%); ss f gr, subang (overgrowths) to subrd, pyr in pt (10%); Cht wh, trip few sd gr (1%); tr Glau; tr salt (? contain 7%).

Table 3.--Continued.

4680-90 sdy	Dol, buff-brn, lt gy-gn, m-c xtal-vf xtal, sdy & sil in pt, mot (83%); sh, a.a. (10%); ss, a.a. (6%); cht, a.a. (1%); tr Glau; salt (? contam. 15%).
4690-4700	Dol, a.a., sdy (85%); ss, a.a., few m gr (10%); cht, a.a. (5%); tr sh; tr Glauc; salt a.a.
4700-10	Dol, a.a., to brn, tr pyr (80%); ss, f-m, subrd-rd fr, overgrowths, pyr in pt (12%); cht, a.a. (8%); sh a.a., tr Glauc on ss, dol, salt (? contam. 18%).
4710-20	Dol, a.a., to mot, less gn dol (80%); ss, a.a., few f-m gr rd sl yel stn (20%); cht wh wthrd, tr sh, a.a., Glau, salt (? ∿ 20%).
4720-30	Dol, a.a., (85%); ss, a.a. (15%); tr Glau, tr sh, cht; salt (? 15%).
4730-40	Dol, a.a., not sdy (95%); ss, a.a. (5%); cht, wh, trip; salt (? ∿ 30%).
4740-50	Dol, a.a., gn few sdy, pyr (90%); ss, a.a., f-c gr (10%); Cht, a.a.; salt (? 35%).
4750-60	Dol, a.a. (97%); ss, a.a. (3%); cht; salt (? ∿ 60%).
4760-70	Dol, a.a. (95%); ss, a.a. (5%); cht; tr calc, clr xtal; salt (? ∿ 65%).
4770-80	Dol a.a. (95%); ss, a.a. (5%); cht; tr calc clr xtal; salt (? ∿ 65%).
4780-90	Dol, a.a. (97%); ss, f-c gr, wrd, fr, lse gr (3%); cht, trip; tr calc; salt (? 15%).
4790-4800	Dol, a.a. (97%); ss, a.a. (3%); cht, trip; tr calc; salt (? ∿ 7%).
4800-10	Dol, buff-brn, dk gy (calc), m-c xtal-f xtal, red, red brn Fe stn (95%); ss, f-c gr, subrd-wrd, overgrowths on f-m gr, fr, C gr, fr & p, rd-wrd, clr to yel stn to fr (5%); tr sh, red, gn, dol.
4810-20	SS, a.a., f-c gr, mainly m-c gr, subrd-wrd, fr, few Fe stn yel-red, milky (78%); dol, buff to dk gy, blk arg, sdy (20%); sh, gy gn, gn, red, dol tr sd (2%); pyr.
4820-30	SS, a.a.,/dol cmt (99%); dol, a.a.; few rd pbl (1%).
4830-40	SS, a.a. (75%); pbl of ls, dol, cht, ang-subrd (15%); poor sample; sh, blk, gy, red (10%).
4840-50	SS, m gr, f-c gr, subrd-rd, fr, few clr, Fe stn in pt, some fr; some overgrowths (100%); tr sh; tr pbl; tr dol.
4850-60	SS, a.a., dol cmt in pt (100%); tr dol; tr calc xtal.

Table 3.--Continued.

4860-70	SS, a.a., few/blk incl (100%); dol a.a.
4870-80	SS, a.a., overgrowths com, ltl dol cmt (99%); col, a.a., (1%).
4880-90	SS, a.a., inc dol cmt, dec overgrowths (100%); dol, a.a.
4890-4900	SS, a.a. (97%); dol buff f xtal, sdy (3%).
4900-10	SS, f-m gr, subrd-rd, fr, dol cmt (90%); dol, buff f xtal (10%), tr calc xtal, clr.
4910-20	SS, a.a. (15%); dol, buff-brn, f xtal, sdy, blk arg (73%); sh, gy, dk gn, gn, red, fis in pt (12%).
4920-30	Dol, a.a., some Fe stn red (53%); sh, red, gn, gy, red & gn mot in pt, dol in pt (40%); ss, a.a. (7%).
4930-40	Dol, buff, buff wk, tan, f xtal, sdy (70%); ss, a.a. (20%); sh, a.a., no mot (10%).
4940-50	Dol, a.a., gn dol (55%); ss, a.a. (25%); sh, a.a. (20%).
4950-60	Dol, a.a., sty (67%); ss, f-m gr, fr, subrd-rd, inc f gr (7%); sh red, gn gy, blk dol to gry (25%); cht, wh, ornge, red, dns, sil, ool (1%); tr calc xtal clr; tr Glau.
4960-70	Dol, a.a., lt gy (44%); ss, a.a., to clr, overgrowths (40%); sh, red, gn (15%); Cht, a.a., mot, struc.
4970-80	Dol, buff gy tan, red, vf gr, few sdy (50%); ss, f-c gr, most f-m, fr to clr, few Fe stn red, yel, subrd-rd, few overgrowths (40%); sh, red, dk red, gy, gn dol to grainy (10%); tr cht, a.a.
4980-90	Dol, a.a. (84%); ss, a.a. (8%); sh, a.a. (8%); cht, a.a.
4990-5000	Dol, a.a. (73%); ss, a.a. (15%); sh a.a. (12%); tr cht a.a., trip wh ool.
5000-10	Dol, a.a. (25%); ss, a.a., mostly clr (75%); sh; tr Glau; tr Ls, dol tan.
5010-20	Dol, a.a. (50%); ss, a.a., dol cmt (50%); tr cht, dns buff; tr Glau.
5020-30	Dol, buff-gy, vf xtal, sl calc in pt, sdy in pt (92%); ss, a.a. (8%); tr cht; tr calc xtal, clr; sh, red.
5030-40	Dol, a.a., 1/2 calc (94%); ss, a.a. (6%); sh red blk; tr cht.
5040-50	Dol, buff wh-gy-tan, vf xtal-crp xll, sl calc, sdy in pt, xtals clr (100%); sh, a.a.; calc clr-brn.
5050-60	Dol, a.a., sty (100%); ss a.a.; tr calc; tr cht, a.a.; tr Glau.

Table 3.--Continued.

5060-70	Dol, a.a. (95%); ss, a.a. (4%); cht, wh-orng, dns sil (1%); tr calc xtal, clr; tr sh, red, gy, gn.
5070-80	Dol, a.a. (97%); sh red gy gn (2%); tr Cht wh sil; ss, a.a. (1%); tr calc, clr-brn xtal.
5080-90	Dol, a.a. (95%); ss, a.a. (3%); sh, a.a., mot (2%); tr calc.
5090-5100	Dol, a.a. (94%); sh, a.a. (6%).
5100-10	Dol, a.a. (64%); sh dk gy-blk, gy, red, fis in pt, pt dol, sdy in pt tr pyr (35%); ss, f-m, subrd-rd, si & dol cmt (1%) tr cht, wh trip.
5110-20	Dol, a.a. (87%); ss, a.a. (3%); sh gy blk red gn (10%); tr calc.
5120-30	Dol, buff-buff gy, vf xtal, sdy (35%); ss f-c gr, most m-c gr fr, rd-subrd-wrd, dol cmt (50%); sh, a.a., mot, gn sdy (15%); tr calc.
5130-40	Dol buff-buff wh, vfn-f xtal, rhmb chty (97%); ss, a.a. (3%); tr sh, tr calc.
5140-50	Dol buff-tan gy, vf-f xtal, few sdy (90%); sh red gn, mot (10%); cht wh dns sil; tr clay
5150-60	Dol, a.a. (94%); sh, a.a. (6%); tr calc xtal, clr.
5160-70	LS buff-buff gy f xtal, some int xtal por (95%); cht, trip, wh/embd dol rhmb (5%); tr sh.
5170-80	Dol, buff-tan f-md xtal, xtals clr (94%); cht, wh, sil, ool, few trip/embd rhmb (6%); tr calc, clr; tr anhy clr, platy.
5180-90	Dol, buff wh-buff, f-m xtal (96%); cht, a.a. (4%); tr anhy.
5190-5200	Dol, a.a., some g int xtal por (88%); cht, a.a., inc trip.embd rhmb (12%); tr anhy.
5200-10	Dol buff wh-buff, vf-f xtal (88%); cht wh-buff sil/inc rhmb & sd incl, few trip, tr pyr (12%).
5210-20	Dol, a.a. (92%); cht, a.a., tr wh-clr vn qtz, chal (8%); tr pyr; tr anhy.
5220-30	Dol, a.a., few sd gr (88%); Cht a.a. (12%).
5230-40	Dol, a.a. (93%), cht, a.a. (7%), sh.
5240-50	Dol, a.a. (90%); cht, a.a., mot, ool in pt (10%); tr anhy.
5250-60	Dol, a.a. (95%); cht, a.a. (5%); tr anhy; tr calc.
5260-70	Dol, a.a. (95%); cht, a.a., sil ool (5%).
5270-80	Dol, tan-buff, f xtal (96%); cht, a.a., sil (4%).
5280-90	Dol, a.a., to red brn (94%); cht, a.a. (6%); tr calc; tr sh.

Table 3.--Continued.

5290-5300	Dol, a.a. (98%); Cht, a.a. (1%); sd f-m gn clr-Fe stn subang-subrd (1%).
5300-10	Dol, tan-buff, f-m xtal (90%); cht wh trip, sil, wh/inc (10%); tr sh gn & red.
5310-20	Dol, tan, buff, brn f-m xtal, rhmb, some por (98%); cht, wh trip few/dol rhmb (2%); tr sd.
5320-30	Dol. a.a. (98%); cht, dns, wh-buff, ool; sil, trip in pt (2%).
5330-40	Dol, tan, brn, f-m xtal, rhmb, some por (100%); cht, wh, trip.
5340-50	Dol, a.a., arg in pt (85%); sh, gy, blk, red, dol in pt, mic in pt, pyr (15%).
5350-60	Dol, a.a. (80%); sh, a.a. (20%); tr cht; tr calc; tr Glau.
5360-70	Dol, a.a., por, xtals, arg, sdy (60%); sh, gy, red, blk, sdy; dol (40%); tr cht, dns, wh; tr ss.

<u>Trempealeau</u> @ 5368

5370-80	Dol, tan-brn, f-m xtal ool, sdy (64%); sh, red, gn, gy (pyr), mot (30%); cht wh-buff dns, sdy, ool, tr trip (6%); ss, f-m gr, fr, dol cmt, c gr, subrd.
5380-85	Dol buff-tan, f xtal, sdy, sl Fe stn pink (91%); sh, a.a. (7%) cht, a.a., tr orng cht, chal (2%); tr sd, a.a.

Table 3.--Continued.

(D)

PEPC-Ford Motor Co. #1-5 31N 9E 5 C SE NE
Alpena County, Alpena Twp. Rotary PN 25690

Black River

5280-90	Ls, lith to vf xtal, brn to tan, foss, arg in pt (92%); sh, blk, red (6%); slt st, buff, tan, vf gr, dol, calc (2%).
5290-5300	Ls, brn, tan, lt gy, lith to vf xtal, foss, pel, arg (78%); sh, blk, red (12%); slt st, buff, tan, vf gr, dol, calc (10%); tr salt.

Glenwood @ 5292

5300-10	Ls, a.a. (65%); sh, a.a., calc (15%); slt st, a.a. (20%); tr salt.
5310-20	Slt st, buff gy, vf gr, sl calc, few Fe stn red (65%); salt, clr, wh, rd (35%), ? contam, poor spl.
5320-30	Ls, brn, gy, tan, lith to vf xtal, foss, v arg, few sdy, sks in pt, (80%); sh, blk, red, tr sdy (16%); slt st (4%); tr salt.
5330-40	Ls, a.a., blk, v arg (70%); sh blk, few sd (25%); slt st, a.a. (5%).
5340-50	Ls, a.a. (75%); sh, a.a. (20%); slt st, a.a. (5%).

Prairie du Chien @ 5348

5350-60	Ls, a.a., buff, gry, slty (78%); sh, a.a. (12%); sltst (10%).
5360-70	Ls, a.a., pel (85%); sh, a.a. (10%); dol, brn-tan f xtal (5%); ss, m gr, ang-subrd sl fr-fr; tr cht wh trip.
5370-80	Ls, a.a. (89%); sh, a.a. (5%); slt st or cly st (4%); ss, a.a. (1%); cht, wh (1%); tr dol.
5380-90	Ls, a.a. (73%); sh, a.a. (5%); dol, a.a., xtal (6%); Cht, wh, trip (10%); ss, f-m gr, fr-clr, subang-subrd,/dol cmt (6%).
5390-5400	Ls, a.a. (90%); ss, a.a., sil cmt, aprs fr, rd-subrd (6%); sh, a.a. (3%); cht, a.a. (1%).
5400-10	Ls, a.a., much cly? (97%); sh, a.a. (1%); ss, a.a. (1%); cht, a.a. (1%).
5410-20	SS, f-m gr, wh, sl fr-fr, subrd-rd, v few overgrowths, some dol cmt, few sph, fri (95%); Cht, wh, trip (2%); Ls, gy brn (2%); sh blk (1%); tr pyr.

Table 3.--Continued.

5420-30	SS, a.a., pyr in pt (99%); cht, a.a. (1%); pyr coat on sd.
5430-40	SS, f-m gr, rd, subrd, w rd, fr, a.a. (98%); cht, a.a. (2%).
5440-50	SS, f-m, few c gr, rd subrd, few overgrowths, some Fe stn pink, sil & dol cmt (100%); tr sh; tr ls; pyr.
5450-60	SS, a.a., m-c gr mainly rd-wrd (100%).
5460-70	SS, f-m gr, a.a., inc overgrowths (100%).
5470-80	SS, f-m gr, subrd-rd, overgrowths, sil cmt, clr to fr/sl Fe stn on some (98%); Cht, a.a. (2%); tr musc.
5480-90	Ss, a.a., many overgrowths, fri (97%); cht, wh, trip (3%).
5490-5500	Ss, a.a., overgrowths give ang look (95%); cht, a.a. (5%).
5500-10	Ss, a.a. (100%); much contam (Ls 25%, sh 5%, cht 25%).
5510-20	SS, a.a. (100%); contam (a.a. - 50%).
5520-30	Ss, a.a. (100%); contam (a.a. - 50%).
5530-40	Ss, a.a. (100%); contam (a.a. ∿ 25%).
5540-50	Ss, f-m gr, rd-wrd, fr, tr overgrowths (100%).
5550-60	Ss, f-m gr, rd, subrd, wrd, fr, sl Fe stn, dol cmt (100%).
5560-70	Ss, a.a., Fe stn red, brn, inc dol cmt (86%); dol, gy-brn, f xtal, sdy, arg (4%); cht, a.a. (10%).
5570-80	SS, a.a. (96%); cht, a.a. (3%); dol, a.a. (1%).
5580-90	X
5590-5600	Ss, a.a. (90%); dol, buff tan gy brn, vf-f xtal, sdy, Fe stn red (6%); cht wh, red mot, sdy (4%).
5600-10	Ss, a.a. (87%); dol, a.a. (7%); cht, a.a., wh (4%); sh, gy, gn, brn (2%).
5610-20	Ss, a.a. (86%); dol, a.a. (6%); cht, a.a. (7%); sh, a.a. (1%).
5620-30	Ss, a.a., few c gr (83%); cht, wh, trip (10%); dol, a.a., sdy in pt (6%); sh gy gn (waxy), red (1%).
5630-40	Ss, a.a. (98%); cht a.a. (2%); tr sh; tr glau on ss.
5640-50	Ss, a.a. (100%); tr cht; tr sh.
5650-60	Ss, a.a. (100%); tr cht, a.a., tr sil, gy
5660-70	Ss, a.a., ltl pink, gy (100%).
5670-80	Ss, a.a. (100%).

Table 3.--Continued.

5680-90	Ss, f-m gr, fr-sl fr, rd-subrd, dol cmt, red col, few c gr (70%); dol, brn, red brn, f xtal, sdy (6%); sh, red, gn gy, mot red & gn (20%); cht, wh trip (4%).
5690-5700	Ss, a.a. (95%); sh, red, gn (4%); Cht, a.a. (1%); tr cht wh sil dns.
5700-10	Ss, a.a. (58%); sh, red, red blk, gn, mic, mot (35%); dol red, sdy f xtal (5%); cht, wh, trip (2%).
5710-20	Ss, a.a. (54%); sh, a.a. (35%); dol, a.a. (7%); cht, a.a. (4%).
5720-30	Ss, a.a. (80%); sh, a.a. (10%); dol, a.a. (6%); cht a.a. (4%).
5730-40	Ss, a.a., arg, reddish (73%); sh, a.a. (20%); dol, a.a. (4%); cht, a.a. (3%).
5740-50	Ss, a.a., gy, red, buff (80%); dol, a.a. (5%); sh, a.a. (10%); cht, a.a. (5%).
5750-60	Ss, a.a., arg (90%); dol, a.a. (5%); sh, a.a. (4%); cht, a.a. (1%).
5760-70	Ss, a.a., pink, gy, buff, v dol (98%); sh gn (1%); cht, a.a. (1%).
5770-80	Dol, buff wh to tan, red, f-m xtal, v sdy (90%); ss, a.a. (10%).
5780-90	Dol, a.a. (95%); ss, a.a., v dol (5%); tr sh, gn.
5790-5800	Dol, a.a. (100%).
5800-10	Dol, a.a., dirty gy (100%); tr sh, blk, dirty.
5810-20	Dol, a.a. (50%); ss, gy-buff, f-m gr, subrd-rd, fr, to blk arg ss (50%); tr cht, wh, trip.
5820-30	Dol blk, arg, few sdy (100%); tr sh, red.
From log:	
5830-50	Dol buff-gy dns, hd; ss, mgr, rd, buff-tan/ dol cmt; sh, gy.
5850-70	Dol buff-gy brn, dns; sh gy.
5870-5900	Dol, a.a.; ss wh, f-m gr, rd.
5900-6010	Dol, tan to brn, dns; sh gy; tr ss, a.a.
6010-40	Dol, tan to red tan to brn, dns; sh, gy.
6040-6140	Dol, tan to brn, mot; sh gy-brn.

Trempealeau @ 6064 (S.J.)