STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION

DEEP OIL POSSIBILITIES OF THE ILLINOIS BASIN

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ILLINOIS STATE GEOLOGICAL SURVEY
John C. Frye, Chief — URBANA
CIRCULAR 368 — 1964

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ABSTRACT

The Middle Ordovician and younger rocks of the Illinois Basin, which have yielded 3 billion barrels of oil, are underlain by a larger volume of virtually untested Lower Ordovician and Cambrian rocks. Within the region that has supplied 99 percent of the oil, where the top of the Middle Ordovician (Trenton) is more than 1,000 feet below sea level, less than 8 inches of hole have been drilled per cubic mile of the older rocks. Even this drilling has been near the edges; and in the central area, which has yielded five-sixths of the oil, only one inch of test hole has been drilled per cubic mile of Lower Ordovician and Cambrian. Yet drilling depths are not excessive, ranging from 6,000 to 14,000 feet to the Precambrian.

More production may be found in the Middle Ordovician Galena Limestone (Trenton), thus extending the present productive regions. In addition, new production may be found in narrow, dolomitized fracture zones in the tight limestone facies on the north flank of the basin. The underlying Platteville Limestone is finer grained and offers fewer possibilities. The Joachim Dolomite oil-shows occur in tight sandstone bodies that should have commercial porosity in some regions. The dark, fetid Dutchtown Limestone in the southern part of the basin has similar sandstone lenses.

At the base of the Middle Ordovician, the St. Peter Sandstone and the underlying Everton Group have much porous rock, but the best possibilities are in the eastern part of the basin, where the St. Peter breaks up into isolated sand bodies.

The Lower Ordovician and Cambrian Knox Dolomite Megagroup (Arbuckle, Ellenburger) is a prolific producer in regions where the production is in part related to the sub-Tippecanoe unconformity, which truncates the Knox. Lenticular sandstones, derived from the north, extend into the basin at several levels. Zones of porous dolomite are present, particularly in the Shakopee Dolomite at the top of the megagroup and in the Potosi (Trempealeau) Dolomite in the Cambrian part of the megagroup.

The Eau Claire Formation, beneath the Knox, is essentially sandstone north of the deep part of the basin, dolomite with some oolitic limestone to the west, and shale to the east. The area in the deep part of the basin where these three rock types interfinger is the most favorable area for deep oil production. Although the Mt. Simon Sandstone at the base of the column is the thickest fluid-yielding unit in the region, it appears to offer fewer production possibilities than other units.

The deep part of the Illinois Basin is promising, because it contains a large volume of untested, unmetamorphosed, near-shore, marine sediments that are saturated with medium to high salinity brine. Its nearness to markets, transportation, and service facilities offer advantages in comparison with geologically comparable but geographically remote prospects.

INTRODUCTION

Three billion barrels of oil have been produced from the Illinois Basin since oil was discovered at shallow depths on the basin margins in 1888. The productive rocks range in age from Middle Ordovician to Pennsylvanian. About 115,000 wells have been drilled to find and produce this oil, but exploration has touched less than half of the sedimentary rocks of the basin. Considering only the area of 41,000 square miles in which the Galena is more than 1,000 feet below sea level and which has produced more than 99 percent of the basin's oil, the Galena and younger formations contain about 32,000 cubic miles of sediment, as opposed to an estimated 44,000 cubic miles for the older formations. If the entire Middle Ordovician is included with the younger sequence, the volume of the upper unit is expanded to 37,600 cubic miles, whereas the Lower Ordovician and Cambrian rocks occupy 38,400 cubic miles. Less than 8 inches of exploratory hole have been drilled per cubic mile of the Lower Ordovician and Cambrian.

This report summarizes current knowledge on stratigraphy and oil possibilities of these deeply buried rocks in the Illinois part of the basin. Although the Illinois area is of primary concern, the report, by necessity, is based upon a projection of thickness and lithologic trends from the adjacent regions, supplemented by the few deep tests. The major publications concerned with the stratigraphy of the region are listed at the end of the report.

REGIONAL STRUCTURE

The Illinois Basin is an oval spoon-shaped structural depression. Rock layers dip inward to a central deep area from a ring of structurally high domes and arches that surround this basin and separate it from other basins (fig. 1).

In a purely structural sense the basin extends out to the axes or crests of the bounding arches and has an area of about 135,000 square miles. However, a restricted basin province is a more natural unit for discussing stratigraphy and oil occurrences. Four lines used to demark an Illinois Basin province from neighboring arch-dominated provinces are shown in figure 1: the extent of the Pennsylvanian, the extent of the Chesterian (Upper Mississippian), the sea-level contour on the top of the Devonian-Silurian Hunton Limestone Megagroup, and the -1,000 foot contour on the top of the Middle Ordovician Ottawa Limestone Megagroup (top of Trenton). Stratigraphic units in this region thicken southward, so that the basin is displaced southward if drawn on older horizons.

The oldest practical mapping horizon is the top of the Ottawa. The -1,000 foot contour on the Ottawa (figs. 1, 2, 3, 4, 7, 8, 10) bounds the region considered in this report and referred to as the deep part of the Illinois Basin. The region covers about 100 counties and has provided 99 percent of the oil produced from the basin. It includes about 41,000 square miles—8,700 in Indiana, 10,100 in Kentucky, and 22,200 in Illinois.

The arches surrounding the basin (fig. 1) had varied geological histories and therefore affected Cambrian and Ordovician sedimentation differently. The Wisconsin Arch is a southward projection of the Canadian Shield, the continental core. The individual clastic grains in the older rocks of the Illinois Basin region originally came from the ancient rocks of the shield. The persistence of the Canadian Shield-Wisconsin Arch region as the source of land-derived sediments had a major influence upon the rocks of the basin.

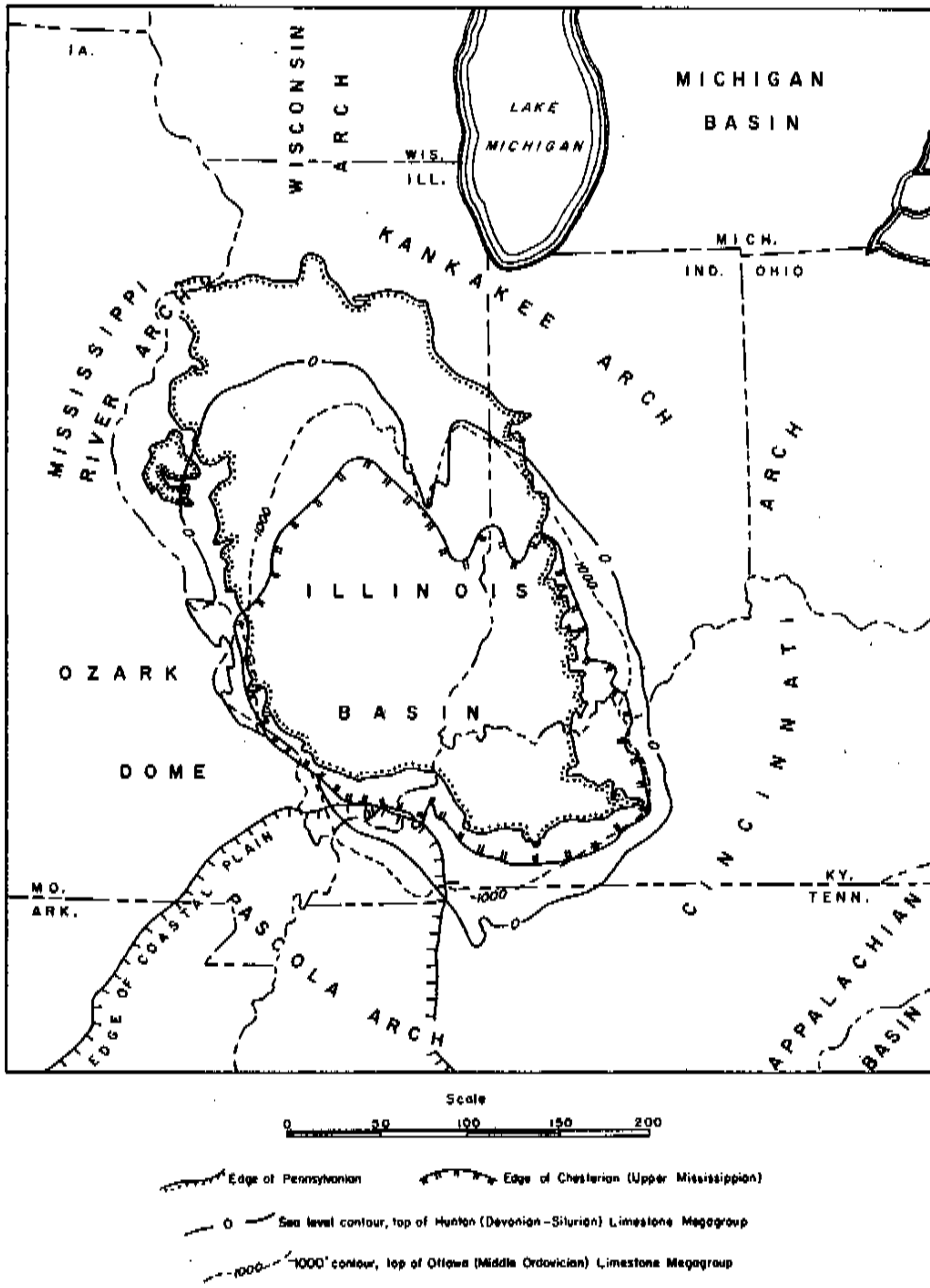


Figure 1 - Structural setting of the Illinois Basin.

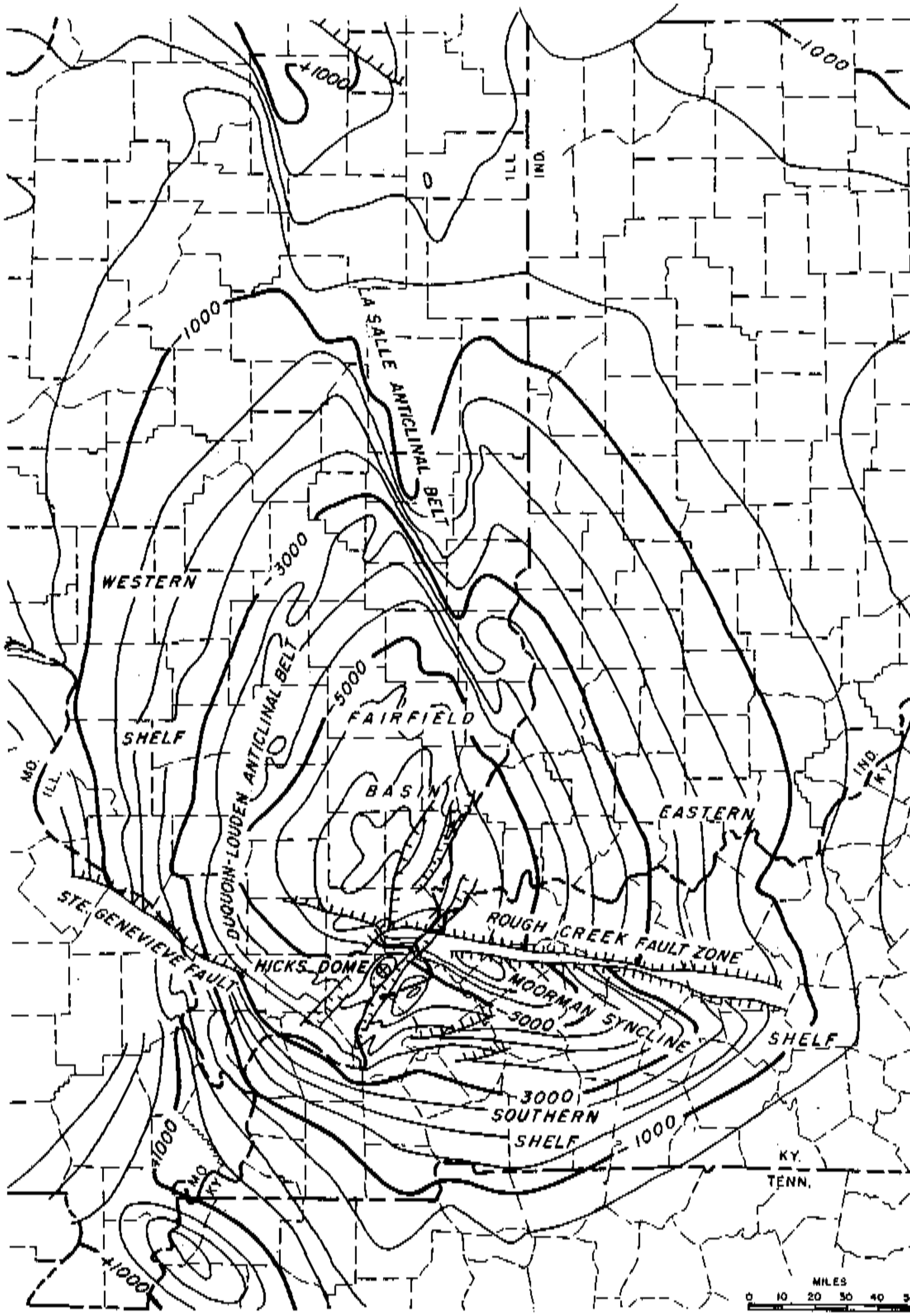


Figure 2 - Structure of the Illinois Basin on the top of the Middle Ordovician Ottawa Limestone Megagroup, contour interval 500 feet. The -1,000' contour outlines the deep part of the basin. (Modified from Tectonic Map of the United States).

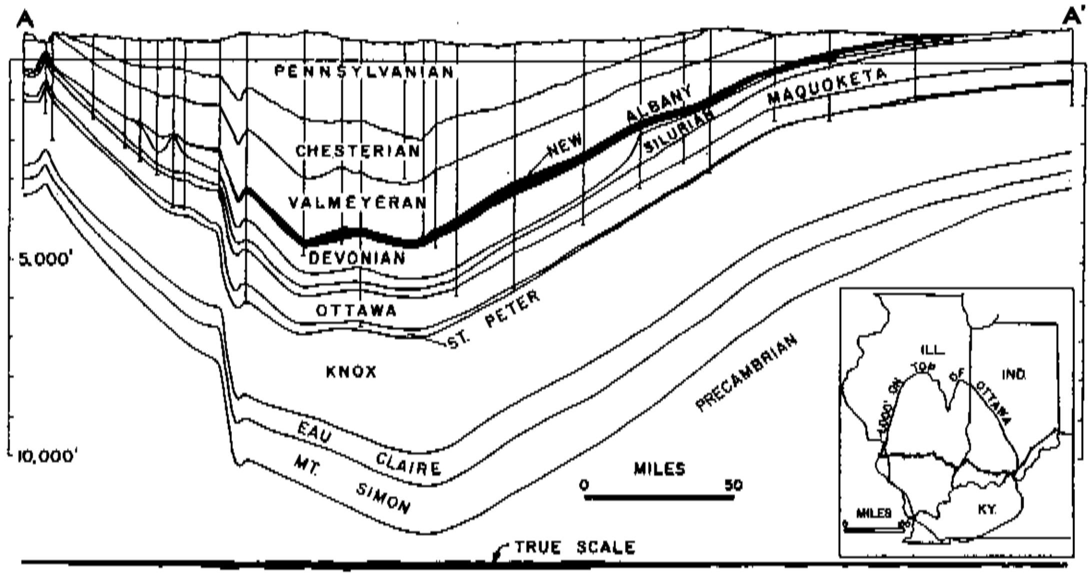


Figure 3 - Cross section of the Illinois Basin. (Modified from Swann et al., 1951). Line of section on figure 4.

Since the beginning of the Paleozoic, a broad but complex regional high has separated the Appalachian Basin from the Illinois, Michigan, and Black Warrior Basins. At different times, the region has included several sets of domes, swells, or "islands," separated by saddles, sags, or "straits." The crest or "axis" has been as far east as central Ohio (the Waverly Arch) and as far west as eastern Indiana (the Ohio-Indiana Platform). The name Cincinnati Arch is applied to the entire positive feature, including its many named and unnamed components. All major stratigraphic units thin westward or northwestward from the Appalachian Basin to the arch, and, with a single exception, all units thin eastward to it from the Illinois Basin. Unlike the Canadian Shield and the Wisconsin Arch, the Cincinnati Arch was never a significant supplier of sediment. It generally acted as a barrier that kept sediments from Appalachia out of the western basins, but occasionally, notably during the late Ordovician Taconic orogeny, served merely as a hinge between a rapidly thickening wedge of Appalachia-derived sediments to the east and a gently thinning wedge to the west.

The presence of the other arches surrounding the Illinois Basin during Cambrian and Lower Ordovician time cannot be proven. The Ozark Dome, which now separates the Illinois Basin from the Cherokee and Forest City Basins, has been a significant feature since the Middle Ordovician. However, the Cambrian and Lower Ordovician sediments, which are absent on the Sioux and Nemaha Arches west of the Cherokee and Forest City Basins, thicken regularly eastward across these basins and across the Ozark Dome-Mississippi River Arch region into the Illinois Basin. Isopach maps, which clearly show local structures and buried Precambrian hills, do not show the Ozark Dome and the Mississippi River Arch. There are no data to prove or disprove the existence during Cambrian and Lower Ordovician sedimentation of either the Kankakee Arch separating the Illinois from the Michigan Basin, or of the Pascola Arch separating the Illinois from the Black Warrior and the eastern end of the Anadarko Basin. The few deep tests are clustered on the higher parts of these arches, and published maps of Cambrian and Lower Ordovician strata have been contoured to show no thinning over the arches and no separation of the basins. However, the Kankakee Arch is clearly shown by the beginning of Middle Ordovician time. On the other hand, there is no indication in the middle and late Paleozoic of the Pascola Arch, which may be post-Pennsylvanian but pre-Cretaceous.

INTRABASIN STRUCTURE

The effect and even the presence of any specific structural features in the deep part of the basin during the Cambrian and Lower Ordovician can only be inferred. However, some structures show repeated movement dating back as far as Upper or possibly Middle Ordovician and, therefore, are of potential interest. The Illinois Basin includes a broad central depression called the Fairfield Basin, partially bounded by three zones of relative uplift, the LaSalle and DuQuoin-Louden Anticlinal Belts and the Rough Creek Fault Zone (fig. 2). The LaSalle and DuQuoin-Louden Belts are both composites of several anticlines and basin-facing monoclines. The major structural movement took place on each during the early part of the Pennsylvanian, when half or more of the total structural relief was developed. Earlier and later movements occurred, although the axes of some of the earlier movements do not coincide with the Pennsylvanian and post-Pennsylvanian axes. Movement on the LaSalle Belt is indicated by definite, but minor, thinning within the Mississippian and Devonian, by the extension southward along it of the Silurian reef complex, by serving as a hinge between the clastic Upper Ordovician deposits of Indiana that thicken slightly eastward and those of Illinois that show little thickening, and perhaps by a purer carbonate facies in the Middle Ordovician than is normal in the region. The distinction between the shelf region west of the DuQuoin-Louden Belt and a deep basin to the east is shown in the distribution of Middle and Upper Devonian units, although the boundary between them does not correspond exactly to the axis of the later folding.

The Rough Creek Zone is essentially an asymmetrical to overturned anticline, broken by a high-angle reverse fault on the steep north side. As a major structure, it extends across the basin from the east side to about 15 miles west of the Indiana-Illinois boundary, where it turns abruptly southward and dies out in a short distance. However, the structural zone continues westward nearly across the State of Illinois in a line of smaller faults and asymmetric anticlines. The Moorman Syncline paralleling and lying south of the Rough Creek Zone is smaller and much narrower than the Fairfield Basin but somewhat deeper. Because of the southward thickening of strata, it is progressively deeper than the Fairfield Basin on earlier horizons, and the difference might reach 1,500 to 2,000 feet by the base of the Cambrian. The major uplift of the Rough Creek Zone took place after the Pennsylvanian, but minor movement occurred during the Pennsylvanian, Upper Mississippian, and Upper Middle Devonian. The Middle Ordovician in well 28 (table 1 and fig. 4) on the crest of the structure seems unusually thin, but no other wells are near it.

STRATIGRAPHY

This report deals primarily with the Cambrian and Lower Ordovician but covers the rest of the Ordovician briefly. The succession is illustrated (fig. 5) by

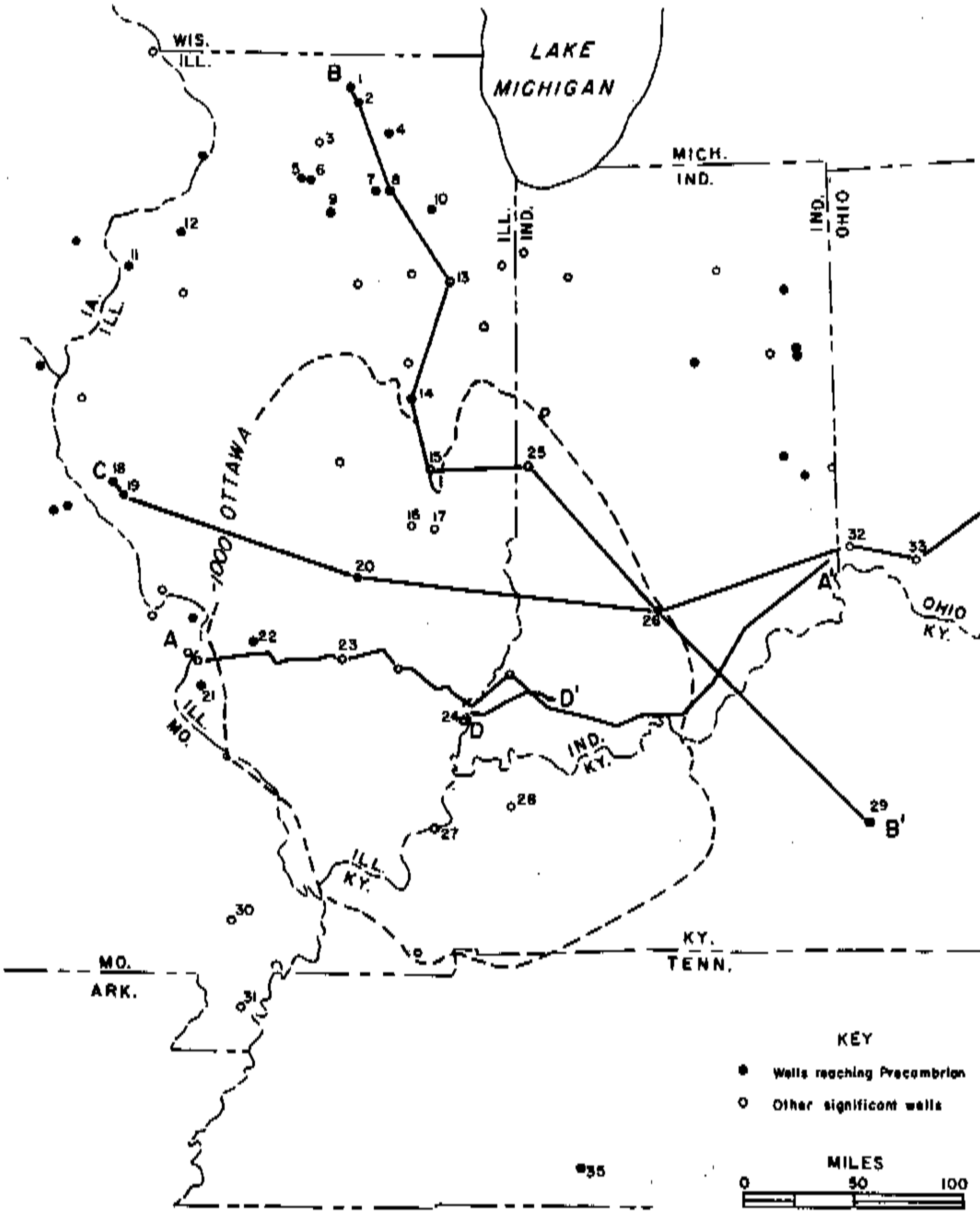


Figure 4 - Index map showing wells reaching the Precambrian basement, other selected deep wells, and lines of cross sections A-A' (fig. 3), B-B' and C-C' (fig. 9), and D-D' (fig. 11). Numbered wells identified in table 1.

the log of well 20, Humble Oil and Refining Company's No. 1 Weaber-Horn Unit, sec. 28, T. 8 N., R. 3 E., Fayette County, Illinois. Table 3 at the end of the report gives the sample study of this well. This is the deepest test drilled to the basement in Illinois, although it is relatively shallow and far northwest of the deepest part of the basin.

Figure 6 and table 2 show the average thickness and estimated lithologic composition of the major rock stratigraphic units. Their geographic variation in thickness is shown in figure 7.

Maquoketa Group

In the Illinois Basin, the Cincinnatian (Upper Ordovician) rocks are commonly placed in the Maquoketa Shale or Maquoketa Shale Group. The Maquoketa is now divided in most of Illinois into three formations: the Brainard Shale (at the top), a relatively thick, green-gray shale; the Fort Atkinson Limestone, a thin carbonate unit; and the Scales Shale, a thick, dark brownish gray, partly fissile shale. The Maquoketa averages 275 feet thick in the deep part of the basin but thickens eastward from about 100 feet near the Mississippi River to 800 feet at the east edge of the deep part of the basin. The Maquoketa is about 90 percent shale including some siltstone and 10 percent limestone.

Ottawa Limestone Megagroup

The succession of Middle Ordovician (Champlainian) carbonate rocks between the Maquoketa Shale Group and the St. Peter Sandstone is the Ottawa Limestone Megagroup. In the deep part of the Illinois Basin, it is divided into (in descending order): the Galena Limestone Group (Trenton), the Platteville Limestone Group, the Joachim Dolomite, and the Dutchtown Limestone. The Dutchtown is present only in the southern part of the basin.

The Ottawa Megagroup thickens southward across the deep part of the basin, from less than 400 to more than 1,400 feet (fig. 7). There is a minor thick trend along the course of the lower Wabash River. Although the overall thickening of the Ottawa appears even and regular, it is unevenly distributed between the different stratigraphic components in different parts of the region.

The Ottawa Megagroup in the deep part of the basin is more than 90 percent carbonate, averaging about 70 percent limestone and 20 percent dolomite (table 2, fig. 6). Limestone is particularly dominant along the eastern and southern margins of the basin, whereas dolomite is relatively common in the central, northern, and western sectors. The Ottawa includes about 3 percent anhydrite, 1 percent chert, and no more than 5 percent clastic rocks. The clastics occur largely in the lower part of the Ottawa, marking a transition from the underlying St. Peter Sandstone. The lower units in the Ottawa in southern Illinois are offshore carbonate equivalents of clastic rocks that are assigned to the Glenwood Formation and to the upper part of the St. Peter Sandstone in northern Illinois.

Galena Limestone Group

The Galena is mainly pure, buff or light tan, medium- to coarse-grained, fossiliferous, stylolitic limestone with a few very thin, brown shale partings. Some

TABLE 1 – PRECAMBRIAN WELLS IN ILLINOIS AND OTHER WELLS MENTIONED IN THE REPORT (FIGURE 4)

No.	Location		Company, No. Farm	Total Depth	Deepest Formation	Elevation Precambrian	Precambrian Rock Type
	County	Sec.-T.-R.					
1	Winnebago	24-44N-2E	Seele, No. 1 Seele	3385	Precambrian	-1786	Pink granite and granodiorite
2	Boone	28-43N-3E	Northern Illinois Oil and Gas, No. 1 Taylor	2998	Precambrian	-2104	Granodiorite
3	Ogle	4-22N-11E	Dresden, Smart	118	Knox		
4	DeKalb	35-41N-5E	Schulte, No. 1 Wyman	4484	Precambrian	-2953	Red granite
5	Lee	30-20N-10E	Amboy Oil and Gas, No. 1 McElroy	3772	Precambrian	-3040	Red granite
6	Lee	35-20N-10E	Carr, No. 1 Vedovell	3653	Precambrian	-2633	Red granite and felsite
7	LaSalle	1-36N-4E	Lawinger, No. 1 Miller	3659	Precambrian	-2788	Granite and granodiorite
8	LaSalle	1-36N-5E	Otto, No. 1 Swenson	3725	Precambrian	-3041	Red granite
9	LaSalle	32-35N-1E	Vickery, No. 1 Mathesius	3556	Precambrian	-2838	Red granite
10	Will	20-35N-9E	Reed, No. 1 McCoy	4315	Precambrian	-3593	Red granite
11	Mercer	19-13N-4W	Kelley, No. 1 Fullerton	3716	Precambrian	-2675	Gray granite
12	Henry	30-16N-1E	Davis, No. 1 South	3863	Precambrian	-3062	Granodiorite
13	Kankakee	32-30N-10E	Natural Gas Storage, No. 7 Schwark	5003	Mt. Simon		
14	Champaign	17-21N-7E	Union Hill Gas Storage, No. 1 Webster	4100	Mt. Simon		
15	Douglas	36-16N-8E	Ohio Oil, No. 1 Shaw	4151	Mt. Simon		
16	Coles	35-12N-7E	Carter, No. 1 Seaman	4908	Knox		
17	Coles	4-11N-9E	Magnolia, No. 1 Rodda	5389	Knox		
18	Pike	15-4S-5W	Herndon, No. 1 Campbell	3207	Precambrian	-2488	Red-brown rhyolite
19	Pike	21-5S-4W	Panhandle Eastern, No. 1-21 Mumford	2226	Precambrian	-1409	Red granophyre
20	Fayette	28-8N-3E	Humble, No. 1 Weaber-Horn	8616	Precambrian	-7676	Rhyolite
21	Monroe	35-1S-10W	Mississippi River Fuel, No. A-15 Theobald	2768	Precambrian	-2093	Red granite
22	Madison	27-3N-6W	Maryland Service, No. S-1 Kircheis	5018	Precambrian	-4506	Red granite
23	Marion	5-1N-2E	Texas, No. 21 Tate	5655	Knox		
24	White	27-4S-14W	Superior, No. C-17 Ford et al.	7679	Knox		
25	Vermillion, Ind.	9-16N-9W	Food Machinery, No. 1 Newport	6160	Mt. Simon		
26	Lawrence, Ind.	20-5N-2E	Indiana Farm Bureau, No. 1 Brown	6806	Precambrian	-5850	Basalt
27	Crittenden, Ky.	17-L-16	Shell, No. 1 Davis	8821	Knox		
28	Webster, Ky.	22-N-24	Ashland, No. 1 Walker	6688	Knox		
29	Lincoln, Ky.	13-L-57	California, No. 1 Spears	5820	Precambrian	-4611	Rhyolite
30	Stoddard, Mo.	3-25N-11E	Marr et al., Barnett	4580	Mt. Simon		
31	Pemiscot, Mo.	24-19N-11E	Strake, No. 1 Russell	4740	Mt. Simon		
32	Hamilton, Ohio	Crosby	Continental, No. 1 Brisbin	2730	Eau Claire		
33	Clermont, Ohio	Stonelick	Continental, No. 1 Wickoff	3435	Mt. Simon		
34	Fayette, Ohio	Union	Kewanee, No. 1 Hopkins	4708	Precambrian	-2583	Metamorphic
35	Giles, Tenn.	4-15S-29E	California, No. 1 Beeler	5750	Precambrian	-4882	Granite

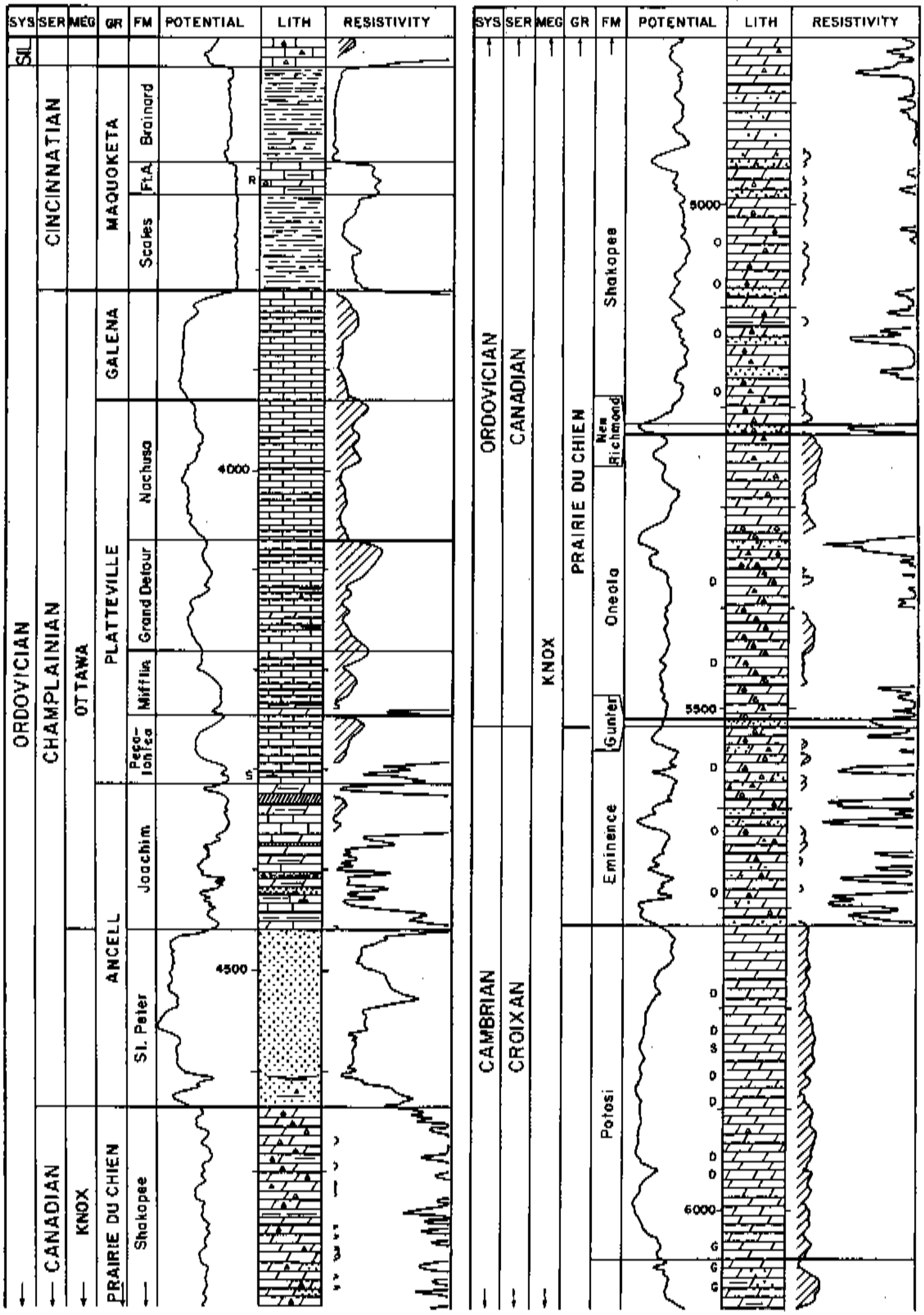
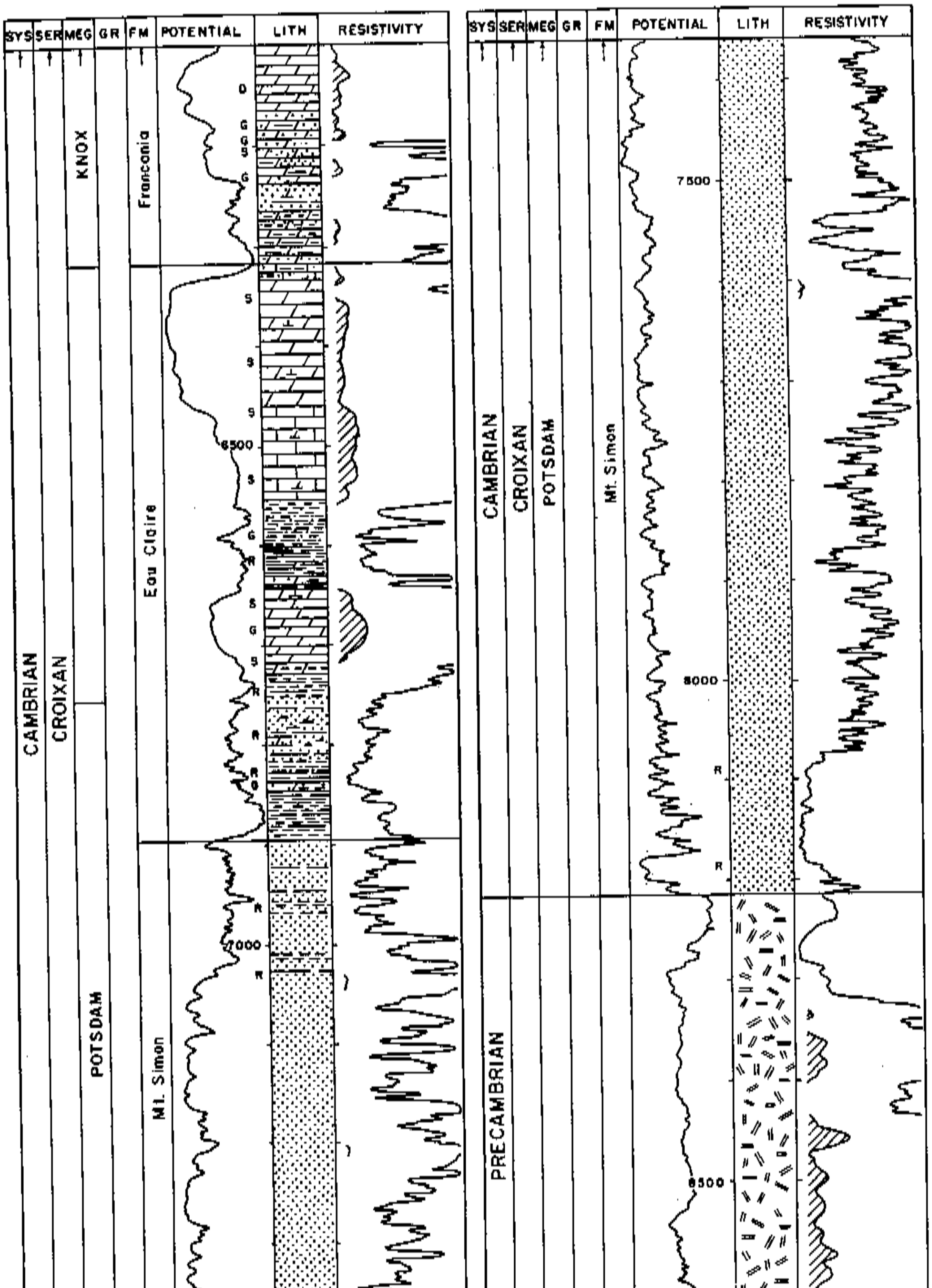


Figure 5 - Log of Ordovician and Cambrian strata in well 20 on figure 4, Humble Oil & Refining Co. No. 1 Weaber-Horn Unit, 619' from S. line, 330' from E. line of NW¼ NW¼, sec. 28, T. 8 N., R. 3 E., Fayette County, Illinois. D = drusy



quartz, G = glauconite, O = oolitic chert, R = red, S = spherulitic limestone or dolomite. See table 3 at end of report for sample study.

TABLE 2 - DATA USED IN THE COMPILATION OF FIGURE 6

	Total		Ottawa		St. Peter		Knox		Eau Claire		Mt. Simon	
	Percent	Cubic miles	Percent	Cubic miles	Percent	Cubic miles	Percent	Cubic miles	Percent	Cubic miles	Percent	Cubic miles
Sandstone	25	11,269	3	176	70	518	2½	555	10	620	94	9,400
Shale and Siltstone	9½	4,189	2	117	15	111	½	111	54	3,350	5	500
Limestone	10½	4,715	70	4,095	0	0	0	0	10	620	0	0
Dolomite	52	23,473	21	1,228	15	111	92	20,424	26	1,610	1	100
Chert and Quartz	2½	1,168	1	58	0	0	5	1,110	0	0	0	0
Anhydrite	½	176	3	176	0	0	0	0	0	0	0	0
Total		44,990		5,850		740		22,200		6,200		10,000

beds are a bit finer and darker, others are slightly dolomitic. Because the Galena is a pure low-porosity limestone, it has high sonic velocity, high electrical resistivity, high neutron response, and high negative self-potential with very low gamma radioactivity.

Marked lithologic and geophysical contrasts make the abrupt upper contact (the top of the Ottawa) an excellent horizon for structural and stratigraphic mapping. The contact of the Galena with the underlying Platteville is equally sharp, but the contrast is very low. The change from dominantly light-colored fossiliferous limestone in the Galena to dominantly medium or dark grayish brown fine-grained to lithographic limestone in the Platteville is characteristic despite the occurrence in both groups of intermediate lithologic types. The self-potential of the upper part of the Platteville is generally lower (i.e. more positive) than that of the Galena; the resistivity is generally higher in the Galena than in the Platteville and the resistivity curve relatively straight in the Galena but somewhat undulating in the Platteville. Three of the most widespread of the many Middle Ordovician bentonite beds, typically about 10 feet apart, occur near the contact, one in the basal part of the Galena and the other two high in the Platteville. Where all three beds are shown on geophysical logs, accurate placement of the contact is simple, but the recognition of only one or two makes precise identification difficult.

The Galena Group is typically 200 to 250 feet thick in northern Illinois and northern Indiana, but it thins southward, largely by truncation. An east-west regional belt of thin Galena extends from north-central and east-central Missouri through southern Illinois and southern Indiana into southern Ohio. In the thinned area in Illinois, the Galena Group is 75 to 100 feet thick, and in southern Indiana it is locally absent. South of this belt, the group thickens to nearly 200 feet in extreme southern Illinois and 200 to 400 feet in Kentucky and Tennessee. Younger somewhat shaly strata are included in the thicker sections both to the south

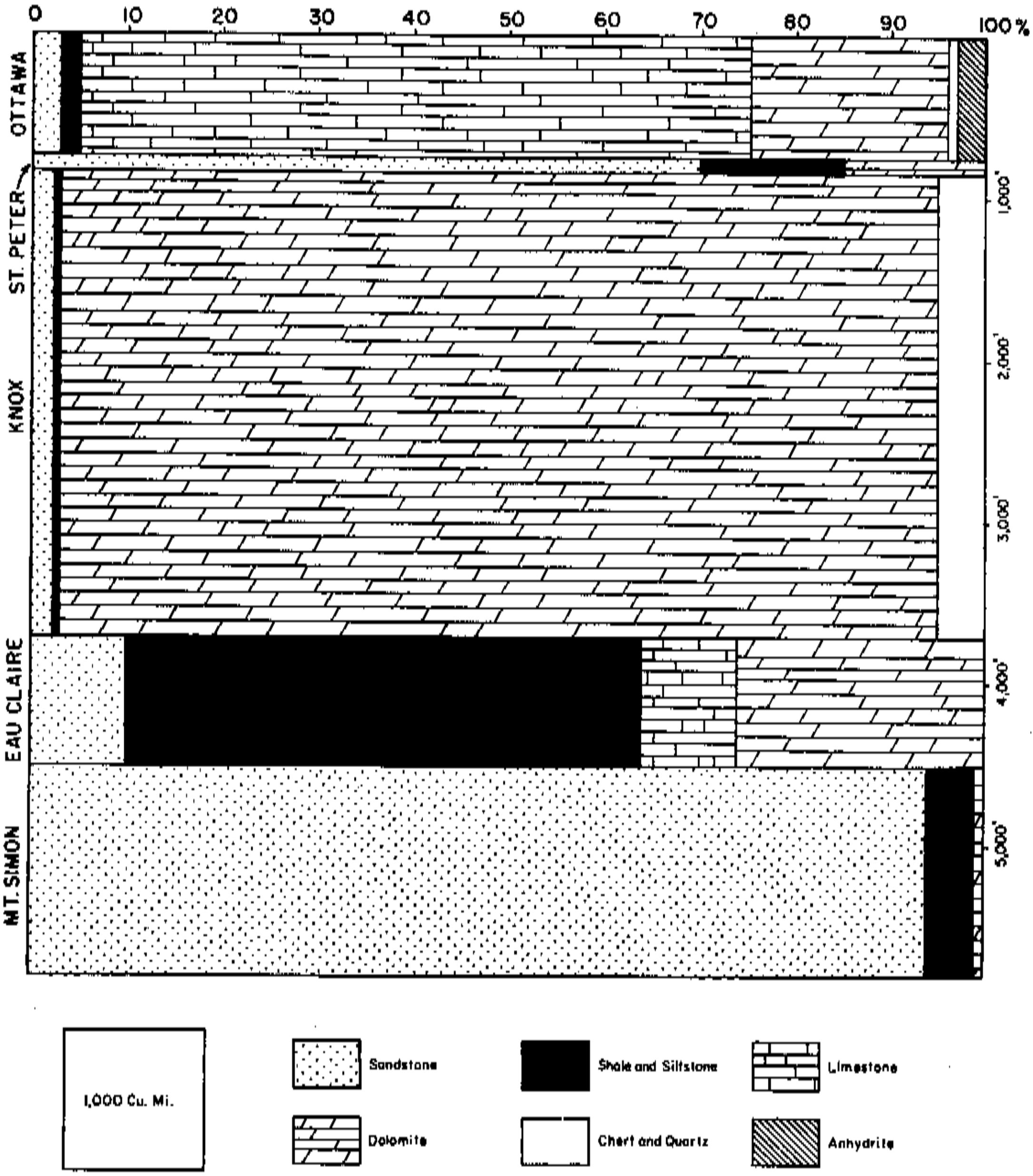


Figure 6 - Estimated volume and lithologic composition of Middle and Lower Ordovician and Cambrian rock units in the deep part of the Illinois Basin.

(Cynthiana and Catheys) and to the north (Dubuque). A shaly unit, the Decorah, marks the base of the Galena around the basin, but the corresponding strata within the deep part of the basin are essentially pure limestone. The formations recognized in the Galena outcrops are less characteristic in the thinner exceptionally pure limestone sequence of the deep part of the basin.

Although the Galena is nearly all limestone in the basin area, it is dolomite in the northern quarter of Indiana, the northern third of Illinois, and along the northern edge of Missouri. North of the dolomite belt, the Galena is again largely limestone. The Trenton production of the old Lima-Indiana oil fields of northwestern Ohio and northeastern Indiana was due in part to the position of these fields at the regional up-dip loss of porosity at the southern edge of the dolomite belt. In Illinois this lithologic change occurs in a down-dip direction high on the northern flank of the Illinois Basin. The Trenton oil pay zone of the west edge of the Illinois Basin is largely Galena, but in some pools, the pay zone extends downward into the underlying Platteville Group.

The Galena Group includes all rocks of Trentonian (late Middle Ordovician) age in the Illinois region.

Platteville Limestone Group

The Platteville in the area under consideration is dominantly medium brown or grayish brown, pure to moderately argillaceous, lithographic limestone with thin shale partings, and a few thin bentonite beds, particularly near the top. Very pure and moderately argillaceous units alternate cyclically, thus producing the characteristic undulating geophysical curves. The purer beds often show dolomitic mottling, and some of the beds, particularly those that are low in the group, may be quite dolomitic. Fossil-fragment limestone, similar to that in the Galena, occurs fairly commonly in the Platteville at the southern edge of the deep part of the basin, but is restricted to thin beds at the north. A thin zone of oolitic limestone and limestone conglomerate occurs in the lower part, although not at the base of the group.

The Platteville, which is thin in northern Illinois and Indiana, thickens southward or southeastward from about 200 feet, along the northern edge of the deep part of the basin to about 700 feet along the southern edge. It is about 400 feet thick at Humble's deep test (fig. 5).

Four formations are recognized in the Platteville Group in the deep part of the basin: the Nachusa (at the top), Grand Detour, Mifflin, and Pecatonica Limestones. The Nachusa includes, at its top, equivalents of the Quimbys Mill Formation that are not readily separable in subsurface in this region. The upper two formations are generally thicker than the lower two. Formational boundaries may be picked more easily on geophysical logs than from well cuttings, although individual members and even beds within these formations can be recognized in cores.

The three upper formations form a sequence of eight or nine cycles of alternating pure and argillaceous beds. The overall argillaceous content increases downward, so that the Nachusa is quite pure, the Grand Detour moderately pure, and the Mifflin the most argillaceous of the three. The Nachusa generally has the highest negative self-potential, the Grand Detour a little lower, and the Mifflin still lower. The lowest self-potential in the Platteville Group, still much higher than that of true shales, marks a shaly limestone unit a few feet thick at the base of the Mifflin. The electrical resistivity of the Nachusa is very high. The Grand Detour resistivity is generally somewhat lower than that of the Nachusa, although a single pure limestone member near the middle of the Grand Detour has resistivity equal to that of the Nachusa. Resistivity in the Mifflin is quite variable from bed to bed; however, the lowest values are much lower than those in the two overlying formations.

Shaly partings in the upper part of the Grand Detour appear reddish, and those in the lower part appear grayish in comparison to the general dark brown color of shale partings in the Platteville. Oolitic and conglomeratic limestones occur in the lower part of the Mifflin. Partings of green soft shale are confined to the lower beds of the Mifflin in the deep part of the basin.

The Precatonica is a massive, pure unit sharply differentiated from its neighbors. It is essentially unfossiliferous and is an extremely fine-grained limestone. It is dolomitized more frequently than the other units within the Platteville. Because of dolomitization, its electrical resistivity is somewhat erratic and ranges from quite low to very high. Its self-potential is uniformly high.

Joachim Dolomite

The Joachim has more dolomite, more noncarbonate rock, and is more varied than any other unit in the Ottawa. It includes fine to extra fine brownish gray dolomite that is partly silty and partly laminated with light and dark layers, brownish gray lithographic limestone, gray to greenish gray siltstone, and medium to dark gray and dark brown shale. The rock types are well differentiated; however, most beds are thin, so that several kinds of rock occur in a short interval. The Joachim rarely has a normal marine fauna. There are numerous algal growths, recognizable in the subsurface by chips of laminated dolomite. Shallow-water sedimentary structures such as mud cracks, edgewise conglomerate, raindrop impressions, and rill and ripple marks are common. The Joachim is nearly 100 feet thick at the northern edge of the deep part of the basin, about 200 feet along much of the western edge, and 300 feet near the center, but it thins to only 100 feet along the eastern edge and is even thinner at the southeastern corner.

Two units, informally designated the upper and lower divisions, can be traced throughout the deep part of the basin. The upper division is a little thinner than the lower. It contains much anhydrite and gypsum, approaching 50 percent in some wells. Algal reefs may have helped isolate the evaporite basin. The upper division is not sandy. It contains some silty dolomite and a little siltstone, but its clastic content is much less than that of the lower division. Its electrical resistivity is high to very high, reflecting its anhydrite content, and it has moderate to fairly high negative self-potential. At the top a notch in the geophysical logs marks a thin, shaly zone, seldom recognized in cuttings, which helps differentiate it from the Pecatonica. Although some thin beds are quite pure, none approach the Pecatonica in uniformity and thickness. The overall color is much lighter and grayer than any part of the Platteville, and anhydrite or gypsum provides sure identification.

The lower division, in contrast to the upper division, has much lower electrical resistivity and lacks anhydrite and gypsum. It has much more shale, siltstone, and sandstone, and the dolomite is generally more porous. The sandstone is largely dolomitic, and much of the dolomite contains fine to medium sand grains. Chert is a minor constituent near the top of the lower division. The deterioration of bentonitic drilling mud, after contamination by sulfate from the upper division, causes poor drilling samples and makes details hard to decipher.

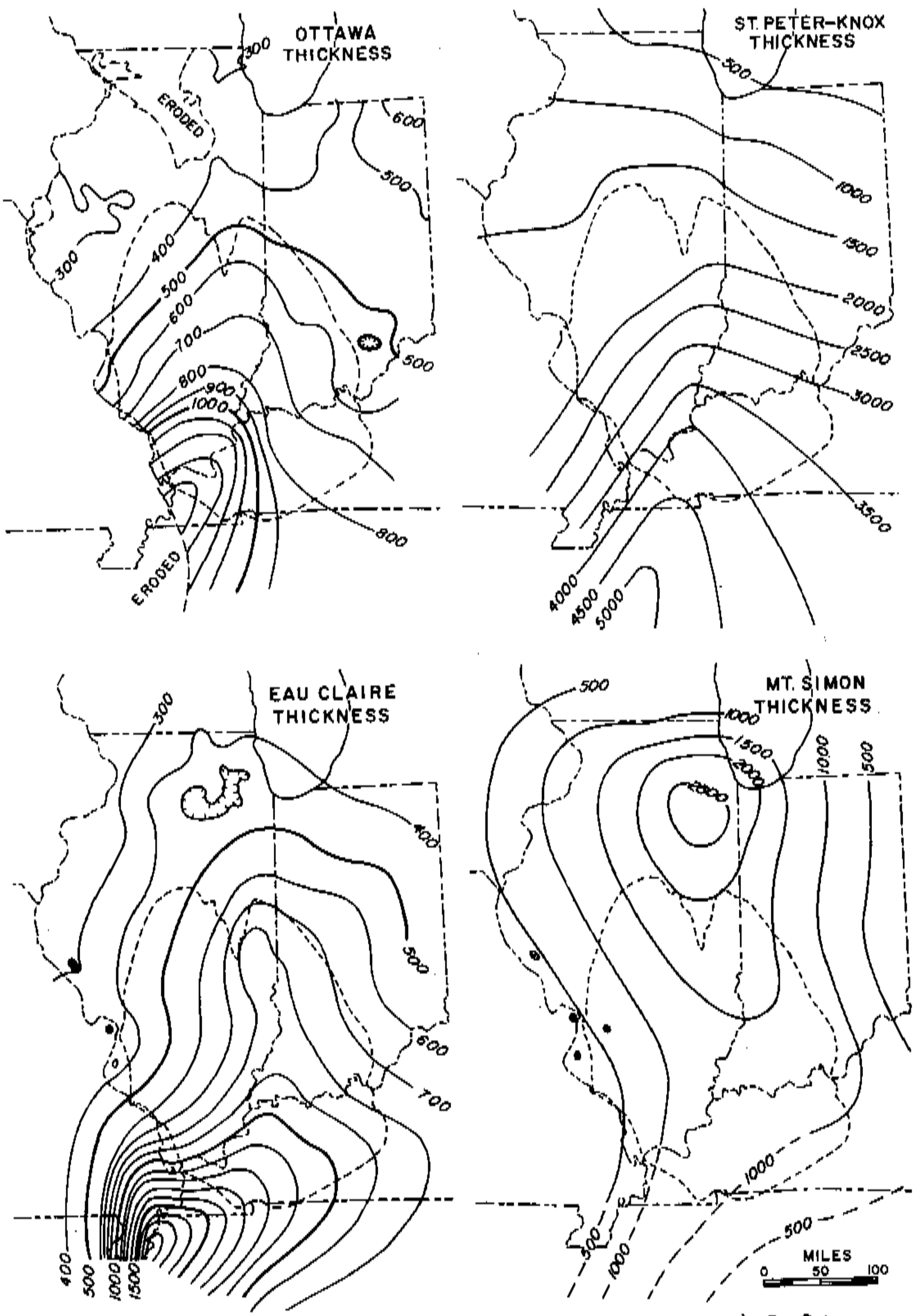


Figure 7 - Thickness of Ottawa Limestone Megagroup (interval 100 feet), St. Peter Sandstone and Knox Dolomite Megagroup including Galesville Sandstone at north (interval 500 feet), Eau Claire Formation (interval 100 feet), and Mt. Simon Sandstone (interval 500 feet). The dashed line is the -1,000' structural contour on top of the Ottawa Megagroup.

The Joachim is underlain by the St. Peter, except in some areas at the eastern edge of the basin where the St. Peter pinches out, and at the south where the St. Peter and Joachim are separated by a southward-thickening wedge of Dutchtown Limestone. In north-central Illinois, north of the deep part of the basin, the Joachim grades laterally to a coarse-grained, pure sandstone, the upper or Starved Rock Member of the St. Peter. In extreme northern Illinois, the Starved Rock grades into the Glenwood Formation. Until recently, some rocks south of the Starved Rock, now placed in the Joachim, were considered Glenwood. In places, the lower division of the Joachim was included in the Dutchtown. In Indiana the upper division is combined with the Platteville as the Black River Limestone, and only the lower division is considered Chazyan (Joachim).

Dutchtown Limestone

The Dutchtown is dominated by dark, almost black, fetid but reasonably pure limestone, whose most significant impurity is clay rather than silt. It contains a few very dark gray and brown, shaly and silty partings. Beds of light-colored dolomite and dolomitic sandstone occur near the top and bottom.

The Dutchtown is confined to the southern part of the basin and does not occur in the Humble deep test (well 20). It underlies nearly all of the seven southernmost counties of Illinois and extends part of the way into the next row of counties. Its northern limit is approximated by the Rough Creek Fault Zone, and it thickens rapidly southward, reaching 200 feet within 50 miles.

The Dutchtown is differentiated from the overlying Joachim by darker color, fetid odor, dominance of limestone over dolomite, a higher ratio of clay to silt, normal marine fauna, and by lack of anhydrite and of structures indicating shallow water. The Dutchtown has higher resistivity and much less shale and siltstone than the lower division of the Joachim. In the outcrop region west of the basin the Joachim-Dutchtown differentiation is sharp, but in the deep part of the basin their characteristic rock types interbed, and the formations grade both laterally and vertically. The Dutchtown is differentiated from dolomitic facies of the St. Peter Sandstone and from carbonates equivalent to the St. Peter, by darker color, higher resistivity, and lower self-potential. Where the St. Peter is exceptionally well cemented, its lower sonic velocity is the most diagnostic geophysical characteristic.

At the west edge of the basin, the Dutchtown grades rapidly northward into a coarse-grained upper member of the St. Peter Sandstone. The Joachim overlaps the Dutchtown and extends 200 miles farther north before it also grades laterally into the relatively coarse-grained sandstone at the top of the St. Peter. In the deep part of the basin, siltstones with interbedded sandstones form the basal part of the Joachim and grade southward into the Dutchtown. A facies relationship between the two formations is suggested by reciprocal thickness, the Joachim thinning southward over the Dutchtown wedge.

The Dutchtown was deposited relatively far from shore in a marine environment with normal salinity. The water was deeper than during either St. Peter or Joachim deposition. Reducing conditions occurred within the sediment body, although not in the overlying sea water. The color and odor of the Dutchtown indicate a potential source of petroleum. Although beds of calcareous or dolomitic sandstone occur near the top and base of the Dutchtown, none have shown commercial permeability and porosity.

St. Peter Sandstone

In Illinois the term St. Peter is restricted to relatively pure sandstone. The sandstone contains only minor amounts of shale and chert-rubble conglomerate, and only insignificant amounts of limestone or dolomite. Sandstone beds above the St. Peter, and separated from it by carbonate or by shale beds, are assigned to the Dutchtown, the Joachim, or the Glenwood and those below it, to the Everton. The unconformity described below brings the St. Peter at the eastern and northern edges of the basin to lie on much older formations, some of which are sandstone similar to the St. Peter and not easily separated from it. However, throughout the deep part of the basin, the St. Peter is overlain by either the Dutchtown or the Joachim Formation and underlain by either the Everton Group or the Shakopee Dolomite.

The St. Peter is composed of highly resistant, stable mineral grains. Quartz is essentially the only light mineral, and the coarser grains are very well rounded and frosted whereas the finest grains are subangular and clear. The limited heavy mineral suite is dominated by zircon and tourmaline. Locally the St. Peter is silty, but in general, the scarcity of clay, silt, and shale is remarkable. Unlike the sandstone beds or sandy zones in some other Ordovician formations, the sand is very well sorted, and commonly considerable thicknesses of sand are nearly uniform in grain size. The St. Peter as a whole is fine-grained. Medium-to coarse-grained phases are almost entirely restricted, both geographically and stratigraphically, to limited parts of the formation.

The most important medium to coarse unit is the Starved Rock Sandstone Member. This member forms the upper third or half of the formation in a belt 60 to 100 miles wide that crosses northern or north-central Illinois and that trends a little south of west into southeastern Iowa. The Starved Rock is the coarse, clastic, shoreward equivalent of the Joachim. It lies entirely north of the deep part of the basin, but at the west edge of the basin, 100 miles farther south, there is a similar, much smaller body of coarse sandstone that extends down into the deep part. Although the southern unit underlies the Joachim and is therefore older than all, or much, of the northern, it is also classified as Starved Rock. It is a shore facies of the Dutchtown.

More than 90 percent of the St. Peter is assigned to the Tonti Sandstone Member. The Tonti is a continuous sheet of fine-grained sandstone which blankets nearly all of Illinois and other states to the west, but to the northeast, it becomes discontinuous and is overlapped by younger strata. To the southeast it grades quite rapidly into light-colored carbonate.

The Kress Member is a variable and discontinuous unit of red, green, or gray clay, chert breccia, chert conglomerate, and shale, which occurs at the base of the St. Peter. In places it consists of residual clay and angular chert fragments incorporated in the sandstone with little or no reworking. Elsewhere the chert fragments are rounded, and the clay is worked into beds of sandy shale. The Kress Member is missing at many localities. It is typically less than 30 feet thick, although at a few places it is as much as 100 feet thick.

Despite the general continuity and simplicity of the St. Peter, its thickness is difficult to predict at a given locality. It fills irregularities on a complex erosional surface, which includes karst and stream topography. The surface has local topographic relief exceeding 200 feet. The interval from the top of the St. Peter to a marker beneath the unconformity can be estimated accurately, whereas the position of the unconformity within that interval tends to be unpredictable.

In general the St. Peter is 200 to 400 feet thick in northern Illinois, 150 to 200 feet thick near the northern margin of the deep part of the basin, 100 to 200 feet thick over most of the deep part of the basin, and 0 to 75 feet thick near its eastern margin.

The Platteville, Joachim, Dutchtown, and St. Peter are assigned to the Blackriveran Stage, the middle stage of the Middle Ordovician (Champlainian).

The Sub-Tippecanoe Unconformity and the Everton Group

Major unconformities divide the North American cratonic succession into a few relatively large unconformity-bounded stratigraphic units called sequences. The lowest of these units corresponds to the Cambrian and Lower Ordovician and is called the Sauk Sequence. The Tippecanoe Sequence overlies it and comprises the Middle and Upper Ordovician, Silurian, and Lower Devonian rocks. The sequences provide apt names for the unconformities separating them. The sub-Tippecanoe unconformity truncates Lower Ordovician, Cambrian, and Precambrian rocks. In various areas it is overlain by rocks of all three Middle Ordovician stages, the Trentonian, Blackriveran, and Chazyan. Names for this unconformity based on relation to local units (i.e. pre-St. Peter or post-Knox) are inadequate regionally. Sub-Tippecanoe, which denotes position, is a more accurate name than pre-Tippecanoe, because Tippecanoe deposition began in some regions when erosion was still occurring elsewhere.

In most of extreme northern Illinois and southeastern Wisconsin, the St. Peter lies on Cambrian rocks. There is no chance for significant petroleum accumulation in the Cambrian rocks of that region, because of flushing by fresh water and because the Cambrian rocks are overlain by several hundred feet of very porous and permeable St. Peter Sandstone. However, in Ontario and Ohio, oil is produced from Cambrian rocks immediately beneath the sub-Tippecanoe unconformity, high on the Cincinnati Arch complex. Here the basal Tippecanoe rocks are tight carbonates, shales, or shaly sandstones that seal the permeable Cambrian dolomites and sandstones and are possible source beds for the oil.

As the unconformity is traced southward in Illinois, the underlying Cambrian and Lower Ordovician strata thicken progressively. In southern Illinois the unconformity has less relief, but the data do not allow detailed mapping.

A wedge of Chazyan (lower Middle Ordovician) rocks assigned to the Everton Group occurs in southern Illinois at the position of the unconformity in northern Illinois—that is, beneath the St. Peter and above the Knox Megagroup. The Everton includes units of sandstone generally coarser but less well sorted than that of the St. Peter. The sandstone is fine to medium or coarse, well rounded, partly calcitic or dolomitic and has zones of marine fossils. Between the sandstone units, there are light to medium gray, generally somewhat silty or shaly dolomite units that lack the oolitic chert characteristic of the Knox. As many as three or four alternations of sandstone and argillaceous dolomite are present in some areas, but only one alternation occurs elsewhere.

The Everton is poorly represented both in wells and outcrops, but it probably covers at least the southern or perhaps southwestern half of the deep part of the basin. It extends north of the Salem and Waterloo fields (wells 23 and 21) but does not occur in well 20 (fig. 5) or in wells shown on the cross sections of figure 9. Everton rocks are included with the Knox in table 2 and figure 6. In wells that stop after penetrating only a few feet below the St. Peter, the pre-St. Peter strata cannot be assigned with certainty to either the Everton or the Knox. The maximum thickness appears to be about 500 feet near the southwest corner of the basin.

The major unconformity of northern Illinois is represented, in the region where the Everton is present, by at least two unconformities. The most prominent unconformity is at the base of the Everton but others occur at the base of the St. Peter and perhaps at various positions within the Everton.

Knox Dolomite Megagroup

The Knox is a large body of somewhat cherty, somewhat sandy Lower Ordovician (Canadian) and Upper Cambrian (Croixan) dolomite in the southeastern and central United States. The term Knox is synonymous with Arbuckle of the central and southern Great Plains and with some uses of Ellenburger in the Texas region. The Knox is a relatively pure dolomite that lies between rocks with much higher clastic content.

The Knox is divided into many different sets of formations and groups in individual areas. In Illinois the formations are the Shakopee Dolomite (at top), New Richmond Sandstone, Oneota Dolomite, and Gunter Sandstone, all in the Lower Ordovician Prairie du Chien Group, and the Eminence Dolomite, Potosi Dolomite, and Franconia Formation, all Upper Cambrian but not assigned to a group. The Franconia is essentially equivalent to the Elvins Group of Missouri, which comprises two formations, the Derby-Doerun and the Davis. These two formations are considered members of the Franconia in Illinois.

There are difficulties in picking the top and bottom of the Knox in the deep part of the basin. The problem at the top involves recognition of the Everton Group and has already been discussed. The Franconia is excluded from the megagroup in northern Illinois where it and the underlying Eau Claire are essentially sandstone. However, the strata become more dolomitic southward, and the Franconia in most of the deep part of the basin in largely dolomite and is included in the Knox. The basal contact of the Knox steps upward to the north as successive units become more and more clastic (fig. 9). The Eau Claire is probably dominated by clastic rocks in most of the deep part of the basin and so is excluded from the Knox. Along the west edge, however, it contains so much dolomite that its local inclusion might be justified.

The Knox is dolomite with little or no limestone but with a small percentage of sandstone and chert and a very small amount of shale (fig. 6). The dolomite is largely light gray or buff to white, although the Potosi is dominated by brown. The grain size is commonly fine but varies from very fine to coarse. Algal deposits are common, but other fossils are rare and poorly preserved. Fine to medium rounded sand occurs both as beds of sandstone and as isolated grains in the dolomite. The rounding is less perfect and the sorting is poorer than in the St. Peter, and the heavy minerals include garnet in addition to the zircon-tourmaline suite. Sandstone units in the Knox are thin compared to the dolomite units. The sandstones are so similar that they cannot be told apart, except by their relation to other strata. Two are recognized as formations, the New Richmond and the Gunter. Two are members: the Momence Sandstone Member, at the base of the Eminence, lies to the north and barely reaches the northern edge of the deep part of the basin; the Davis Member, at the base of the Franconia, can be distinguished over most of the basin but is good sandstone only in the northwestern quarter.

The differences between the dolomite units are slight. Basically, the Shakopee is fine grained and sandy, the Oneota medium grained and not sandy except at the base, the Eminence sandy, the Potosi not sandy and darker and browner than the others, and the Franconia glauconitic and argillaceous.

The maximum thickness of the Knox Megagroup is near the south margin of the basin, where it is at least 4,100 feet thick at well 27 and might exceed 4,500 feet. The Knox thins northward by truncation, by thinning of individual units, and by an upward shift in the basal boundary due to the facies change from dolomite to clastic rocks.

The Knox as a whole is characterized by moderate to high electrical resistivity and self-potential, low gamma radioactivity, moderate to high neutron response, and high sonic velocity. It is distinguished from the overlying St. Peter Sandstone by an increase in resistivity and a marked increase in sonic velocity. The thin sandstones within the Knox are distinguished most readily by their decreased velocity.

Shakopee Dolomite and New Richmond Sandstone

The Shakopee is essentially fine-grained, light gray, buff, and white dolomite with a moderate amount of chert, much of it oolitic. Algal reefs are particularly common, and there is more shaly dolomite than in most of the Knox. Sand occurs in discrete beds of sandstone throughout much of the formation, particularly along the north and east edges of the basin. The Shakopee, which is 583 feet thick in well 20 (fig. 5), is 300 feet thick at the northeast corner of the deep part of the basin and must exceed 1,000 feet near the south edge.

The New Richmond Sandstone is essentially a northern Illinois unit. It is 175 feet thick in the central part of northern Illinois but extends only into the northern or northwestern quarter of the deep part of the basin and is 10 feet thick in well 20 (fig. 5). Beyond the southern limits of the New Richmond, the Shakopee Dolomite rests directly on the Oneota Dolomite, and in places, the contact between them is arbitrary.

Near the east edge of the basin, an isolated sequence of sandstone bodies interrupted by many dolomite units occurs within the general Shakopee-New Richmond succession. In well 26 in south-central Indiana, a 415-foot sequence consists of about 60 percent sandstone and 40 percent dolomite. Farther east, the succession is truncated by the sub-Tippecanoe unconformity, and it is entirely cut out in easternmost Indiana.

The New Richmond is equivalent to the basal few feet of the Roubidoux Formation of Missouri. The Shakopee corresponds to the rest of the Roubidoux and to several younger formations that are not differentiated in the deep part of the basin. It correlates with Long View-Newala in the Kentucky subsurface.

Oneota Dolomite and Gunter Sandstone

The Oneota is medium-grained dolomite that is coarser than the Shakopee but similar in color. It varies from light gray to buff to white and is rarely pink. It is less sandy than the Shakopee, and the sand occurs as individual grains in the dolomite. The upper part is slightly cherty, but the thicker lower part is quite cherty. The chert is white and opaque or banded and occurs as vug fillings and networks. Oolitic chert is less common than in the Shakopee. Drusy quartz that lines open vugs is practically unknown in the Shakopee, occurs rarely in the Oneota and Eminence and is characteristic of the Potosi. The Oneota is 287 feet thick in well 20 (fig. 5), and ranges from a little over 200 to several hundred feet, although it has not been differentiated where the Knox is thickest, at the south end of the basin.

Although the Oneota is relatively nonsandy, the Gunter Sandstone beneath it at the base of the Ordovician is the most persistent sandy unit in the entire Knox. The Gunter is a dolomitic sandstone that grades to moderately sandy dolomite and generally is less than 20 feet thick.

The Oneota is equivalent to the Gasconade of Missouri and to the upper non-sandy portion of the Chepultepec in the Kentucky subsurface. The Gunter is the Rose Run sand of eastern Kentucky, at the top of the sandy part of the Chepultepec.

Eminence Dolomite

The Eminence is a relatively light colored, fine- to medium-grained dolomite that is very slightly glauconitic, somewhat sandy, and somewhat cherty. Part of the chert is oolitic. The Eminence is coarser than the Shakopee, sandier than the Oneota, lighter and with less drusy quartz than the Potosi, and less glauconitic than the Franconia. Until recently it was included in the Oneota in some areas and in the Trempealeau (Potosi) in others.

The Eminence is generally less than 100 feet thick in extreme northern Illinois but 150 to 200 feet thick at the north edge of the deep part of the basin. In Missouri it varies from about 200 to 350 feet. At the east edge of the basin, it is 200 to 300 feet thick. Its thickness in the thick Knox section toward the south is not known.

The Eminence grades laterally into the Jordan Sandstone of Wisconsin and, together with the Gunter, forms the lower sandy zone of the Chepultepec of Kentucky and Ohio.

Potosi Dolomite

The Potosi is a fine- to medium-grained dolomite that is relatively chert-free, relatively sand-free, and slightly glauconitic. It contains much drusy quartz. The upper part is light gray to tan, but the lower part is medium-brown and generally the darkest part of the entire Knox. In many areas it is vuggy or even cavernous. In northern Illinois, caves are developed in the upper part, so that cable tools drop freely as much as several feet in some wells. Loss of circulation is common in rotary tests. The commercial barite deposits of Missouri occur as fillings in such vugs or caverns. The Trempealeau oil pay of Ohio is in rocks equivalent to the Potosi where these rocks directly underlie the sub-Tippecanoe unconformity and are covered by impermeable rocks called Chazyan but probably of Blackriveran age.

The Potosi is 332 feet thick in well 20 (fig. 5). It is 250 to 300 feet thick at the north edge of the deep part of the basin and must be at least 1,000 feet thick in the areas of extremely thick Knox at the south edge of the basin.

The Potosi and the overlying Eminence are assigned to the Trempealeauan Stage (latest Croixan). The Potosi is equivalent to the upper part of the Copper Ridge Dolomite of most areas to the south and east.

Franconia Formation

The Franconia Formation, in the deep part of the Illinois Basin, is gray to light gray, glauconitic, somewhat silty, somewhat argillaceous, somewhat sandy dolomite. It is chert-free in northern Illinois but contains a trace of chert farther south. A little limestone is present in Missouri and southern Illinois and is the only limestone in the entire Knox. In Wisconsin, the Franconia is fine-grained, silty, argillaceous, glauconitic sandstone. In northern Illinois it is similar but more dolomitic. From northern Illinois southward, the Franconia is readily divided into two members, the Derby-Doerun (above) and the Davis. In north-central Illinois the Derby-Doerun is silty, argillaceous dolomite; whereas the Davis is silty sandstone. Farther south the Derby-Doerun becomes quite pure, except for a thin zone at the top which remains slightly argillaceous and glauconitic, and the Davis is very silty and partially sandy dolomite. In Kentucky the Derby-Doerun is practically as pure as the Potosi, and both are included in the Copper Ridge; whereas the Davis is nonporous argillaceous dolomite, locally called Conasauga. In Ohio the "B" zone in the Trempealeau or Copper Ridge marks the top of the Derby-Doerun, and the Davis is called Maynardville.

The Franconia is 150 to 175 feet thick in the northeast part of the basin, 265 feet in well 20 (fig. 5), 200 to 350 feet thick on the Missouri outcrop, and probably 500 to 700 feet thick in the south and southeastern part of the basin, where it is hard to differentiate from the Potosi. The Davis is 100 to 175 feet thick in the sandstone phase, drops to only 50 or 75 feet in the argillaceous dolomite phase in the northeastern and presumably the central part of the basin, and then thickens slowly southeastward to 100 or 150 feet.

In the deep part of the basin, the Derby-Doerun is dolomite that geophysically is like the rest of the Knox, although a slight notch sometimes marks the faint argillaceous zone at its top. The Davis has somewhat lower resistivity, sonic velocity, and self-potential and notably higher radioactivity. The values lie midway between those for the rest of the Knox and the Eau Claire. In northern Illinois, the two members of the Franconia converge geophysically as well as lithologically, but the entire unit has lower resistivity than the overlying Potosi and lower self-potential than either the Potosi or the underlying Ironton-Galesville Sandstones.

Ironton and Galesville Sandstones

The Ironton and Galesville Sandstones are essentially northern Illinois formations that barely reach the deep part of the basin. They are best developed in the subsurface of northern Illinois. The upper formation, the Ironton, is a relatively poorly sorted, fine- to coarse-grained sandstone that is slightly glauconitic, somewhat dolomitic, and sparingly fossiliferous. Its greatest thickness is a little more than 100 feet. It is somewhat friable and has a moderately low electrical resistivity and a high negative self-potential. The Galesville is much better sorted, finer grained, and more porous, than the Ironton. It is nearly incoherent or loose and generally free from dolomite and fossils. It has unusually low resistivity except at the top and bottom. It averages about 40 feet thick and has a maximum thickness of about 75 feet.

The combined thickness of the formations is less than 100 feet in the northeast corner of the deep part of the basin. In a very short distance, these formations change into sandy, partly oolitic carbonate that farther south either lenses out or becomes so similar to parts of the Davis or the underlying Eau Claire that it is included in them. The Ironton contains some coarse sand, which distinguishes it from the Franconia and the Galesville. The Ironton is not as silty as the Franconia. Both the Ironton and the Franconia are assigned to the Franconian Stage.

The Galesville is a cleaner sandstone than the units above and below. It contains no fossils in its outcrop, but historically it is placed at the top of the Dresbachian, the oldest of the three stages in the Croixan (Upper Cambrian).

Pre-Knox Formations

No wells penetrate the entire Knox in the deep part of the Illinois Basin except for a few tests at the margins. The area with no drilling expands southward from an apex in north-central Illinois to a width of about 300 miles between well 31 in extreme southeastern Missouri and well 29 in south-central Kentucky (fig. 4). The gap to the south is broken only by a single basement test in south-central Tennessee (well 35 on fig. 4), which cannot be correlated to either of the other anchor points.

Eau Claire Formation

The Eau Claire near the Canadian Shield is largely sandstone with beds of fossiliferous siltstone. In southern Wisconsin it is basically siltstone with minor amounts of dolomite and sandstone. In northeastern Illinois it consists of an upper member that is dominantly siltstone, a middle dolomite member with much shale, and a lower member dominated by sandstone but with some shale, siltstone, and a little dolomite. At the north edge of the deep part of the basin, oolitic limestone occurs within the major dolomite unit.

Shale in the Eau Claire is very micaceous, gray to dark gray, green to light green, and maroon to red. The dolomite is generally sandy or silty, medium crystalline, and brownish gray. Much of the siltstone is pinkish gray. The sandstone is fine to medium, well-sorted, but only moderately rounded. Much of it is dolomite-cemented and fossiliferous with dark gray to black trilobite and brachiopod fragments. Glauconite is relatively common and is generally coarser than in the Franconia. Many sand grains near the base of the formation are covered with thin films of minute pyrite crystals that give these grains a sooty appearance. In places, sooty grains also occur at the top of the underlying Mt. Simon.

Zones of inarticulate brachiopods and zones of abundant trilobites can be recognized in well cuttings from the Eau Claire but not from other Cambrian and Lower Ordovician formations. They can be traced from well to well over distances of 50 to 100 miles or more.

On the west side of the basin, the amount of dolomite increases southwestward as the Eau Claire grades into the relatively pure Bonneterre Dolomite of Missouri. Limestone increases to about a quarter or a third of the total carbonate, and oolite is reasonably common in both limestone and dolomite. Chert is relatively uncommon and is not oolitic. The section thickens but remains dolomite to well 30, then changes in 40 miles to over 80 percent shale in well 31 in extreme southeastern Missouri.

Traced down the east margin of the basin from northern Illinois, the Eau Claire becomes progressively shalier, contains less siltstone, very little sand except toward the base, and gradually decreasing amounts of dolomite and limestone. It has fairly uniform thickness. Internal zonation and a moderate amount of control make correlation through Indiana and into Ohio reasonably definite. We place the Davis Member of the Franconia Formation in the base of the Knox rather than at the top of the Eau Claire, as is done in Indiana. A zone characterized by fine to medium dolomite-cemented sandstone in the base of the Eau Claire is put in the top of the Mt. Simon in Indiana. This puts both boundaries of the Eau Claire about 100 feet lower in Illinois than in Indiana. The Eau Claire in well 29 in south-central Kentucky is dark gray, green, red, micaceous, and partly glauconitic shale containing silty sandstone and thin dolomite and limestone beds. Published correlations across the 150-mile gap to south-central Indiana all agree, although the nomenclature used varies. Recently the Eau Claire has been called Rome in Kentucky and split into Conasauga, Rome, and Shady in Ohio. However, we consider it equivalent to the Nolichucky Shale, the upper part of the type Conasauga of the Appalachians.

The Eau Claire is the shaliest unit in the entire Cambrian, as shown by its moderate to low resistivity, low self-potential, slow sonic velocity, and high radioactivity. Beds of relatively pure dolomite, sandstone, and limestone produce peaks on the geophysical logs, particularly where sandstones, along the north edge of the basin, and carbonates, along the west edge, reach their greatest abundance.

The Eau Claire is largely carbonate along the west side of the basin, largely sandstone and siltstone along the north edge, and micaceous and somewhat silty shale along the east margin. The zone of interfingering of these lithologies lies within the deep part of the basin. The thickness of the Eau Claire is shown on figure 7.

Mt. Simon Sandstone

A thick, fairly pure, rather coarse-grained, white and pink, unfossiliferous noncalcareous sandstone, called Mt. Simon in Wisconsin, Illinois, and Indiana and Lamotte in Missouri, blankets the Precambrian basement in the Illinois Basin region, with the following exceptions. At the west edge of the basin, the Mt. Simon is overlapped by the Eau Claire against some isolated Precambrian hills. In well 29 in south-central Kentucky, several hundred feet of Mt. Simon is underlain and separated from igneous basement rock by 80 feet of calcareous siltstone, dolomite, and limestone, tentatively assigned to the Middle Cambrian. In well 35 in south-central Tennessee, the entire Lower Ordovician and Cambrian section is dolomite, but the basal 200 feet is quite sandy and may correlate with the Mt. Simon.

Sandstone in the Mt. Simon varies from fine to coarse. It is neither as well rounded nor as well sorted as other Cambrian and Ordovician sandstones. There is generally an alternation between sections of fine sandstone and those dominated by medium to coarse sandstone that contains granules or very small pebbles 2 to 4 mm. in diameter. The Mt. Simon has been split into an upper white and lower pink or red unit in some areas, but in many regions, the white and hematite-stained portions intergrade laterally, and this distinction cannot be maintained.

Beds or lenses of gray, green, or red micaceous but nonglauconitic shale and siltstone occur, but nowhere do they exceed 5 percent of the formation. The sand is nearly pure quartz in most of the formation. The principal cementing material is quartz, with a little hematite and clay. It contains no carbonate. In the shallow regions north and west of the basin, the Mt. Simon is moderately compact to friable. Deep in the basin and on the east margin, many beds are tightly cemented, even quartzitic, and have greatly reduced porosity. In some regions, a basal zone, typically 20 to 40 feet thick, but ranging from 0 to nearly 400 feet, contains much feldspar and is, locally, an arkose. A basal conglomerate, a few inches or a few feet thick with pebbles of locally derived basement rock, occurs in a few wells. The Mt. Simon is characterized by high self-potential and low gamma radiation. Depending on porosity, the electrical resistivity and the neutron response vary from moderate to fairly high and the sonic speed from low to moderately high.

The Mt. Simon differs from the basal sandstones of the Eau Claire, in larger grain size, the presence of very fine quartz pebbles or granules, the general lack of pyrite-coated, "sooty" grains, a marked decrease in the amount of shale and siltstone, and the complete lack of fossils, glauconite, dolomite, and calcite.

The Mt. Simon is by far the thickest formation in the Illinois Basin region (fig. 7). The thickness is inferred except for the handful of Precambrian tests shown on figure 4. Scattered seismic data suggest that the thickness shown is minimal (fig. 11). The Precambrian surface is relatively rugged, as shown by seismic data and by outcrops and wells at the west margin of the basin, so that the Mt. Simon thickness varies several hundred feet in a short distance.

Deposition of the Mt. Simon may have begun in some places in the Middle or Lower Cambrian, and in some areas even Precambrian sandstones may be included. However, the essential uniformity of the section from top to bottom makes this seem unlikely, and the entire Mt. Simon is classified as Upper Cambrian because it is conformably overlain in large areas by the fossil-bearing Upper Cambrian Eau Claire Formation.

Possible Middle Cambrian Strata

In the deep test in south-central Kentucky, the Mt. Simon is underlain by 40 feet of slightly micaceous red siltstone. The siltstone grades to calcareous sandstone and would be included in the Mt. Simon despite its calcareous content, if it were not in turn underlain by 40 feet of light gray fine-grained dolomite, light-colored limestone, and varicolored shale streaked with sandstone containing rhyolite pebbles. This marine section, lying on basement rhyolite beneath several hundred feet of Mt. Simon, may be Middle Cambrian in age. It is located on the Cincinnati Arch and is significant in suggesting that Middle (or perhaps Lower) Cambrian seas may have entered the part of the Illinois Basin that lies south of the Rough Creek deformational belt.

Precambrian

The total thickness of the rocks between the top of the Ottawa Megagroup and the Precambrian basement is the summation of the individual isopach maps of figure 7 and is shown on figure 8. The structure on the Precambrian surface (fig. 10) was obtained by combining the thickness from figure 8 with the structure of the Ottawa (fig. 2). The method of construction tends to obscure irregularities and to show the basement too shallow in areas without control.

Figure 11 compares the depths obtained in this manner with estimates based on geomagnetic anomalies and on seismic reflecting horizons. The geomagnetic

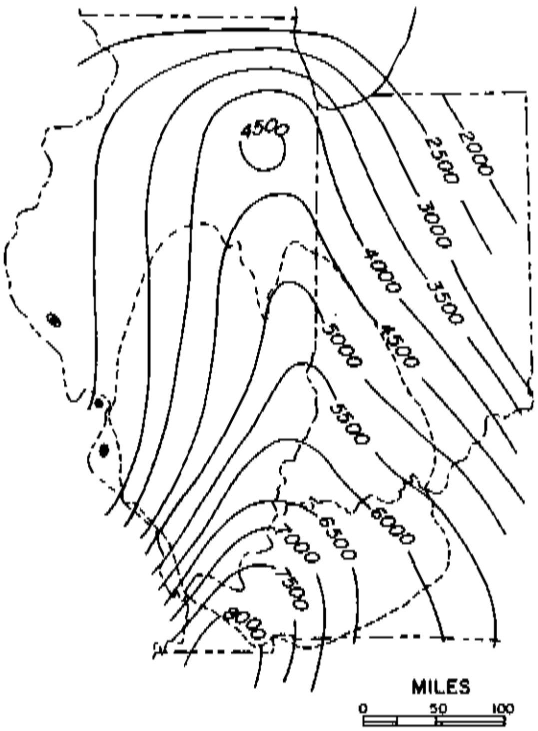


Figure 8 - Total thickness of strata from the top of the Ottawa Limestone Megagroup to the base of the Cambrian, contour interval 500 feet. The dashed line is the -1,000' contour on the top of the Ottawa Megagroup.

method has inherent inaccuracies of about 10 percent, but subsequent drilling in Indiana has shown such estimates to be 10 to 30 percent too shallow. The limited public seismic data show the basement surface deeper and more rugged than that determined by stratigraphic projection.

All 16 basement tests in Illinois penetrated acidic igneous rock (table 1). Magnetic anomalies show that the basement in Illinois contains some basic rock. Many of the wells in table 1 may have been drilled over buried Precambrian hills composed of the more resistant rock types. Wells in Indiana encounter metamorphic and basic as well as acidic igneous rock. The Grenville line extends from the Canadian Shield down through western Ohio. The Precambrian rocks east of it are mostly metamorphic and much younger than those to the west that underlie the Illinois Basin.

OIL AND GAS POSSIBILITIES

Specific Stratigraphic Units

The Galena (Trenton) is moderately productive on the west flank of the basin and slightly productive on the LaSalle Anticlinal Belt. Major extension of this type of production, which is largely related to the sub-Maquoketa unconformity, seems unlikely. Very slight to slight shows of oil and gas occur in many tests in the deep part of the basin and in nearly all tests in the north half in rock too tight to produce. There is the possibility of production in this region from narrow, vertical, fracture-controlled, porous dolomitization streaks similar to the northwest-trending Scipio-Albion oil trend of southern Michigan. This would include areas ranging from essentially the bottom of the basin up to extremly shallow.

The Platteville is essentially an extremely fine-grained lithographic limestone that offers little as a pay zone but that might include source beds. A very small shallow well has been completed in its basal dolomite, the Pecatonica, in eastern Iowa.

The Joachim has had oil staining or light oil-shows in tight sandstone in wells 16, 17, 22, and 24. It is potentially attractive, because the anhydrite in its upper part provides an effective seal, and scattered bodies both of sandstone and of medium-grained dolomite, particularly in the lower part, are potential reservoirs. Individual porous beds may not cover large areas. The "St. Peter sand," which has two small gas fields and several oil-and gas-shows in east-central Kentucky, has characteristics resembling those of sand beds in the Joachim rather than those of

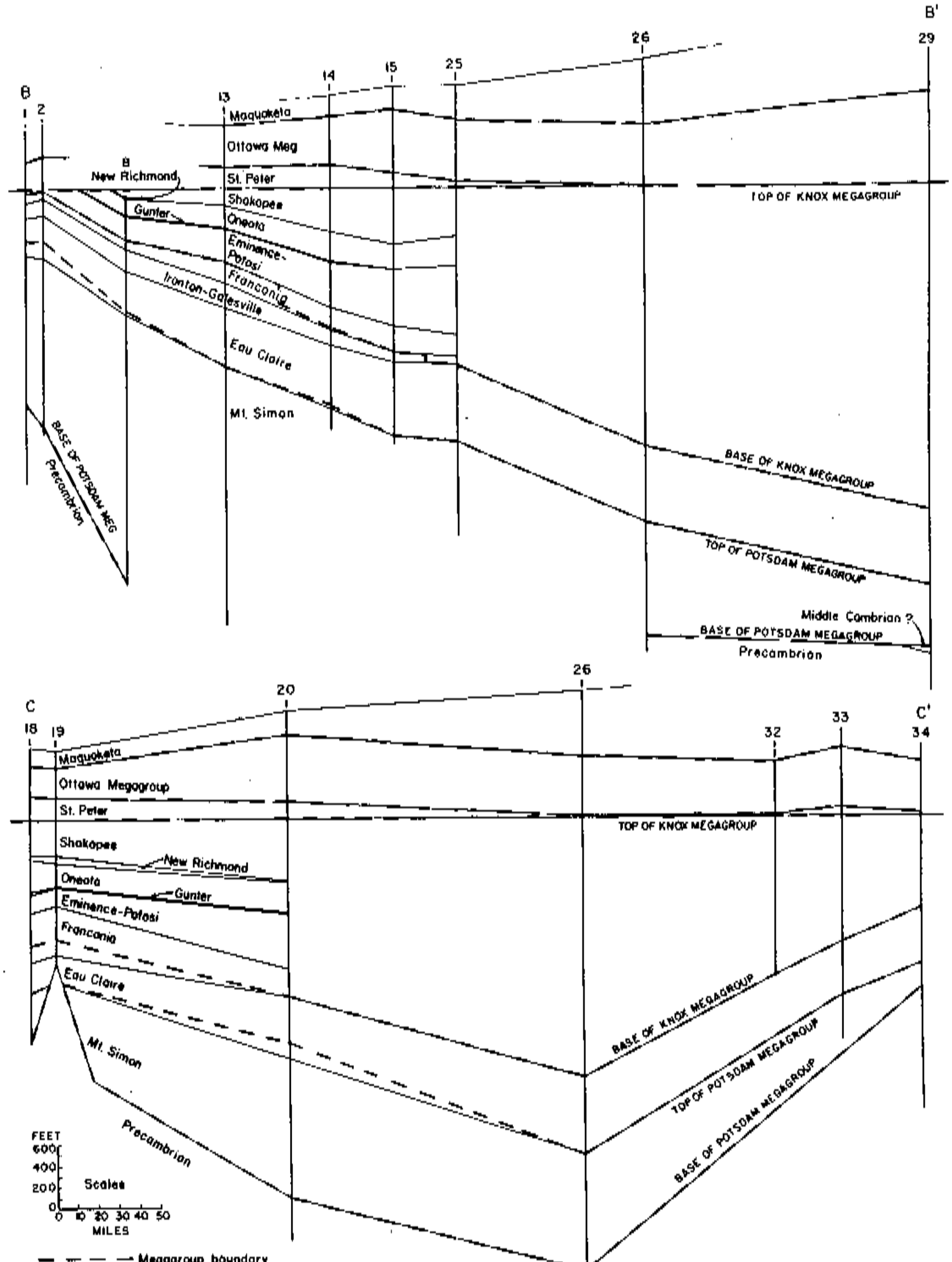


Figure 9 - Cross sections B-B' (NW-SE) and C-C' (W-E) of Cambrian and Ordovician strata. Lines of sections on figure 4.

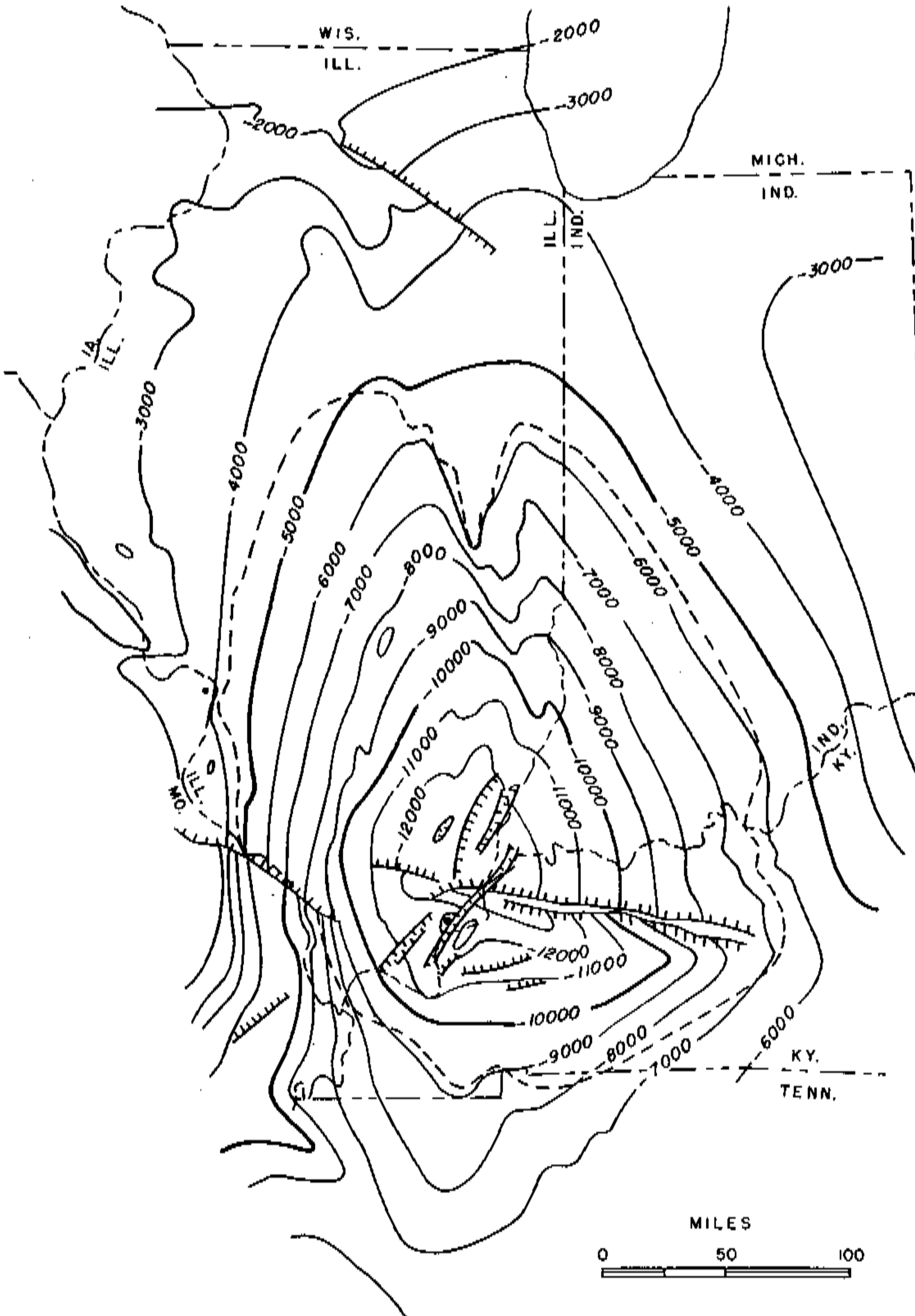


Figure 10 - Structure of the Precambrian basement surface based on projection from younger horizons. The dashed line is the -1,000' contour on the top of the Ottawa Megagroup.

the main body of the St. Peter and probably represents a basal Joachim sand body. In Oklahoma much oil comes from sands in the Simpson Group, equivalent to parts of the Joachim, Dutchtown, St. Peter, and Everton.

Because of its dark color and fetid odor, the Dutchtown is perhaps more favorable than the Joachim. It, too, contains occasional sand bodies that at places may be open enough to provide reservoirs. The northern edge, which was an updip wedge during deposition, is an obviously favorable situation.

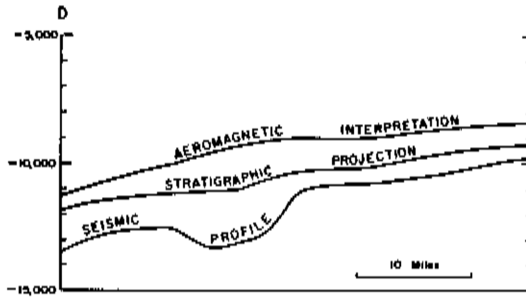


Figure 11 - Comparison of aeromagnetic interpretation (Henderson and Zietz, 1958), stratigraphic projection (this paper), and seismic profile (Rudman, 1963) of the basement surface along line D-D'. Line of section on figure 4.

There have been no oil-shows in the thick St. Peter of the central or western part of the basin, and such blanket sands seldom make effective oil reservoirs. Along the eastern margin of the basin in Indiana, western Kentucky, and perhaps easternmost Illinois, the St. Peter consists of small broken sand bodies interbedded with other material and is much more attractive than to the west.

The Everton in the western part of the basin offers more potential than the overlying St. Peter, but present knowledge is so sketchy that no outline of the internal stratigraphy or even the limits of the Everton is possible. It contains sandstones, some thick and porous enough to provide reservoirs, and it contains a little shale and much shaly dolomite, some of which may provide suitable caps. The distribution and extent of any individual unit is not known.

Equivalents of the Knox Dolomite Megagroup produce much oil in Ohio, Kansas, Oklahoma, and Texas, and some oil in Kentucky and Tennessee. Some of this Lower Ordovician and Cambrian oil comes from rocks shortly beneath the sub-Tippecanoe or a younger unconformity where it may have been derived from younger rocks above the unconformity. However, there are many pools in which such derivation is virtually impossible and a larger number in which it seems unlikely. Well 3, a very shallow water well in northern Illinois, has produced a small amount of live oil from the Potosi, which, however, is in fault contact with the Galena only a few hundred feet away. Some high-capacity industrial water wells in Chicago produce enough asphaltic material from the Potosi along with the water, to cause problems in filter maintenance. Well 22 at St. Jacobs in southwestern Illinois had shows of heavy asphaltic oil at several positions in the Knox, the most prominent being about 60 feet below the top of the Shakopee Dolomite and at the top of the Potosi Dolomite.

Although sandstones are a minor part of the Knox and have provided little of the oil produced elsewhere, they cannot be ignored in considering the Illinois Basin. The main body of the New Richmond Sandstone barely reaches into the north edge of the deep part of the basin, but it shows that the sand bodies in the Knox have a lenticular shape. Thick sandstone bodies at about this position in south-central Indiana indicate that substantial reservoirs may occur in this part of the Knox in the deep part of the basin. The Gunter Sandstone is recognized at more localities than any other sandstone and may occur in almost any part of the basin. The Davis Member at the base of the Knox appears to be a good sandstone in about the northwest quarter of the deep part of the basin, and it could be productive, particularly where the underlying Eau Claire is rather shaly or limy.

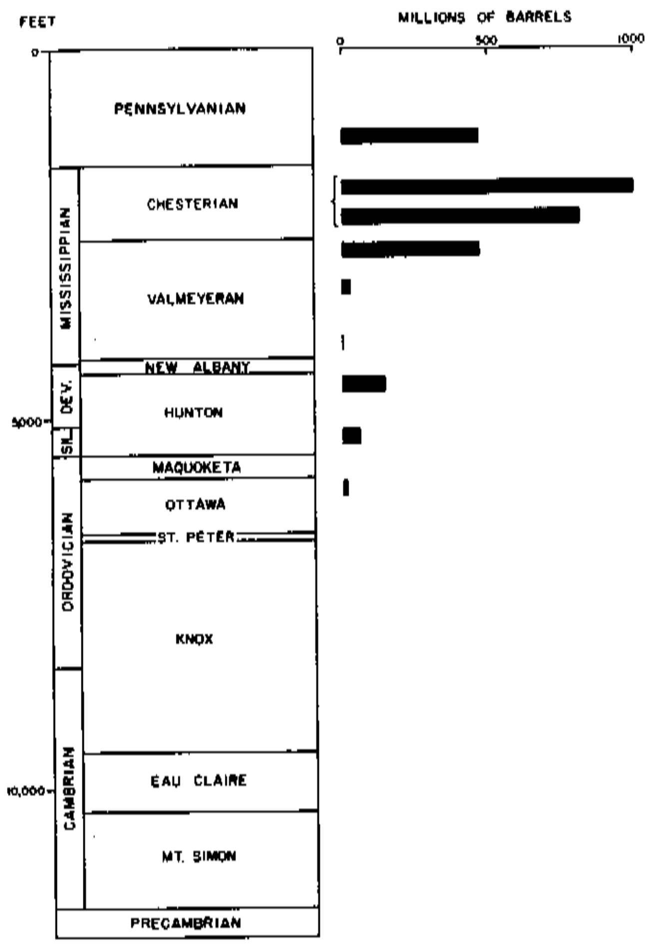


Figure 12 - Generalized column for the deep part of the Illinois Basin showing cumulative oil production by major stratigraphic units to January 1964.

The major porous zones in the dolomites of the Knox appear to be concentrated in the Shakopee and the upper part of the Potosi. Those in the Shakopee may actually be related to the sub-Tippecanoe unconformity. The vuggy and cavernous parts of the Potosi at the west and north edges of the basin become much tighter to the southeast but retain a fair degree of porosity and permeability well into the deep part of the basin.

The Eau Claire ranks first as a potential producer in the deep part of the Illinois Basin, although its greater depth makes it less attractive in the immediate future. It has not yielded oil in other regions. Three lithologic end-components correspond closely to three geographic regions: sandstone (Eau Claire) to the north in Wisconsin, dolomite and limestone (Bonneterre) to the west in Missouri, and shale (Nolichucky) to the east in Kentucky and Indiana. The area most favorable for oil accumulation lies where the three rocks types interfinger in the deep part of the basin, probably in the central to southwest sector corresponding to southeastern and south-central Illinois. The most favorable area shifts for different parts of the Eau Claire, farther south for the sandy lower part, farther east for the dolomitic middle part, and farther west for the upper section in which shale predominates. An increase in the rate of southward thickening in southeastern Missouri, coupled with the change from dolomite in well 30 to at least 80 percent shale in well 31, suggests an active mobile hinge-belt near the present-day Rough Creek Fault Zone and a carbonate build-up interfingering southward into the shaly basin facies. By this interpretation the carbonate facies extends far to the east along, and just north of, the Rough Creek Zone, whereas the argillaceous facies extends westward entirely across the basin at the latitude of the Moorman Syncline.

Although the Mt. Simon is the thickest fluid-yielding zone in the region, it appears at present to be too continuous a blanket sand to offer much hope as a petroleum reservoir. The exception would be at its edge where it might be pinched out beneath the Eau Claire against Precambrian topographic highs and perhaps at the extreme south end of the basin where the sandstone might disappear or interfinger into other lithologies. The thin sliver of dolomite, shown in the lithologic composition of the Mt. Simon on figure 6, was added to express this possibility. If the Middle Cambrian dolomite and shale on the Cincinnati Arch in south-central Kentucky is found to extend into the deep part of the basin, the possibility of Mt. Simon production will be considerably enhanced.

General Considerations

The Illinois Basin produced its 3 billionth barrel of oil early in 1964. All came from the upper half of the stratigraphic column (fig. 12), which is now largely, but not completely, explored. In contrast, the larger block of Lower Ordovician and Cambrian rock in the deep part of the basin is untested. The area within the -1,000 foot contour on the top of the Ottawa Megagroup (top of the Trenton) contains 41,000 square miles and has yielded 99 percent of the oil from the basin. The area contains about 38,400 cubic miles of Lower Ordovician and Cambrian sediments reached by 28 tests, but only 16 penetrate more than 200 feet. The total section drilled in all tests is only 24,727 feet, which is less than 8 inches of test hole for each cubic mile of rock. Five-sixths of the production has come from within the -3,500 foot contour, where only 5 wells that penetrated a total of 1,526 feet have tested the 18,000 cubic miles of Lower Ordovician and Cambrian, about one inch per cubic mile.

Much can be told about the petroleum potential of these rocks, despite negligible amounts of testing. Their volume is large. They are unmetamorphosed sediments, primarily of near-shore marine origin, saturated with moderately to highly saline brine. The proportion of lithologic types (table 2 and fig. 6) is favorable, although more shale and less dolomite would be better.

Most of the world's oil comes from sedimentary basins. The earliest petroleum discoveries were in arch-dominated provinces, where shallow depths made exploration relatively inexpensive. Later, exploration turned to the more prolific deep basins where oil is generally lighter in gravity, gas is more common, and condensate production is possible. Lower Ordovician and Cambrian rocks were deposited in the sedimentary basin shown on figure 8 and lie in the present structural Illinois Basin (figs. 2, 3, and 10). The distribution of datum points and the method of drawing figure 8 make the depositional basin appear less prominent than it probably is.

Although structures in young rocks tend to extend downward, the converse is not true, and pre-St. Peter structures in the Ozark, Cincinnati, and Wisconsin Arch regions, and even the deep part of the Illinois Basin, have little or no effect on rocks above the sub-Tippecanoe unconformity. Moreover, structures produced long after sedimentation tend to be barren of oil. Until many deep wells have been drilled, only geophysics can identify individual pre-St. Peter structures or those younger structures that have a pre-St. Peter component and are, therefore, likely to trap Lower Ordovician and Cambrian oil.

During the early Paleozoic, a mobile hinge-belt approximating the present Rough Creek Zone, may have divided the Illinois Basin into a southern basin-like portion and a northern shelf-like portion. Structures south of the belt are tighter and more faulted, suggesting a thicker sedimentary or layered section above the massive basement. Middle Ordovician units (Galena, Dutchtown, and possibly Everton) disappear or thin abruptly northward at about the latitude of the Rough Creek Zone. Changes in the Lower Ordovician and Cambrian may occur abruptly at this belt, but the wells are spaced too widely to prove this. The eastward extention of the southern basin is the "Rome" trough of eastern Kentucky. A depositional hinge-belt provides a concentration of structural and stratigraphic irregularities that tend to localize oil accumulation.

Although there is some tendency for oil pools in different stratigraphic intervals to be stacked one above another, patterns of oil accumulation may show abrupt changes at major unconformities. Such changes in pattern occur in the younger strata in the Illinois Basin. Above the sub-Pennsylvanian unconformity, the Pennsylvanian oil, which dominated Illinois production before 1937, is concentrated on the LaSalle Anticlinal Belt. Mississippian oil, the mainstay of the industry since 1937, occurs in moderate amounts on the LaSalle Belt and in the other structural regions of the basin (fig. 2) but is particularly concentrated in the Fairfield Basin and on the DuQuoin-Louden Belt. "Deep" wells drilled 30 to 50 years ago failed to find Mississippian oil beneath many Pennsylvanian fields, and conversely no Pennsylvanian oil was found over most of the major Mississippian fields. The Salem pool area was condemned by a single dry hole at the structural crest that tested the entire Pennsylvanian and extended 200 feet into the Mississippian but stopped 300 feet short of the largest oil reservoir in Illinois. At the next major unconformity, beneath the Middle Devonian, there is another shift in the pattern of oil distribution. Silurian and Galena (Trenton) pools are concentrated in the Cincinnati Arch province and the west flank of the Illinois Basin, with very little oil in the most prolific Mississippian regions. Another realignment should occur beneath the sub-Tippecanoe unconformity, but details of the pattern of oil occurrence cannot yet be even surmised.

The scarcity of oil shows beneath the Galena, and particularly their absence in well 20 at Louden, a major Mississippian pool, is disappointing. However, at Louden, there is no production in the Pennsylvanian, which is the major producer in pools in the same depth range 60 miles farther east where there is little Mississippian production. About 45 untested counties that produce 90 percent of the basin's oil lie deeper in the basin than well 20 at Louden.

The lack of shows in a given stratigraphic interval in one region need not condemn another region. This is demonstrated by the Middle Devonian Dutch Creek Sandstone, which had no shows in scores of tests on the flanks of the Illinois Basin and was found productive only in a small area in the deepest part of the Fairfield [redacted] Basin.

Porosity and permeability of many of the Cambrian and Ordovician formations are very high north and west of the basin where these rocks supply large quantities of fresh water, but they are much tighter in the deep part of the basin. Sandstones that are friable to loose in northern Illinois, with permeabilities in the hundreds and even thousands of millidarcies, are compact in the wells to the south where the few available analyses show permeabilities ranging from fractional to tens of millidarcies. The situation is comparable in the dolomites. Fortunately for deep oil and gas production everywhere, the processes that reduce porosity in water-saturated rocks are ineffective in oil-saturated rocks. Productive carbonate and carbonate-cemented sandstone reservoirs in which the water-bearing portions are tightly cemented, are common in the Mississippian McClosky lime and Aux Vases sand of the Illinois Basin. The corresponding situation for silica-cemented sandstones is amply demonstrated elsewhere by high-pressure oil and gas sands out of hydrostatic equilibrium with their environment.

Geophysical Exploration

Geophysic[redacted]s offers the best possibility for reducing the ultimate cost of exploration for deep oil by allowing choice of the most favorable sites for tests. In this region there has been no direct connection between geomagnetic bodies and oil reservoirs, but magnetometer surveys can suggest broad regions of the basement whose boundaries became the hinge belts most favorable for oil accumulation. Recent magnetic work has shown that Hicks Dome in southeastern Illinois (fig. 2) has no igneous core. This finding suggests that the Omaha Dome, a smaller oil-bearing structure twenty miles to the north, commonly compared to Hicks Dome, may likewise lack an igneous core, although both structures do contain small intrusive peridotite bodies.

Gravity work, in addition to its use in delineating regional structural trends, could point directly to Precambrian hills over which Lower Ordovician and Cambrian strata thin and are draped. Seismic work will be most helpful in indicating pre-St. Peter structure by convergence between reflecting zones within the Lower Ordovician and Cambrian and the strong reflecting surface at the top of the Ottawa.

Economic Factors

Because of the splitting of lease and royalty holdings in the shallow productive regions, it is difficult and costly to assemble the large lease blocks needed for deep exploration. A cooperative effort will be needed, particularly in the preliminary stages, to discover a new deep province beneath the present Illinois Basin province. The details will vary with the lease situation but may include cooperative agreements, assignment of deep rights, unitization of potential deep zones, and pooling of information, in addition to the normal farm out and drilling support commitments.

Drilling in the deep part of the Illinois Basin is costly. The depths, from 6,000 to about 14,000 feet, are not great by modern standards, but the rock is fairly hard from the grass roots down, and there are cherty sections in the Middle Mississippian and the Lower Devonian. However, the fact that transportation, market outlet, and oil field services are already available makes the lower half of the Illinois Basin more attractive than similar bodies of sediments in less developed regions.

TABLE 3 – SAMPLE STUDY, HUMBLE OIL REFINING CO., NO. 1 WEABER-HORN UNIT, FAYETTE COUNTY, SEC. 28, T. 8 N., R. 3 E., SAMPLE SET 36,377, DESCRIBED BY T. C. BUSCHBACH

	Thickness (feet)	Depth (feet)
Base of Silurian System		3598
ORDOVICIAN SYSTEM		
CINCINNATIAN SERIES		
MAQUOKETA GROUP (222')		
BRAINARD SHALE		
Shale, silty, slightly dolomitic, greenish gray, brittle, micaceous; few black specks in upper 40	95	3693
FORT ATKINSON LIMESTONE		
Limestone, slightly dolomitic, light gray to light brown, dark gray pyritic mottling, medium, scattered pink and red grains; little chert; some interbedded shale, silty, greenish gray	34	3727
SCALES SHALE		
Shale, silty, dark greenish gray, brownish tint, brittle	93	3820
CHAMPLAINIAN SERIES		
GALENA GROUP (110')		
DUNLEITH AND WISE LAKE FORMATIONS (110')		
Limestone, brown, very fine to medium, fossiliferous, partly calcarenitic; a few dark brown shale partings and stylolites (cored interval, 3826-3870')	20	3840
Limestone, light grayish brown, fine to coarse, fossiliferous; few thin dark brown argillaceous partings	90	3930
PLATTEVILLE GROUP (384')		
NACHUSA FORMATION		
Limestone, brown, lithographic; some thin dolomite stringers, calcitic, light brown, associated with thin dark brown shale partings	140	4070
GRAND DETOUR FORMATION		
Limestone, brownish gray to brown, lithographic; little dolomite, calcitic, light grayish brown; few dark brown argillaceous partings; little chert at 4120-4130'	110	4180
MIFFLIN FORMATION (65')		
Limestone, brown to light brown, lithographic	20	4200
Limestone, grayish brown to brown, fossil fragments; some reddish brown shale partings; few dolomite streaks, calcitic, light grayish brown	45	4245
PECATONICA FORMATION (69')		
Limestone, light brown to brown, lithographic; some fossil fragments	45	4290
Limestone, slightly dolomitic, light brown to brown, lithographic, slightly oolitic, slightly pyritic	24	4314
ANCELL GROUP (321')		
JOACHIM FORMATION (146')		
Anhydrite, light grayish brown; dolomite, light grayish brown, very fine, silty and argillaceous in part; shale, silty, green, dark brownish gray	26	4340
Limestone, light brown, lithographic; grades downward to dolomite, light grayish brown to light gray, extra fine; anhydrite; shale, dark brown, brittle; siltstone at base	65	4405
Dolomite, argillaceous, silty, brown to dark brown, very fine; shale, dark brown, brittle	10	4415
Sandstone, dolomitic, white, fine, well cemented	5	4420
Limestone, light brown to brown, lithographic; grades downward to dolomite argillaceous, silty, brown to dark brown, very fine; shale, dark brown, brittle	40	4460
ST. PETER SANDSTONE (175')		
Sandstone, white, fine to medium, friable, mostly rounded; some secondary crystallization	80	4540
Poor samples; interpreted from logs as sandstone, white, fine to medium, friable	65	4605
Shale, light blue, bentonitic	2	4607
Sandstone, white, fine to medium, friable; some white chert and bentonitic shale	28	4635
CANADIAN SERIES		
PRAIRIE DU CHIEN GROUP (887')		
SHAKOPEE DOLOMITE (583')		
Dolomite, cherty, light gray to light tan, very fine; little shale, green, brittle	100	4735
Dolomite, slightly cherty, light tan to light gray, very fine; little sandstone, dolomitic, white, fine	125	4860
Dolomite, light gray to light brown, very fine to fine, sandy in part; little sandstone, siliceous, white, fine, friable to firmly cemented	100	4960
Dolomite, slightly cherty, light gray, light grayish tan, pink, very fine, sandy in part; little sandstone, siliceous, dolomitic, fine, firm; little oolitic chert; at 5090 to 5130-few thin shale partings, light brown, green	180	5140
Dolomite, cherty, light tan to tan, light yellowish brown, very fine to fine, slightly sandy in part; some oolitic chert; little sandstone, siliceous, white, fine to medium	78	5218
NEW RICHMOND FORMATION		
Dolomite, very cherty, sandy, light yellowish gray, fine; sandstone, siliceous, white, fine to medium	10	5228
ONEOTA DOLOMITE (287')		
Dolomite, slightly cherty, light gray, to light tan, fine to medium, some coarse; little green clay	62	5290
Dolomite, very light gray, medium, some coarse, crystalline	30	5320
Dolomite, very cherty (chert is white, chalky), light brownish gray, fine	10	5330
Dolomite, cherty, light gray to light yellowish gray, fine to medium, sandy in upper 10'; some geodic quartz; little green clay	185	5515
GUNTER SANDSTONE		
Dolomite, cherty, light gray, fine; shale, silty, dark brown. Samples contain wide variety of rocks; geophysical logs indicate sandiness at this interval	7	5522
CAMBRIAN SYSTEM		
CROIXAN SERIES		
EMINENCE DOLOMITE (196')		
Dolomite, cherty, light gray to light brown, fine to medium, slightly sandy in part; little drusy quartz	78	5600
Dolomite, cherty, light gray to light yellowish brown, medium; little drusy quartz and oolitic chert; sandy streaks in upper 20'	45	5645
Dolomite, light gray, fine to medium; trace of pyrite and glauconite	10	5655
Dolomite, slightly cherty, light yellowish brown, light gray, medium; some sandstone and oolitic chert	63	5718
POTOSI DOLOMITE (332')		
Dolomite, light gray, fine to medium, slightly glauconitic, partly coated with tan clay	67	5785
Dolomite, light gray, light grayish brown, fine to medium; drusy quartz; some drusy dolomite in lower 20'	55	5840
Dolomite, light brown, fine, (dark brown spherules in light brown matrix); some drusy quartz	5	5845
Dolomite, light gray to light brown, fine to medium, weak pellet structure; drusy quartz	20	5865

TABLE 3 – Continued

	Thickness (feet)	Depth (feet)
Dolomite, brown, fine, some medium, crystalline; drusy quartz	50	5915
Dolomite, light gray to brown, fine to medium; some chalky white silica (chert) replacement around scattered dolomite crystals; considerable drusy quartz	10	5925
Dolomite, brown to light brownish gray, fine to medium, slightly glauconitic; little chert replacement; little drusy quartz	125	6050
FRANCONIA FORMATION (265')		
Dolomite, light gray to light brown, fine, slightly glauconitic; dolomite, sandy, gray, light green, fine, glauconitic, slightly pyritic	20	6070
Dolomite, slightly argillaceous, light gray to brown, fine, sandy in part, slightly glauconitic and pyritic; some light-colored dolomite crystals in brown dolomite matrix	15	6085
Dolomite, light gray to brown, fine, some medium, slightly glauconitic and pyritic, argillaceous at base; few dark brown argillaceous partings at top	80	6165
Dolomite, argillaceous, brown, fine, slightly glauconitic, sandy in part; sandstone, dolomitic, light brownish gray, very fine, glauconitic	30	6195
Dolomite, brown, fine; some faint oolites; some dolomite, very sandy, brownish gray, glauconitic	15	6210
Sandstone, dolomitic, light gray, very fine, glauconitic; dolomite, slightly sandy, light brown, fine, slightly glauconitic; shale, silty, greenish gray, brittle, micaceous	55	6265
Dolomite, silty, sandy, argillaceous, brownish gray to dark brown, fine; some shale in lower 20'	35	6300
Dolomite, very silty, argillaceous, grayish brown to brown, very fine; shale, silty, green, brown, brittle; few pieces of sandstone, dolomitic, light brownish gray, medium	15	6315
EAU CLAIRE FORMATION (580')		
Limestone, sandy (sand is very fine), dolomitic, light brownish gray, extra-fine, slightly glauconitic, fossiliferous in part; little siltstone, calcareous, light gray, slightly glauconitic	15	6330
Dolomite, brown, fine; consists of numerous brown dolomite spherules in sparse light gray dolomite matrix	30	6360
Dolomite, calcitic, light brown, fine; consists of brown spherules as above, but slightly lighter color, and contains more light gray matrix of calcitic dolomite; calcite content increases downward	100	6460
Limestone, dolomitic, light yellowish brown to brown, very fine, fossiliferous in part, some vague spherules as above, but larger; lower 50' contains green shale and light gray to light brown dolomite – which may be caving	102	6562
Siltstone, finely sandy, dolomitic, grayish orange, coarse, micaceous, glauconitic	33	6595
Shale, silty, red, green, brittle, micaceous; dolomite, grayish brown, fine, sandy in part, slightly glauconitic, slightly calcitic; some brown spherules	50	6645
Dolomite slightly calcitic at top, light brown to light gray, fine, slightly glauconitic; faint brown spherules	75	6720
Siltstone, sandy, grayish orange, coarse, glauconitic; shale, silty, red, green	38	6758
Sandstone, silty, dolomitic, white to light greenish gray, fine, glauconitic; small, brown fossil fragments; shale, silty, red, green	17	6775
Sandstone, silty, slightly dolomitic, light orange, very fine, glauconitic; grades to siltstone at base; few brown fossil fragments; some interbedded shale, silty, red, green; little dolomite, sandy, hematitic, very glauconitic	65	6840
Dolomite, silty, light gray, red, medium, fossiliferous, very glauconitic (coarse); shale, silty, red, green, brittle, micaceous	10	6850
Siltstone, argillaceous, siliceous, slightly dolomitic, light gray, brownish gray, coarse, micaceous, glauconitic; shale, silty, gray	45	6895
MT. SIMON SANDSTONE (1,319')		
Sandstone, siliceous, white to pink, fine to coarse (poor samples)	20	6915
Sandstone, siliceous, pink, coarse, poorly sorted, hematitic in part; coarse grains are subrounded, some evidence of secondary crystal growth; shale, red, green, micaceous	40	6955
Siltstone, sandy, siliceous, pink, hematitic; sandstone, white to pink, coarse; shale, red, green	15	6970
No samples	10	6980
Sandstone, white to pale pink, coarse, poorly sorted, partly cemented by quartz; some fine quartz pebbles; little pink siltstone and red shale at 7010	75	7055
Sandstone, white, coarse to very coarse, subangular; fine quartz pebbles; some sandstone, siliceous, pale pink, very fine to fine	205	7260
Sandstone, white, coarse, subangular; little pyritic speckling; fine quartz pebbles; little pale orange feldspar in lower half; at base, shale, green, reddish brown, brittle	505	7765
Sandstone, white, coarse, subangular; feldspar, pale orange to light orange (10-15% of sample, increases downward); some sandstone, pale orange, feldspathic, fine to medium; fine quartz pebbles	170	7935
Sandstone, light orange, coarse, poorly sorted, subangular; feldspar (15-20%); at top—few pieces of sandstone, fine and coarse, composed of quartz, feldspar, and unknown green mineral	85	8020
Sandstone, reddish orange, coarse, poorly sorted, subangular; feldspar (20-25%), orange; few fragments of green mineral as above	58	8078
Sandstone, reddish orange, medium to coarse, poorly sorted (more fine sand than above); feldspar, as above; a little shale, red, green, micaceous, brittle	97	8175
Sandstone, reddish orange, coarse, poorly sorted, subangular; feldspar, orange, some weathered dark red; sandstone, arkosic, pink to red, fine	30	8205
Conglomerate, very arkosic, coarse, angular (broken grains), few grains hematitic	9	8214
PRECAMBRIAN (399' sampled)		
Rhyolite porphyry, dark red matrix, light gray and light greenish gray phenocrysts; few bright red feldspar phenocrysts, weathered	71	8285
Rhyolite porphyry, red matrix, light gray phenocrysts; little clear quartz; less weathered than above	30	8315
Rhyolite porphyry, red matrix, light red feldspar phenocrysts; scattered black mineral; some clear quartz	298	8613
No samples	2	8615

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