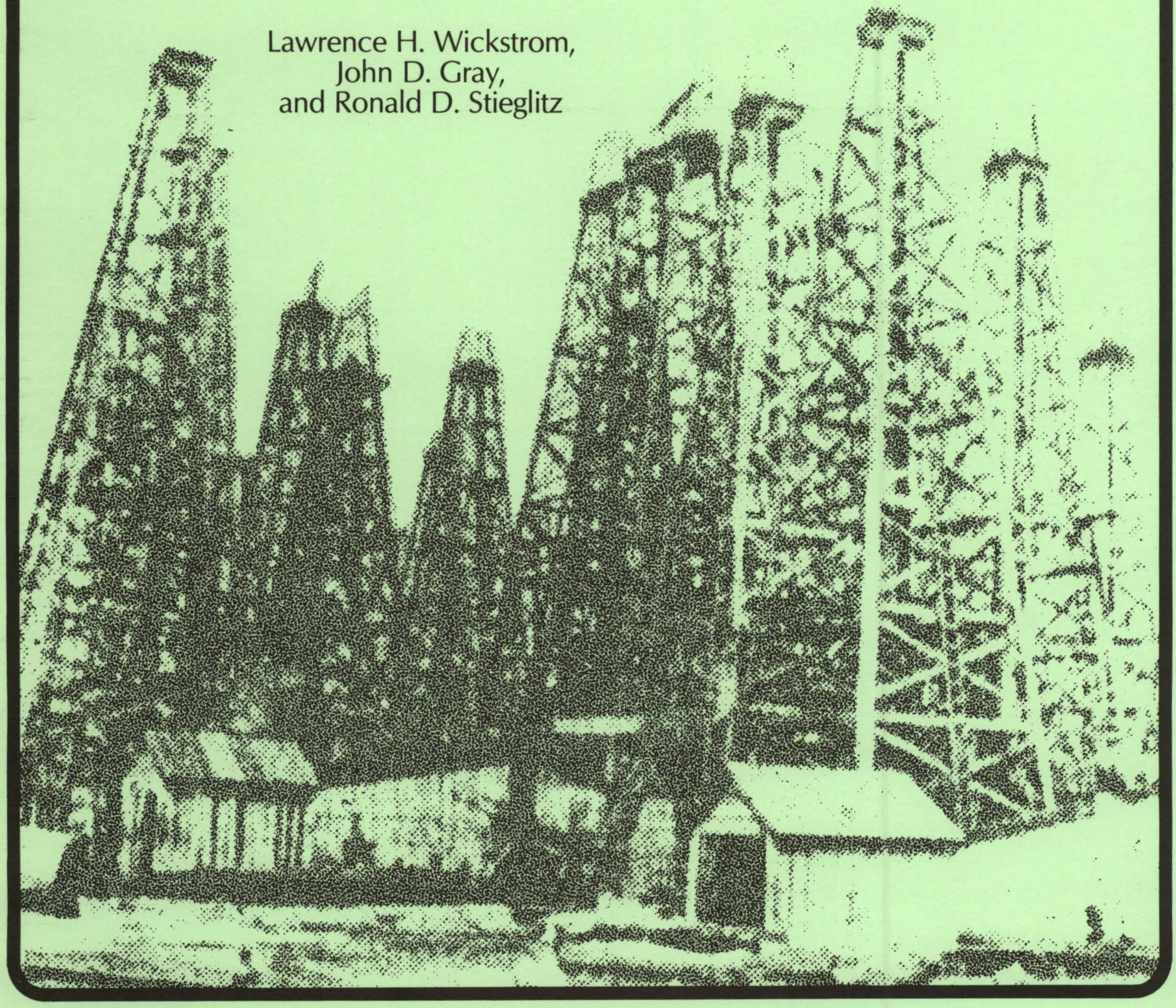
Report of Investigations No. 143

STRATIGRAPHY, STRUCTURE, AND PRODUCTION HISTORY OF THE TRENTON LIMESTONE (ORDOVICIAN) AND ADJACENT STRATA IN NORTHWESTERN OHIO

by

Lawrence H. Wickstrom,
John D. Gray,
and Ronald D. Stieglitz



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REPORT OF INVESTIGATIONS NO. 143 ON THE TRENTON LIMESTONE

Although a 1985 film script by Dr. Joseph J. Arpad is credited as a major source of the information for the discussion of the historical development of the Lima-Indiana trend on pages 35-40 of Ohio Division of Geological Survey Report of Investigations No. 143, *Stratigraphy, structure, and production history of the Trenton Limestone (Ordovician) and adjacent strata in northwestern Ohio*, the material taken directly from Dr. Arpad's script was not properly or fully acknowledged. The Survey expresses its deep regrets and apologies to Dr. Arpad for the omission.

The text of the historical discussion beginning with the first full paragraph in column 2 of page 37 to the end of the section on page 40 is reproduced here, and direct quotations from Arpad are noted by italics.

More than any other individual, Dr. Charles Oesterlin was responsible for the opening of the gas field in northwestern Ohio. Dr. Oesterlin was a *German-educated physician who had come to Findlay in the 1830's.* Aside from medicine he was an amateur scientist primarily concerned with geology. He *decided he would make a study of these gas seepages, mostly for purely scientific reasons. He studied scholarly books on geology and took field trips in and around Findlay and Hancock County to study rock formations* in local quarries. *In the 1870's, while serving as Findlay's representative in the Ohio General Assembly, he studied geology at Ohio State University and discussed the seepages with his professors, including Dr. Edward* [given as *Edwin* in Arpad] *Orton, the State Geologist.* Dr. Orton had studied the fields in Pennsylvania and eastern Ohio and was of the strong opinion that no gas or oil could exist in the Trenton Limestone of northwestern Ohio.

Despite Orton's pronouncement . . . , Oesterlin came away convinced that there must be an immense volume of gas trapped below the upper strata of limestone to cause gas to seep through the cracks in the porous rock. Until 1884, however, he couldn't find anyone to back his idea of drilling to the Trenton Limestone to tap his theoretical gas reservoir. In that year *the Findlay Natural Gas Company was formed by selling stock to local citizens.* Their first drilling venture was on Dr. Oesterlin's farm east of Findlay. They found a strong gas seep at only 7 feet in May 1884, so they stopped and hired a professional driller from Bradford, Pennsylvania, to drill the well. The drilling finally commenced in September 1884. The drillers were prepared to go 2,000 feet if necessary to find the gas source. *By November 1, they had already found gas on three levels . . .* at 314 feet, 516 feet, and 618 feet. At this third level *the gas was strong enough to shoot a flame 6 feet high when ignited out of the 7-inch casing.* When this occurred the stock in the Findlay Natural Gas Company soared, and crowds gathered daily to watch the progress. The top of the Trenton was penetrated at 1,092 feet on November 16. More than 3,000 people had gathered to watch; *to satisfy the crowd* the drillers *ran a pipe to the top of the derrick and lit it. The flambeau could be seen five miles away that night, fueling more excitement.* The company's *stock prices exploded, as speculation became rampant.* On December 5, 1884, the well had reached 1,648 feet and began to encounter salt water. Drilling stopped and the well was shot with 30 quarts of nitroglycerine. *The resulting blast of gas, when ignited, could be seen . . . 15 miles away . . . .* This first gas well produced about 250,000 cubic feet per day and set off a drilling spree all over northwestern Ohio.

The Findlay Natural Gas Company and other gas companies continued to drill wells, even though there was no market for the gas or infrastructure to transport it. Throughout 1885 eight more wells were drilled around Findlay, *each more spectacular than the last.* Estimated production was as much as 4 million cubic feet of gas. The most spectacular of the gas wells was the 13th, drilled in early 1886. This well was located on the bank of the Blanchard River, which flows through Findlay, on the lot of the Karg Slaughter House. *On January 20, 1886, the city was awakened with a frightening roar as the monstrous Karg well came in* at 1,146 feet, blowing 20 to 50 million cubic feet of gas per day. The gas escaped with such a ferocious roar that the drillers were afraid to light it.

The gas saturated the city for five days before the well *could be brought under control. During that time, not a fire was lit in Findlay. A 10-foot-high standpipe was erected 200 feet away and hooked into the well.* When lit, *the flame shot more than 100 feet in the air and . . . was plainly visible 25 miles away in Bowling Green.* The great flambeau burned for four months before the well could be brought under control. During this time it became a major tourist attraction and was reported in all the national newspapers. It proclaimed to the world the arrival of a great new field and marked the beginning of a period of rapid development.

Responding to this amazing abundance of gas, the civic leaders of Findlay decided to boom the town . . . . They hired C. C. Howells, a professional publicity person, who had just successfully boomed Wichita, Kansas, as a cattle town. Howells *set out to create all the hoopla of a wild west show—then America's number one kind of entertainment.*

First, he had advertisements run all over the country that Findlay was offering free gas to manufacturers who would locate here. Next, he had 19 arches built across downtown Main Street, each festooned with blazing gas jets in multicolored glass globes (fig. 30). Each arch had a banner bragging about the city's virtues: "Findlay—the center of the world," "Women split no wood in Findlay," etc. Then Howells *had three of the largest gas wells piped to the north end, the south end, and the center of town.* They were *fitted to 60-foot-high standpipes and burned continuously to show off how abundant the gas was and to make sure the city would never see night. To entertain prospective industrialists and investors, he had a huge convention hall built on the banks of the Blanchard, facing the Karg well.* He named the hall "The Wigwam." Finally, *to bring all of this to a climax, he put on a three-day celebration* (June 8-9-10, 1887), *complete with marching bands, drill teams, equestrian troops, military outfits, politicians, sports teams, singers, dancers, lecturers—all peppered with 100-gun salutes and similar fanfare. More than 30,000 people, from all over the United States, attended the event.*

The end results of Howells' hoopla were 50 new industries locating in Findlay, including many glass factories; a quadrupling of the population of the town, creating an attendant real estate and housing boom; and a massive infusion of outside capital into the town.

All of this splendor helped the people in Findlay overlook the negative aspects of the boom—the millions of feet [cubic feet] *of gas wasted daily just to promote the boom. The numerous sets of gas lines running in the streets, mostly above ground, leaking and buckling, causing a stench and a danger of explosion.* Once a well was turned into the town lines it was permitted to flow continuously—no one bothered to turn off the gas—so stoves, lights, etc., continued to burn indefinitely. *Then there were the saloons, the fighting and the thieving, the houses of prostitution* that accompanied any sort of boom.

Findlay absorbed all of this and became an industrial town. Almost all of the small towns in northwestern Ohio that were in the newly discovered gas field tried to mimic Findlay's boom, but none were quite as successful.

Some people were appalled at the tremendous waste of natural gas, but no one could control the boom. In 1888, the Bowling Green newspaper quoted Edward Orton, who predicted the gas in northwestern Ohio would not last another 10 years. The news was met with delight because nearly everything the state geologist had said about the Trenton had turned out vice versa. However, for once he was right—*within only three years, the glass factories in Bowling Green and North Baltimore had closed down for lack of fuel.* By 1891 northwestern Ohio's gas boom was over, just seven years after the first large discovery.

The oil boom in northwestern Ohio began in early 1885, a year after the gas boom, but it lasted much longer. *It began when Benjamin Faurot* [given as *Farout* in Arpad], *a Lima businessman, took one of those railroad excursions to Findlay to see the sights.* Being a civic leader, he did not want *a rival town to get the better of Lima; he came home and announced, "If Findlay can get gas, so can we."* He put together a group of investors and hired a Pennsylvania driller to drill for gas on his property. The gas would be used to manufacture strawboard, which had recently revolutionized the packaging and shipping industry. On May 9, 1885, the drillers reached the Trenton but there was no gas, only a show of oil. Discouraged, Faurot decided to shoot the well with explosives before abandoning it. To his astonishment and that of the spectators, the well flowed 200 barrels of oil per day briefly before settling down to about 25 barrels per day.

This was the first oil well in northwestern Ohio and marked the opening of the Lima field. The gas excitement in Findlay was now matched by growing oil excitement in Lima as derricks sprang up all over the city. The Citizens Gas Company, another local prospecting company, completed the second well at Lima in December 1885, and it produced oil in greater quantities than Faurot's, about 40 barrels of oil per day.

Meanwhile, Faurot gave up the strawboard paper business, and with fellow investors, started the Trenton Rock Oil Company to prospect for oil—not gas—and the oil boom was on. By 1886, the company had drilled 250 wells, from Lima southwest through St. Marys and into Indiana, producing a plentiful supply of crude.

The discoveries in Lima initially did not cause a great stir in Pennsylvania because the Lima crude had a high sulfur content. *When refined, the crude produced a yellowish kerosene,* which, when burned, *smelled like rotten eggs, gave off less light, and left a sulfurous crust on the wick.* One year's operation of the Lima field convinced the oil world that northwestern Ohio contained a great quantity of oil, but its poor quality made it virtually worthless. Because of the poor quality, development of the field was left to locals, who had insufficient capital to provide transportation and storage facilities. The oil was used initially to generate steam for surrounding communities.

By this time, the Standard Oil Company, under John D. Rockefeller, operating initially out of Cleveland, Ohio, had monopolized the refining and transportation of crude oil from the Pennsylvania fields. The Lima-Indiana trend, however, caused a big problem for the Standard Oil Company. *The Lima crude . . . couldn't be refined into an illuminating oil that met the standard it had set for its kerosene. At the same time, it couldn't afford not to buy the Lima crude, for fear of losing its monopoly in the refining business. On John D. Rockefeller's advice, Standard's board of directors decided to buy the crude and store it until the company could find a way to refine it into an acceptable product.* The National Transit Company, which was Standard Oil Company's distribution subsidiary, surveyed the scene in northwestern Ohio and quickly formed the Buckeye Pipeline Company to buy up the production.

On May 11, 1886, one year after Faurot's discovery well, the Buckeye Pipeline Company entered the Lima area with tank cars and started to buy oil at 40 cents a barrel at the well. They also began erecting storage tanks (which had been disassembled in Pennsylvania), and on June 2, 1886, the first oil was run into the tanks.

Then, in late 1886 and early 1887, great oil "gushers" started coming on in southern Wood and northern Hancock Counties. The Fulton well, drilled near North Baltimore, between Bowling Green and Findlay, in December 1886, was the first, but was to be only the smallest tip of the iceberg. The well was initially drilled to a depth of 1,194 feet searching for gas. The owners decided to drill another 200 feet and at nearly 1,400 feet they hit a boomer which came on at 500 barrels a day. Two months later the Henning well flowed 2,000 barrels a day. Then, five months later, in the spring of 1887, the Slaughterhouse-Beds well, drilled near Cygnet, came on at 5,000 barrels a day. In September 1887, the Ducat, the Potter, and the Foltz wells *came in, all gushing more than 10,000 barrels a day each.* For the next two years, enormous gushers came on regularly—some supposedly produced as much as 50,000 barrels per day—and startled the oil industry with each new discovery.

When these gushers came in . . . there was usually no way to collect that much oil . . . . It didn't make any sense to provide storage or pipelines in advance, because a well could always be a dry hole . . . . So gushers were allowed to run free until storage facilities were built or until they could be capped off. When that happened, the fields would be knee deep in oil, which *would run off into the ditches and rivers. At best, the flowing well would be directed into an open earthen pit or into a hastily made lake.*

In response to the deluge, Standard reduced its price to 15 cents a barrel. But still the excitement mounted, for even at 15 cents a barrel, these wells could bring in $1,500 a day. It only cost $1,200 to drill the well.

The producers around Lima couldn't compete on 15-cent oil. *Their wells tended to produce only 50 to 100 barrels a day—$15 worth, at best.* Thus, 14 independent Lima-area oil producers *formed a combine, the Ohio Oil Company,* the predecessor of the modern Marathon Oil Company, *trading their wells and leases for stock in the company, and took their production off the market until Standard would pay at least 40 cents a barrel for their crude.*

Meanwhile, Standard took even more aggressive steps to deal with the excitement. First, it built a refinery at Lima, the Solar Refining Company, to permit its chief refining specialist, J. W. Van Dyke, and the recently hired Canadian scientist Herman Frasch to work out the sulfur problem. Then Standard *redoubled its storage and pipeline efforts, creating the Cygnet Pipeline Company and the Connecting Pipeline Company to handle the gushing Wood County crude.* Next, the Manhattan Oil Company was created near Gallatea (north of Findlay) to market an inferior grade of kerosene. Ownership of the refinery was hidden so it couldn't be traced back to Standard. *Finally, John D. Rockefeller proposed that Standard do what he had always said it should never do—go into the production end of the industry . . . to stabilize the situation.*

The plan was to buy up all of the leases and producing wells and then take the field out of production. They tried to do it secretly, but *word quickly got out that Standard was buying up everything in sight . . . . In 1889 Standard bought the Ohio Oil Company, its only real competitor* in the area, and so owned 75 percent of the Lima-Indiana trend.

Standard was ready to shut down the field when two things happened. First, *Frasch and Van Dyke perfected the sweetening stills necessary to refine* the sulfur out of the crude, so *there was no need now to shut down the field.* Second, and more importantly, *in 1889 the Pennsylvania Supreme Court ruled that the old common law of mineral rights was not applicable in the case of gas and oil rights. Instead, the common law of hunting rights applied.* The court invoked *"the law of capture," the common law principle that migratory wildlife belongs to the person who can capture the game on his or her property.*

This meant that you did not own the oil or gas that was beneath your property until you brought it to the surface and captured it. If your neighbor could drill a hole and capture it on his property, it was his. Suddenly, the situation had changed. If Standard *tried to control production by shutting down its 75 percent of the field, the independent producers, who owned the other 25 percent, could legally pump the field dry. Thus, just to maintain its 75 percent control,* Standard drilled, pumped, and sold the Lima-Indiana crude as fast as it could to get rid of the production.

The end result was an appalling waste of a major natural resource. *No one bothered with geology. Instead, everyone practiced "close-ology," which meant getting a well down as close as you could to a known producing well then trying to pump the oil out faster than the neighboring well. Thus, when you obtained a lease, you used the first wells that you drilled to offset any existing wells on adjacent leases . . . and then continue drilling on your perimeter to protect your supply.* In the better producing areas the derricks were stacked almost on top of one another (see cover photo).

In this atmosphere of dog-eat-dog competition the Lima-Indiana trend quickly reached its peak production of 20 million barrels per year (see fig. 29). Ohio was the leading oil-producing state in the nation from 1895 to 1903. By 1910, however, the fields were largely depleted.

The excitement in the Lima-Indiana trend died down abruptly in 1901 when news of the Spindletop well of Texas reached Ohio. *That phenomenal gusher near Beaumont, Texas, came in roaring 100,000 barrels a day,* and the focus of the oil industry shifted permanently to new fields in the midcontinent and the southwest. The new gusher glutted an already oversaturated market and the price of oil dropped to 3 cents a barrel; the barrel was worth more than the oil it contained. *The wells in Ohio could no longer pay their way, and the oil companies shut down and abandoned all but the heavy producers.* The Standard Oil Company produced the Lima-Indiana trend until 1911, when the government broke the Standard trusts into 32 separate companies. After 20 years the Ohio Oil Company was again an independent producing company, and it continued operating wells in the field until 1937. Since that time there has been little activity by the major oil companies in northwestern Ohio.

The Lima-Indiana trend produced prolifically for only about 20 years, but its development came at an important time. It bridged the period between the decrease in production from the Pennsylvania fields and the development of the midcontinent and southwestern fields. It also came at a time when new inventions such as the internal combustion engine were increasing the need for fuels and lubricants. Thus, the Lima-Indiana trend provided the nation with an ample supply of cheap petroleum products at a time when shortages could have greatly slowed technological development.

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Cover photo: Mass of oil derricks at the North Baltimore oil field (Wood County) during peak of drilling boom, *circa* 1890.

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PLATE

1. Stratigraphic and structural cross sections of northwestern Ohio ... accompanying report

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ABSTRACT

The Ordovician strata of northwestern Ohio are composed of a thick, transgressive sequence of mixed carbonate and clastic rocks which are bounded above and below by unconformities. The Middle Ordovician Trenton Limestone was the principal reservoir rock of the once-prolific Lima-Indiana oil and gas trend.

Recent study of the Trenton Limestone and its bounding units has led to a new understanding of the geology of this formation. The Trenton of northwestern Ohio was deposited in three primary marine environments: open shelf, platform margin, and platform. Three types of secondary dolomite may be present in the unit: cap, fracture, and facies dolomite. Presently available evidence indicates that a combination of shale-dewatering and ascending-fluid-migration models best explains these dolomite types.

The Point Pleasant Formation is thought to be an interplatform basin-fill unit that is stratigraphically equivalent to the thick platform deposits of the Trenton. Geochemical analyses of the Point Pleasant show it to have good potential to have been the primary source rock for the Trenton hydrocarbon reservoirs.

Structural and isopach mapping of the Ordovician has led to a new interpretation of the tectonics of this area. An extensive wrench-fault system is postulated for northwestern Ohio and is thought to be a response to tectonic forces related to the Taconic Orogeny. The maps and cross sections of this study also help explain the combined trapping mechanisms for the hydrocarbon occurrences within the Trenton.

The Trenton Limestone has been the traditional target of oil and gas operators in northwestern Ohio since the 1880's. From 1884 through the early 1900's the Trenton produced in excess of 380 million barrels of oil and approximately 1 trillion cubic feet of gas from the Ohio portion of the Lima-Indiana trend. The oil and gas boom of the 1880's and 1890's was an era charged with a colorful history. Sufficient reservoir volumes and pressures no longer exist within the old Lima-Indiana fields because of unchecked production methods and plugging practices of the early drillers. However, modern operators continue to discover new Trenton plays outside the old productive trend.

INTRODUCTION

The area of this report (fig. 1) includes the Ohio portion of the Lima-Indiana oil and gas trend (fig. 2), which was extensively drilled in the late 1800's and early 1900's. The Trenton Limestone was the principal reservoir rock of this trend, which was the largest producing oil and gas field in the world during the late 1800's and still carries the distinction of having been Ohio's only giant field. Since the 1930's, exploration activity targeting the Trenton in northwestern Ohio has been low or sporadic at best. In recent years, however, several significant hydrocarbon discoveries in Ohio and southern Michigan have sparked renewed interest in this area. Our investigation was undertaken to gain a modern, thorough understanding of the overall geology of the Trenton Limestone.

In our attempt to gain a comprehensive understanding of the structures and sedimentation patterns we were mapping in the Trenton, it quickly became apparent that a much larger portion of the geologic record must be studied than just this one formation in a small portion of northwestern Ohio. Therefore, the entire Ordovician System was studied for a 31-county area of northwestern Ohio (fig. 1). Moreover, the tectonics and sedimentation of this system in the northeastern United States and Canada were considered to gain further insight into our own corner of northwestern Ohio.

This report is the result of an investigation begun in the mid-1970's by R. D. Steiglitz during his employment at the Ohio Division of Geological Survey. L. H. Wickstrom and J. D. Gray initially began this study as a simple update to publish Dr. Stieglitz's manuscript. However, the wealth of new information available and the amount of perceived public interest in this subject warranted an expansion of the study area, remapping of the units, and an independent investigation of the geology, of which this report is the result.

METHODS

More than 750 geophysical-log suites and 100 sample suites in combination with drillers' records from wells in the study area were examined. Wells and formation tops used in this investigation are listed in the Appendix. It must be pointed out that the Trenton Limestone and its upper and lower contacts were the principal objects of the sample examinations; the entire Ordovician was not examined or described in most of the sample suites. As a basis for the determination of facies in the Trenton, eight cores were examined. To establish consistency in the correlations, a network of cross sections was constructed (pl. 1). The isopach and structure contour maps in this report were originally drawn at a scale of 1:250,000. Most of the areas displaying structural irregularities also were mapped at larger scales of 1:62,500 or 1:24,000.

Proprietary seismic sections and engineering and geologic reports were sought out and taken into account wherever possible. As part of preparation for this report, Wickstrom and Gray assisted the Standard Oil Production Company in a study of oil-source rock correlations in Ohio (see Cole and others, 1987). Sample and core descriptions and methods follow closely those outlined by Swanson (1981). Carbonate classifications follow Dunham (1962). Facies analysis and models follow Miall (1984) and Wilson (1975).

FIGURE 1.—Study area.

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PREVIOUS WORK

In spite of the tremendous amounts of hydrocarbons they produced, there have been few modern, published reports concerning the Ordovician strata, and the Trenton Limestone in particular, in northwestern Ohio. Orton (1888, 1889) observed the development of the Lima-Indiana trend, reported the depths to the producing intervals, and gave some first-hand production figures. He was the first to note the Bowling Green Fault Zone, which he termed the "Findlay Break," and to associate it with increased production. Orton also presented chemical analyses of the rock and noted the relationships of productive areas to high amounts of magnesium carbonate and depth.

Bownocker (1903) reviewed and expanded upon Orton's work. He appears to have been the first to state clearly (p. 64) that oil and gas traps within the Trenton Limestone might be the result of textural change within the rock as well as structure.

Carman and Stout (1934, p. 522) mapped the structure of the Trenton Limestone (Trenton Formation) and pointed out that a magnesium carbonate content of at least 20 percent is required for production. They, as did Orton, suggested that porosity in the producing rock was the result of dolomitization, an idea made popular by Landes in 1946.

In 1948 Cohee published a study of the Cambrian and Ordovician rocks in the Michigan Basin, and Fettke published a study on the Trenton and sub-Trenton rocks in the Appalachian Basin. Shearrow (1957) published a cross section with sample and insoluble residue descriptions of Paleozoic rocks across Ohio. Woodward (1961) was concerned primarily with the southeastern part of the state, but he did present isopach maps and cross sections that extend into northwestern Ohio. Although each of these studies is of great value, their emphasis was on a larger, regional scale and could not treat the intricacies of the Trenton in northwestern Ohio.

Calvert (1962, 1963a, 1963b, 1964) subdivided the Trenton and sub-Trenton rocks of Ohio primarily on the basis of log characteristics and used southern Appalachian Basin nomenclature.

Ver Wiebe (1929) suggested that an unconformity exists at the top of the Trenton in the Lima-Indiana trend. Rooney (1966) presented various points as evidence for such an unconformity, many of which Keith (1985) disputes.

Janssens and Stieglitz (1974) discussed the history of the Findlay Arch and the relationships of the lower and middle Paleozoic strata to this structure. Stieglitz (1975) commented upon the occurrence of sparry white dolomite

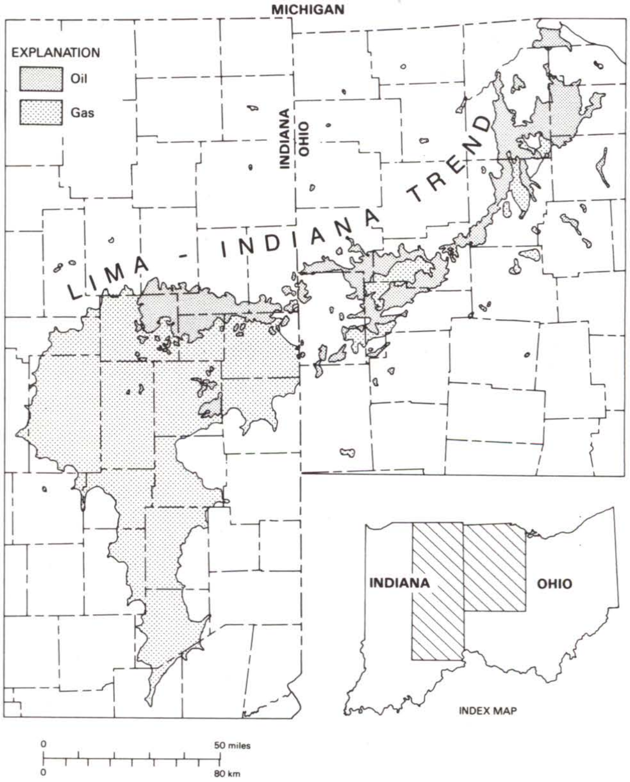


FIGURE 2.—Location and extent of the main body of the Lima-Indiana oil and gas trend in Ohio and Indiana. Figure courtesy of the Indiana Geological Survey.

within the Trenton and its association with structure and production. Coogan and Parker (1984) published a series of maps for northwestern Ohio and presented six possible hydrocarbon trapping mechanisms for the area.

REGIONAL SETTING

Northwestern Ohio is situated within the cratonic interior of North America between three structural and depositional basins. A generalized structure contour map (fig. 3) drawn on the top of the Trenton Limestone illustrates the overall regional geologic setting. The western flank of the Appalachian Basin covers approximately the eastern third of the study area. A small, arcuate portion of the southern flank of the Michigan Basin extends into northwestern Ohio, from approximately Lucas County to southern Paulding County. The Illinois Basin lies to the southwest.

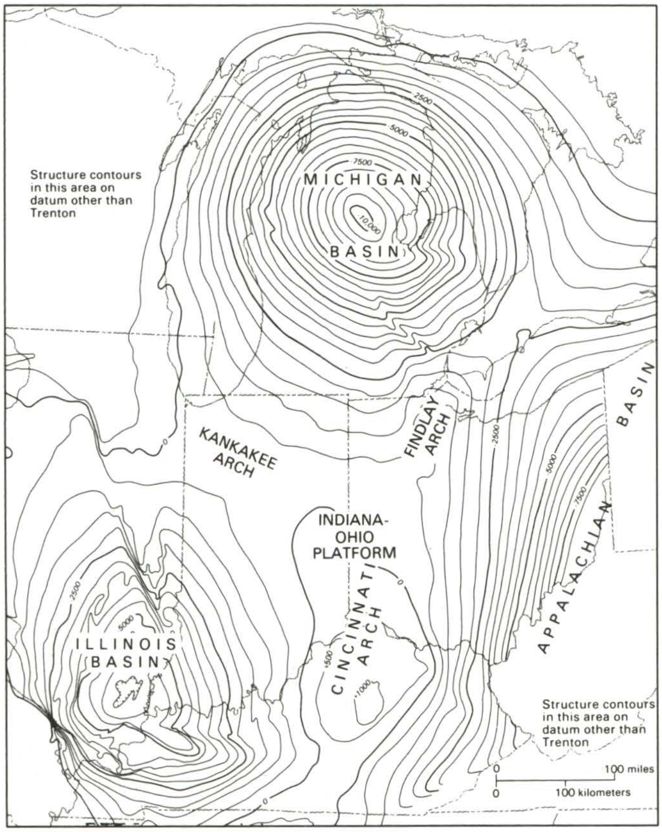


FIGURE 3.—Generalized, regional structure contour map drawn on top of the Trenton Limestone (modified from Cohee, 1962). Contour interval 500 feet.

These basins are separated by a series of arches, the Cincinnati, Findlay, and Kankakee. Throughout the subsidence of the surrounding basins, these arches have remained relatively stable, or subsided at a slower rate. Therefore, the structural relief of the arches is thought to be more the result of differential subsidence than of actual uplift. However, it should be pointed out that the majority of the subsidence of these basins occurred in the Silurian and later (Droste and Shaver, 1983). Therefore, deposition of the Ordovician strata discussed in this report was, more or less, continuous across the region. The Sebree Trough, a more localized, sediment-filled depression in western-central Ohio, is discussed in detail later.

PRECAMBRIAN GEOLOGY OF NORTHWESTERN OHIO

On both regional and local scales, we propose that many structural features of the Paleozoic sedimentary strata have their origin in, or are a result of, Precambrian influences. Additionally, many stratigraphic changes such as pinchouts and facies changes appear to be the result of these deep-seated features. The relationship between Precambrian and Paleozoic features appears to be common in northwestern Ohio. Therefore, a brief synopsis of the Precambrian geology of this area is presented here and will be referred to in later sections of the text.

McCormick (1961) reported on the petrography of selected Precambrian cuttings from 24 wells in Ohio. Janssens (1973) described samples from an additional 56 wells which reached the Precambrian. For detailed lithologic descriptions the reader is referred to these

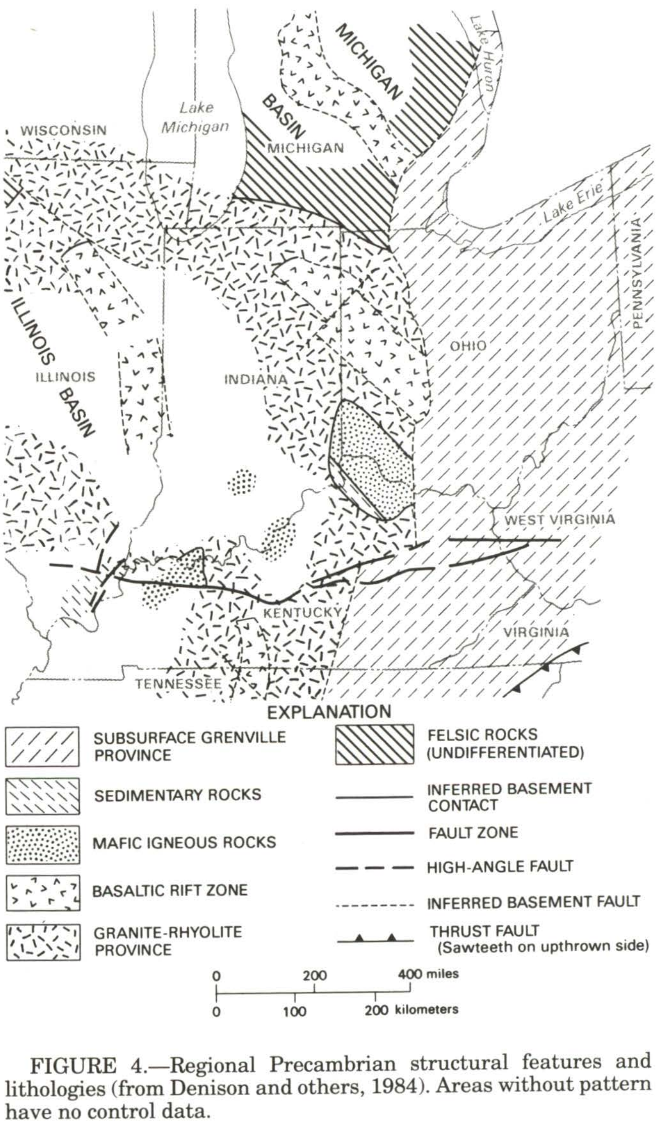


FIGURE 4.—Regional Precambrian structural features and lithologies (from Denison and others, 1984). Areas without pattern have no control data.

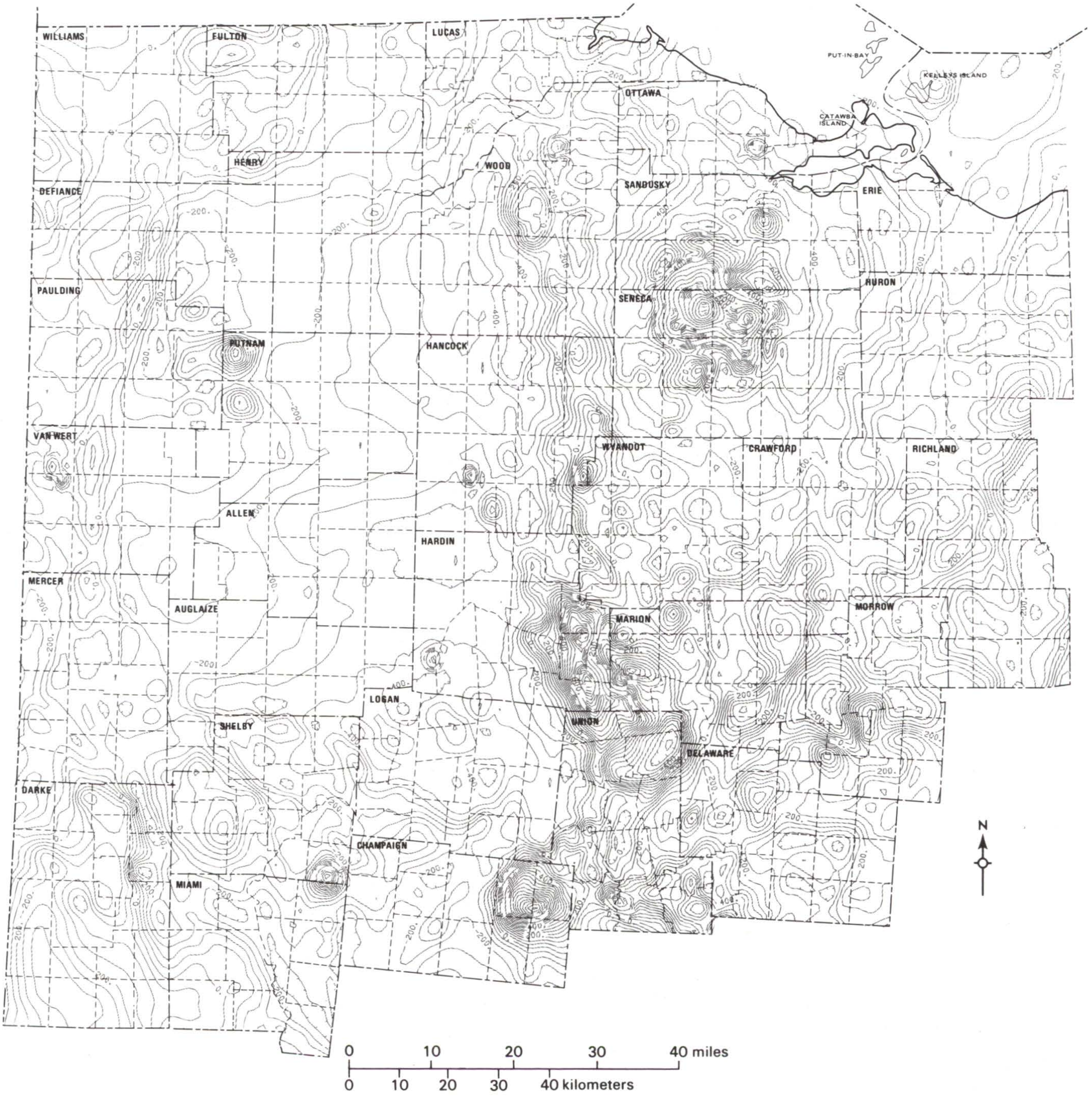


FIGURE 5.—Residual total intensity magnetic map of northwestern Ohio (from Hildenbrand and Kucks, 1984a). Contour interval 50 gammas.

publications.

On the basis of age determinations and lithologic contrasts, McCormick (1961) and Janssens (1973), as well as Bass (1960) and Lidiak and others (1966), all conclude that two major Precambrian provinces exist in Ohio. In northwestern Ohio the boundary between these two provinces trends slightly west of north-south from central Lucas County to western Union County. East of this boundary the Precambrian is composed mainly of amphibolite-grade metamorphic rocks; to the west the Precambrian is a dominantly granite-rhyolite terrain (Lidiak and others, 1966). This boundary represents the subsurface extension of the Grenville Front, which is exposed to the northeast on the Canadian Shield. In Ohio, the Grenville Front separates deformed metamorphic rocks of the Grenville Province to the east from the largely undeformed, anorogenic granite-rhyolite rocks of the Central or Granite-Rhyolite Province to the west (Denison and others, 1984) (fig. 4). The position of the front is well expressed on the residual aeromagnetic map of the state (Hildenbrand and Kucks, 1984a), extending in a sinuous manner from Brown County along the Ohio River to Lucas County on the north. Figure 5 reproduces the northwestern portion of this map.

Directly east of the Grenville Front, the magnetic signature is marked by a 10- to 40-mile-wide zone of tight, circular, high-amplitude anomalies that are thought to represent plutonic bodies at varying depths in the Precambrian (W. H. Hinze, personal communication, 1984). These plutonic bodies are inferred to be the result of crustal weakening along this zone due to collision of continental plates during the Precambrian. The high-amplitude anomalies represent, at the least, zones of stark lithologic change in the Precambrian rocks. Such zones of lithologic contrast are excellent prospects for faulting, which may have been reactivated during Paleozoic time.

On the basis of seismic studies, Beardsley and Cable (1983) indicate that the Grenvillian, and possibly pre-Grenvillian, metasediments compose a very thick sequence in the Appalachian Basin and probably drape over both ancient continental and oceanic crust. They further state that the Grenvillian strata were emplaced as large, thrusted accretion wedges, which were introduced from the east as a result of episodic convergent tectonics.

West of the Grenville Front, the character of the magnetic contours is relatively quiescent; the anomalous areas generally are broad and of low amplitude. On the basis of geophysical investigations Denison and others (1984) report a possible basaltic rift zone (or failed rift zone) trending northwest through western-central Ohio into Indiana (fig. 4). This proposed rift zone coincides with the position of numerous historical earthquakes centered around the town of Anna, in Shelby County, Ohio (Hansen, 1975).

The most recent structure map on the Precambrian surface in Ohio is that of Lucius (1985); his map does not differ markedly from that of Owens (1967). These maps illustrate a structurally high area trending north-south in west-central and southwestern Ohio. Green (1957) named this area the Indiana-Ohio Platform (see fig. 4). In central Ohio the dip of the Precambrian surface steepens to the east into the Appalachian Basin. It is rather intriguing to note that the point at which the Precambrian surface begins to dip into the Appalachian Basin is also fairly coincident with the line of the Grenville Front. This observation suggests that the previously deformed and metamorphosed Grenvillian strata were more conducive to subsidence, whereas the granite-rhyolite terrain west of the front remained as a stable or resistant province.

The above observations illustrate that a better understanding of the Precambrian in this region is necessary to fully evaluate the overlying Paleozoic strata and structures. As more geophysical data, such as the aeromagnetic and gravity maps of Ohio (Hildenbrand and Kucks, 1984a, 1984b), and deep well control become available, our knowledge of the Precambrian will increase and undoubtedly shine new light on the overlying Paleozoic rocks and structure.

CAMBRIAN-ORDOVICIAN STRATIGRAPHY

When reviewing the nomenclature of most stratigraphic units throughout the Appalachian Basin and the Midwest, one is faced with a seemingly endless list of names which have been, and still are, applied to each rock unit. Calvert (1962) presents a fairly thorough synopsis of the development of the nomenclature for the Cambrian through Trenton units to that date. The nomenclature used in this report represents the most widely recognized names for each unit, as far as the authors can determine. These names are also those currently acknowledged by the Ohio Division of Geological Survey (Hull, 1990).

To illustrate the depositional history leading up to and immediately following deposition of the Trenton Limestone, we will briefly discuss the stratigraphy, lithology, and relations of the rocks in northwestern Ohio from the Cambrian Knox Dolomite through the Upper Ordovician Cincinnati group. (The name "Cincinnati group" is currently considered to be informal; see Shrake and others, 1988, p. 8.) It is desirable to examine this entire sequence in order to gain a more complete understanding of any one unit, as this sequence represents one large sedimentation package bounded below and above by major unconformities. The Precambrian has been discussed in the previous section; Janssens (1973) discussed the Cambrian Mount Simon Sandstone through the Knox Dolomite at length.

Figure 6 illustrates the general stratigraphy as presented in this report. To aid in regional correlations and discussion, figure 7 depicts the nomenclature of Cambrian through Lower Silurian strata from surrounding states, Ontario, and New York. The reader is also referred to the correlation charts of Patchen and others (1985) and Shaver (1985). Graphic illustration of the changes in the stratigraphy across the study area may be seen on plate 1.

In the traditional time-rock classification of North America, the entire Champlainian Series, represented by the Wells Creek Formation through the Trenton Limestone, has always been regarded as Middle Ordovician in age. In the mid-1980's the American Association of Petroleum Geologists published the results of a massive undertaking called the Correlation of Stratigraphic Units of North America, or COSUNA, charts (see Patchen and others, 1985, and Shaver, 1985). These correlation charts adopted the use of the global system of time-rock classification which is based largely on European strata. Through this reclassification, the bulk of the Champlainian-age rocks are now assigned to the Late Ordovician. Although the COSUNA charts are an effective tool for regional correlations, there is still considerable debate over the age reclassification (S. M. Bergström, personal communication, 1989). Therefore, in this report we continue to assign the Black River Group and Trenton Limestone to the Middle Ordovician (fig. 6).

KNOX DOLOMITE

Perhaps more than any other stratigraphic interval in Ohio, the Upper Cambrian-Lower Ordovician Knox Dolomite has received the most confusing treatment of its subdivision. Many geologists refer to this interval using Michigan Basin nomenclature; others use names common in West Virginia and Kentucky (see fig. 7). Calvert (1962) introduced terminology from Virginia; still others describe these same rocks using Illinois Basin nomenclature. We chose to follow Janssens (1973) work in which he demonstrated the difficulty of subdividing the Knox Dolomite in the subsurface and consequently referred to this interval in northwestern Ohio as undifferentiated Knox Dolomite.

The Knox Dolomite was truncated by a major regional unconformity, the "Knox unconformity." A series of drainage patterns and possibly localized karst topography developed on this exposed surface (Dolly and Busch, 1972; Mussman and Read, 1986). Moreover, Janssens' (1973, pl. 8) isopach map of the Knox Dolomite depicts an area void of Knox Dolomite in portions of Ottawa, Sandusky, and Erie Counties, and an area in Darke County where the Knox is in excess of 1,000 feet thick. Janssens and Stieglitz (1974) attributed this regional unconformity to an episode of folding which resulted in a gentle southward-plunging anticline, referred to as the Waverly Arch by Woodward (1961, p. 1652). Because of this erosional unconformity, the entire Knox in northwestern Ohio is of Cambrian age.

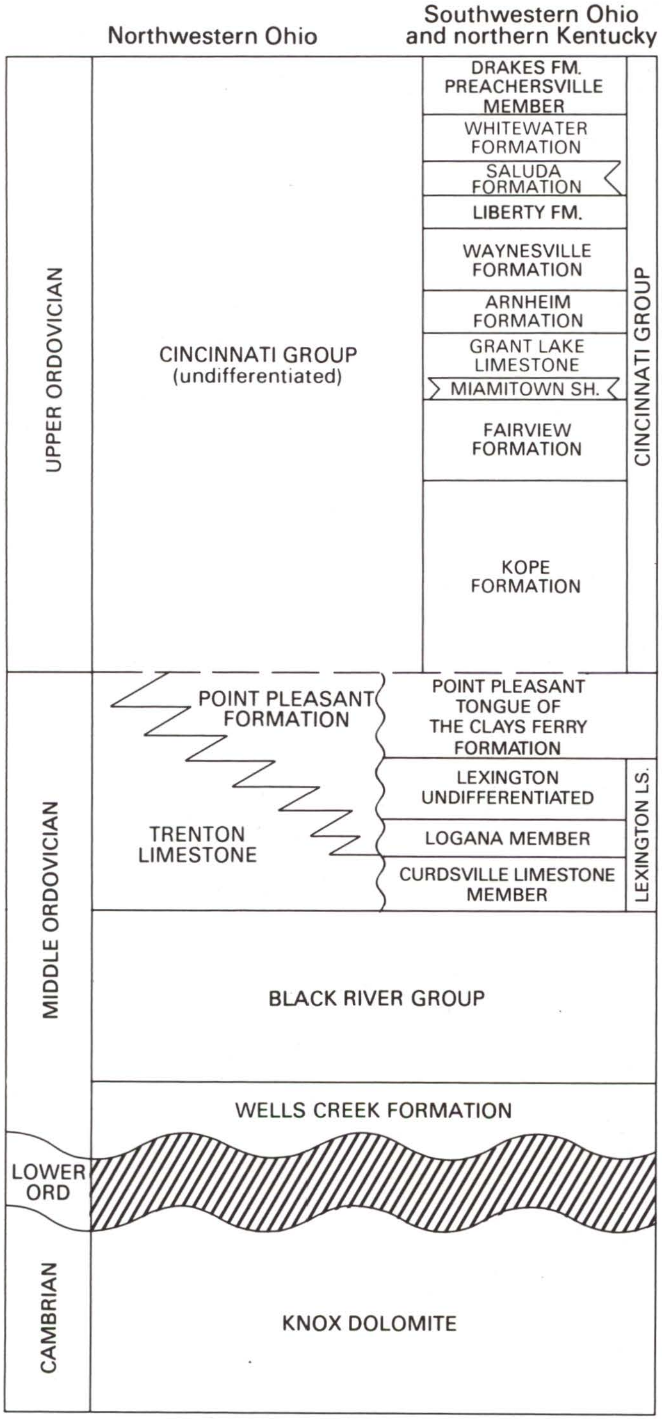


FIGURE 6.—Stratigraphic column of the rocks discussed in this report. Cincinnati group nomenclature is that currently mapped at the surface in southwestern Ohio by the Ohio Division of Geological Survey (Schumacher and others, 1987). Lexington Limestone nomenclature modified from Cressman (1973).

The Knox unconformity is thought to represent the transition from deposition on a passive margin to deposition associated with a convergent margin (Read, 1980). Although the effects of the convergent-margin tectonics (the Taconic Orogeny) were greatest in the eastern and central portions of the Appalachian Basin (Rodgers, 1971), relationships in the overlying Ordovician strata, as presented herein, illustrate that repercussions of the Taconic Orogeny may be seen as far west as northwestern Ohio, Michigan, and Indiana.

The Knox Dolomite in northwestern Ohio consists of white to light-gray dolomite and dolomitic sandstone. Glauconite is prominent at the top of the unit and is associated with the unconformity at the top of the Knox. Fossils cannot be recognized in most well samples; however, some cores show stromatolitic structures and some appear to be burrow mottled.

The Knox is thought to have been deposited in a shallow restricted-marine environment (Beardsley and Cable, 1983). Laporte (1971) attributed the Knox to tidal-flat deposits.

The main aspect of the Knox Dolomite of concern in this report is the nature of its upper contact. Because this contact represents a major unconformity, the contact relationships vary. Because of this variability, it is generally difficult to pick with certainty the exact position of the contact on geophysical logs.

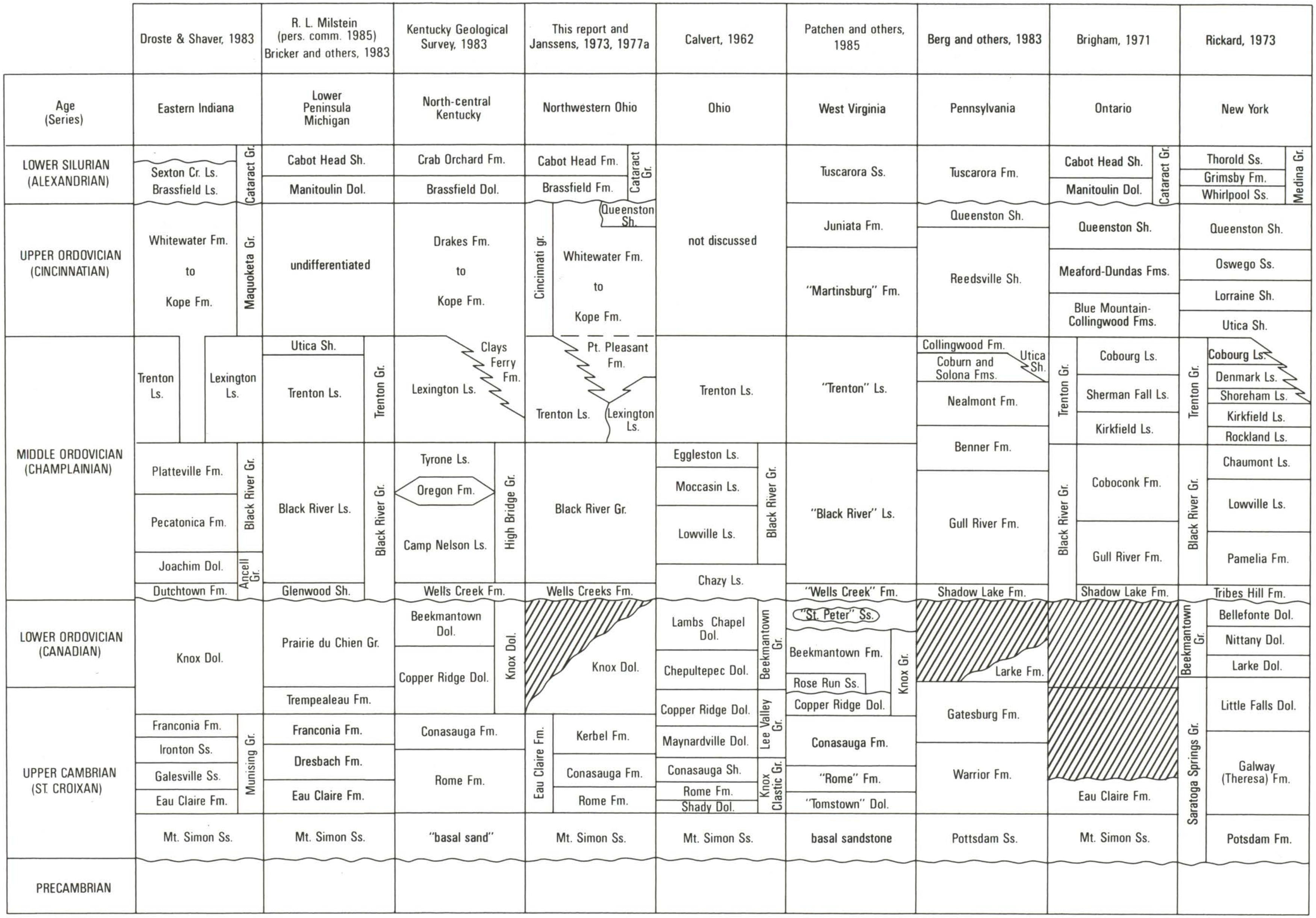
In many wells the top of the Knox appears to be a very clean dolomite overlain by a relatively small amount (5 to 20 feet) of shales and argillaceous carbonates of the Wells Creek Formation. This relationship is the most common in the study area and is the easiest contact to discern. This relationship is illustrated on the cross sections on plate 1 (for example, cross section A-H, Morrow County permit number 93).

It is not uncommon to find a very glauconitic, sandy dolomite at the top of the Knox and overlain by the Wells Creek Formation. The log signature of this interval can be very misleading. It appears that, as the glauconite content increases, the log response resembles more and more a shale interval. Only with good sample or core control through this zone can one ascertain whether it is a very thick section of Wells Creek shale or the glauconitic, sandy dolomite of the Knox. An example of this relationship can be seen on cross section D-G, Champaign County permit number 10 (pl. 1).

Finally, the Wells Creek Formation may be absent, and the clean dolomite of the Knox may be directly overlain by carbonates of the Black River Group. This relationship represents deposition on Knox paleotopographic highs. It can be demonstrated in a few wells that as much as 75 feet of the basal portion of the Black River Group, as well as the Wells Creek, is absent owing to nondeposition on these highs. An example of this contact relationship may be seen on cross section A-H, Morrow County permit number 3402 (pl. 1). In addition, in a few wells the lower part of the Black River Group has been dolomitized and rests directly on the Knox Dolomite; it is virtually impossible to place the contact between these units without good sample control.

WELLS CREEK FORMATION

Throughout most of the study area, the Knox Dolomite is overlain by the Wells Creek Formation. These rocks



	Droste & Shaver, 1983	R. L. Milstein (pers. comm. 1985) Bricker and others, 1983	Kentucky Geological Survey, 1983	This report and Janssens, 1973, 1977a	Calvert, 1962	Patchen and others, 1985	Berg and others, 1983	Brigham, 1971	Rickard, 1973
Age (Series)	Eastern Indiana	Lower Peninsula Michigan	North-central Kentucky	Northwestern Ohio	Ohio	West Virginia	Pennsylvania	Ontario	New York
LOWER SILURIAN (ALEXANDRIAN)	Sexton Cr. Ls. Brassfield Ls. Cataract Gr.	Cabot Head Sh. Manitoulin Dol.	Crab Orchard Fm. Brassfield Dol.	Cabot Head Fm. Brassfield Fm. Cataract Gr.	not discussed	Tuscarora Ss.	Tuscarora Fm.	Cabot Head Sh. Manitoulin Dol. Cataract Gr.	Thorold Ss. Grimsby Fm. Whirlpool Ss. Medina Gr.
UPPER ORDOVICIAN (CINCINNATIAN)	Whitewater Fm. to Kope Fm. Maquoketa Gr.	undifferentiated	Drakes Fm. to Kope Fm.	Queenston Sh. Whitewater Fm. to Kope Fm. Cincinnati gr.		Juniata Fm. "Martinsburg" Fm.	Queenston Sh. Reedsville Sh.	Queenston Sh. Meaford-Dundas Fms. Blue Mountain-Collingwood Fms.	Queenston Sh. Oswego Ss. Lorraine Sh. Utica Sh.
MIDDLE ORDOVICIAN (CHAMPLAINIAN)	Trenton Ls. Lexington Ls. Platteville Fm. Pecatonica Fm. Black River Gr. Joachim Dol. Dutchtown Fm. Ancell Gr.	Utica Sh. Trenton Ls. Trenton Gr. Black River Ls. Black River Gr. Glenwood Sh.	Clays Ferry Fm. Lexington Ls. Tyrone Ls. Oregon Fm. Camp Nelson Ls. High Bridge Gr. Wells Creek Fm.	Pt. Pleasant Fm. Trenton Ls. Lexington Ls. Black River Gr. Wells Creeks Fm.	Trenton Ls. Eggleston Ls. Moccasin Ls. Lowville Ls. Black River Gr. Chazy Ls.	"Trenton" Ls. "Black River" Ls. "Wells Creek" Fm.	Collingwood Fm. Coburn and Solona Fms. Utica Sh. Nealmont Fm. Benner Fm. Gull River Fm. Shadow Lake Fm.	Cobourg Ls. Sherman Fall Ls. Kirkfield Ls. Trenton Gr. Coboconk Fm. Gull River Fm. Black River Gr. Shadow Lake Fm.	Cobourg Ls. Denmark Ls. Shoreham Ls. Kirkfield Ls. Rockland Ls. Trenton Gr. Chaumont Ls. Lowville Ls. Pamelia Fm. Black River Gr. Tribes Hill Fm.
LOWER ORDOVICIAN (CANADIAN)	Knox Dol.	Prairie du Chien Gr.	Beekmantown Dol. Copper Ridge Dol. Knox Dol.	Knox Dol.	Lambs Chapel Dol. Chepultepec Dol. Beekmantown Gr.	"St. Peter" Ss. Beekmantown Fm. Rose Run Ss. Knox Gr.	Larke Fm.		Bellefonte Dol. Nittany Dol. Larke Dol. Beekmantown Gr.
UPPER CAMBRIAN (ST. CROIXAN)	Franconia Fm. Ironton Ss. Galesville Ss. Eau Claire Fm. Munising Gr. Mt. Simon Ss.	Trempealeau Fm. Franconia Fm. Dresbach Fm. Eau Claire Fm. Mt. Simon Ss.	Conasauga Fm. Rome Fm. "basal sand"	Kerbel Fm. Conasauga Fm. Rome Fm. Eau Claire Fm. Mt. Simon Ss.	Copper Ridge Dol. Maynardville Dol. Lee Valley Gr. Conasauga Sh. Rome Fm. Shady Dol. Knox Clastic Gr. Mt. Simon Ss.	Copper Ridge Dol. Conasauga Fm. "Rome" Fm. "Tomstown" Dol. basal sandstone	Gatesburg Fm. Warrior Fm. Pottsdam Ss.	Eau Claire Fm. Mt. Simon Ss.	Little Falls Dol. Galway (Theresa) Fm. Saratoga Springs Gr. Potsdam Fm.
PRECAMBRIAN									

FIGURE 7.—Correlation of Precambrian through Lower Silurian rocks in Ohio and surrounding areas.

have, in the past, been variously called the Glenwood Shale, the Lower Dolomite Member of the Chazy Formation, the Glenwood-St. Peter interval, and the Wells Creek Formation. The Wells Creek Formation was first described by Lusk (1927) in Tennessee and, following Janssens (1973), is the preferred name in this report.

Some records on file at the Ohio Division of Geological Survey indicate the presence of St. Peter Sandstone underlying or occupying the position of the Wells Creek in northwestern Ohio; however, it is difficult to establish the validity of most such records. We have not observed any sandstone which fits the description of the St. Peter in the current study area. Droste and others (1982) indicate that the eastern depositional (erosional) limit of the St. Peter runs approximately north-south through the center of Indiana, although outliers may exist east of this line.

Samples from the Wells Creek interval in northwestern Ohio contain waxy, dolomitic, pyritic green shales; argillaceous limestones and dolomites; minor brown, gray, and black shales; and small amounts of sandstone and siltstone. The thickness of the Wells Creek Formation is highly variable because of the relief on the Knox unconformity. For this reason and because of the scale and control of the maps for this report, a Wells Creek isopach map was not prepared. In general, the Wells Creek in northwestern Ohio ranges in thickness from 0 to 60 feet; the unit averages about 20 feet and thickens to the east. Well data for the Wells Creek are listed in the Appendix. Where the Wells Creek is absent, the Black River Group rests directly on the Knox unconformity.

The contact relationships between the Wells Creek Formation and the underlying Knox Dolomite have already been discussed. The contact between the Wells Creek and the Black River Group is generally fairly sharp and well defined and is placed where the lithology changes from the shales or argillaceous ("dirty") carbonates of the Wells Creek to the relatively clean micritic limestone, or dolomite, of the Black River. This contact relationship is illustrated on the stratigraphic cross sections on plate 1 (for example, cross section E-K, Erie County permit number 34).

BLACK RIVER GROUP

The name Black River Group was first proposed by Vanuxem in 1842 for rocks exposed along the Black River in Oneida and Lewis Counties, New York. Apparently, Newberry (1873) was the first to apply this name in Ohio.

Calvert (1962) subdivided the Black River in Ohio into, in ascending order, the Lowville, Moccasin, and Eggleston Limestones. Later, Calvert (1963a) assigned the Lowville and Moccasin limestones as members of the Platteville Formation. Calvert (1962) also used the name Chazy in Ohio (see fig. 7) and subdivided the Chazy into the lower, middle, and upper units. Because of lithologic, depositional, and geophysical-log similarities of the rocks in the Black River Group it is not formally subdivided by the Ohio Division of Geological Survey at this time.

The Black River Group directly overlies the Wells Creek Formation and, locally, the Knox Dolomite. The Black River consists of tan, light-brown, or gray lithographic (micritic) to very finely crystalline limestone. Clear crystalline calcite fills fenestrae in parts of the formation (birdseye texture). Chert is present in small amounts, particularly in the upper part of the unit. Primary and secondary dolomite also is present. Fossils are not abundant in well samples, but fossiliferous zones have been noted in core sections. The fossils include brachiopods, ostracodes, gastropods, mollusks, trilobites, and the tabulate coral *Tetradium*. Burrows are common and in some sections are so abundant that the rock is burrow mottled.

The Black River Group thickens from about 300 feet in western Williams, Defiance, and Paulding Counties to 560 feet in eastern Huron and Richland Counties (fig. 8). Depositional strike is dominantly north-south, illustrating the east-to-west transgressive deposition of the unit.

The depositional environments of the Black River are, for the most part, typical of shallow epeiric-sea deposition (Irwin, 1965) that was common in the Cambrian and Ordovician Periods. In northwestern Ohio these environments range from shallow subtidal to supratidal. Stith (1979), in a study of the Black River in southwestern Ohio, discusses the depositional environments and associated lithologies in more detail. Stith (personal communication, 1985) has examined a number of cores from northwestern Ohio and has found the unit to be rather uniform over the entire western half of the state. Primary dolomite in the Black River is associated with supratidal deposition. This dolomite is very fine grained and occurs in thin laminations (Stith, 1979). Secondary dolomitization has also taken place in the unit. The secondary dolomites have two main types of occurrence: (1) associated with fractures, and (2) in the basal portion of the unit, generally associated with highs on the Knox unconformity. The genesis of fracture-associated dolomites will be discussed in a later section of this report. Cores of the lower Black River dolomite were not available at the time of this study and therefore their genesis cannot be reliably addressed.

In many wells, up to 75 feet of the basal portion of the Black River may be absent (for example, pl. 1, cross section A-H, Morrow County permit number 3402). The absence of the basal portion of the Black River is especially apparent in the southeastern part of the study area in Morrow, Richland, Delaware, and Marion Counties. This absence may be due to increased erosion or karstification of the Knox surface in this area or may simply reflect the increased density of data points. The absence of the lower Black River also is notable in Hancock and Hardin Counties (fig. 8) just west of the southern portion of the Bowling Green Fault Zone. This absence is apparently due to a preexisting structural high on the Knox surface.

BLACK RIVER-TRENTON CONTACT

The contact relationship between the Black River Group and the overlying Trenton Limestone is complex, and the exact contact position is difficult to pick consistently by use of geophysical logs alone. In the northwestern part of the study area this contact is generally at or near a prominent bentonite zone (see pl. 1). To the south and east the upper portion of the Black River becomes more argillaceous and contains a larger number of bentonite beds. This fact, along with thinning of the Trenton (see fig. 10) and the possible addition of a bed at the top of the Black River (The Eggleston Formation(?) of Calvert, 1962), makes this contact increasingly difficult to pick. Consequently, we have placed great emphasis on locating the Black River-Trenton contact by examination of well cuttings and cores. Once the contact had been determined by use of the rock materials, it was transferred to the corresponding geophysical log, and the contact then correlated to surrounding logs.

The sedimentological features of the Black River-Trenton contact zone are variable and are best characterized by core examination. In one core from the study area (Logan County, Zane Township) and one core from southwestern Ohio (Butler County, Wayne Township), the contact appears sharp; a very distinct hardground is developed on the uppermost surface of the Black River Group (fig. 9A). Keith (1985) has also noted the occurrence of hardgrounds at this contact in Indiana. Hardgrounds typically display borings and have a distinctive rind developed on them, indicating at least partial lithification prior to continuation of (Trenton) deposition (Kennedy and Garrison, 1975). In two other cores from the study area (Seneca County, Liberty Township, and Wyandot County, Crane Township), the contact is gradational; Trenton and Black River lithologies are interlayered through a zone as much as 10 feet thick. In the Wyandot County core the contact zone contains at least one discernible hardground in the alternating sequence (fig. 9B).

Generally the Black River-Trenton contact zone is

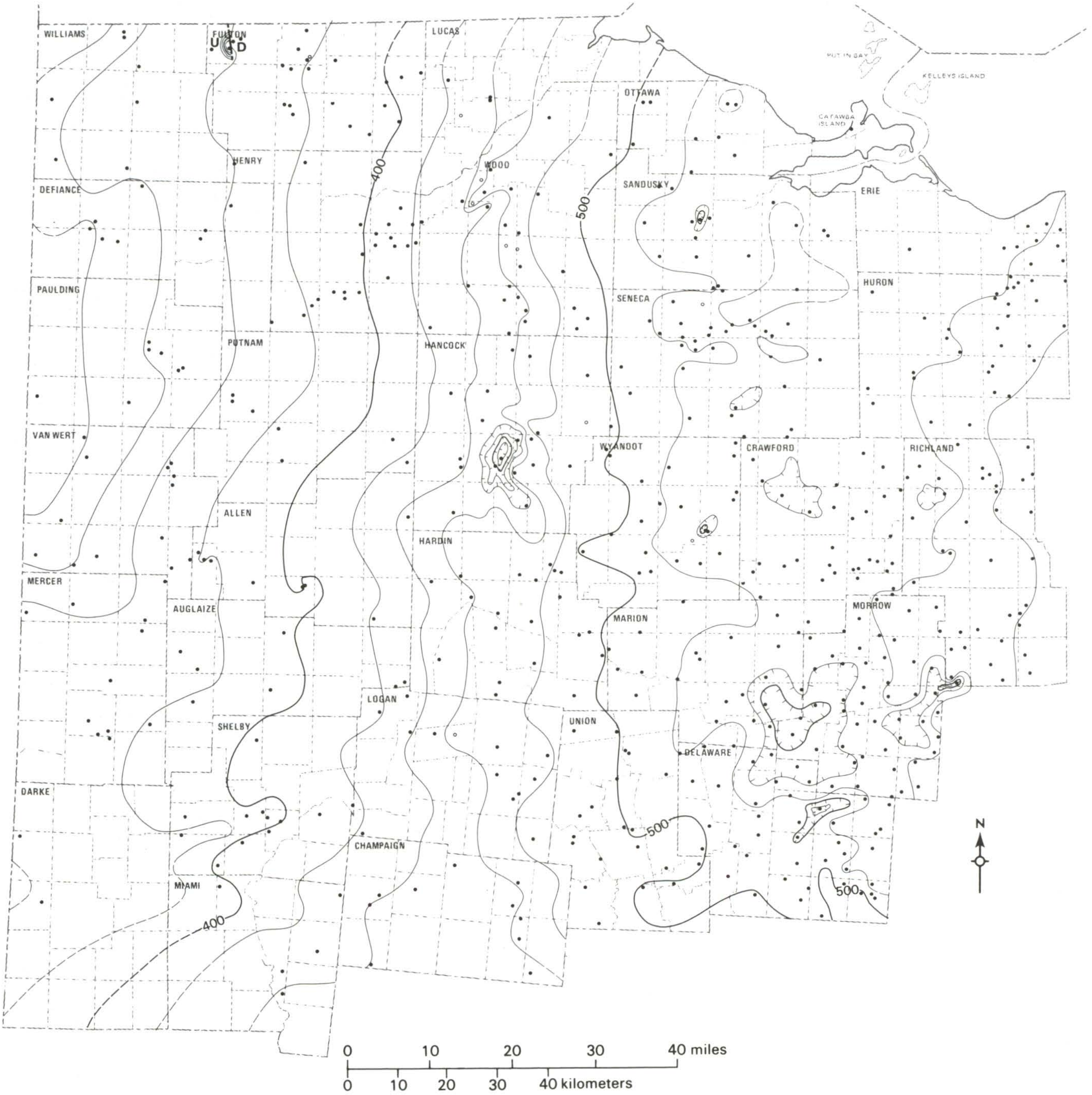


FIGURE 8.—Isopach map of the Black River Group. Contour interval 20 feet.

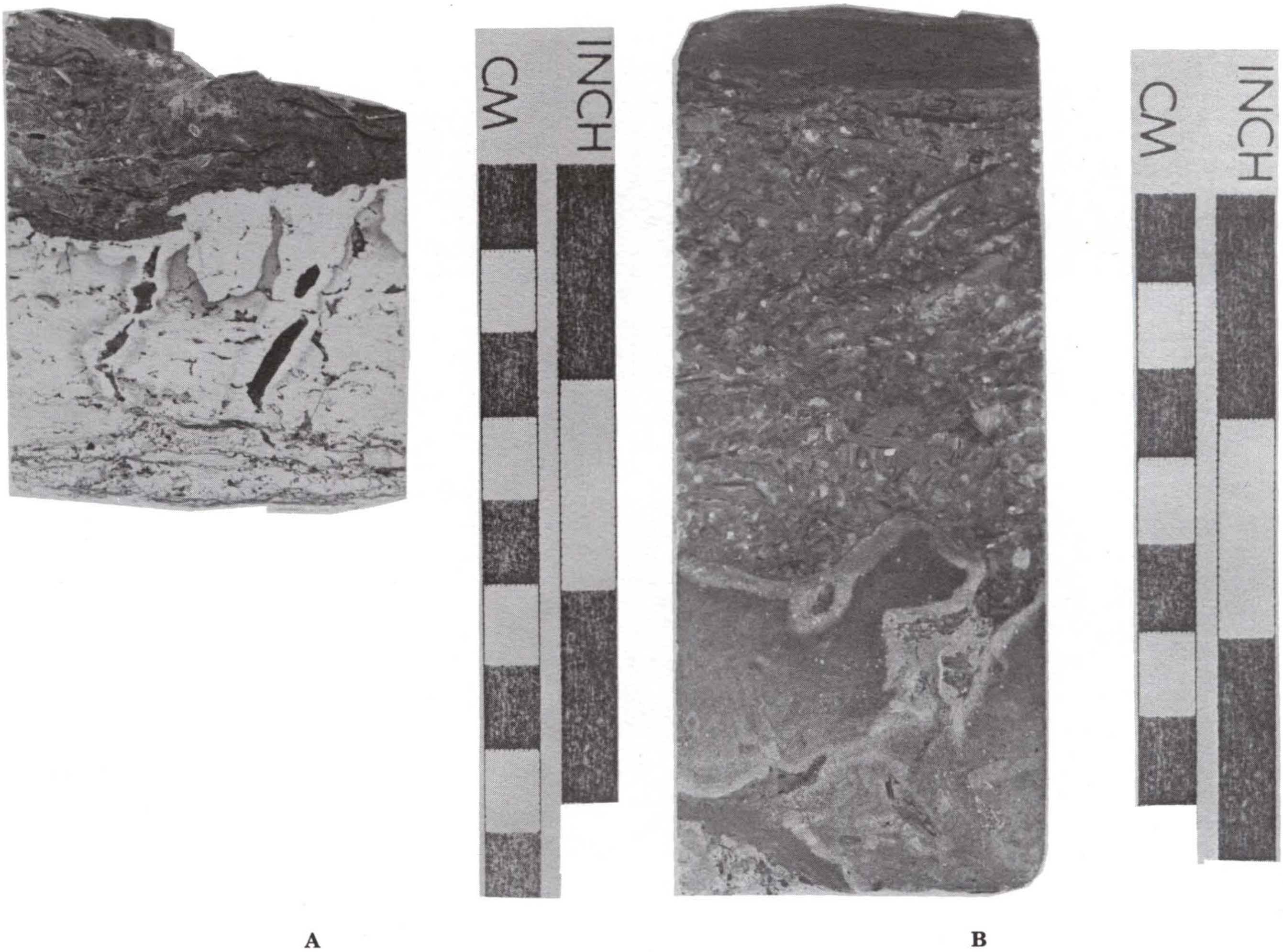


FIGURE 9.—Photographs of core slabs showing hardgrounds at the Black River-Trenton contact. **A**, core #2537, Wayne Township, Butler County (southwestern Ohio), depth 937 feet. **B**, Marathon Resources core TWC-4, Crane Township, Wyandot County, depth 1,569 feet.

marked by increased frequency of bentonite layers, which range in thickness from a few millimeters to a few centimeters. The scale of geophysical logging typically is not capable of discerning each individual bentonite layer. The log may show a number of small "bentonitic" spikes through this zone, or one or two large deflections.

On the basis of these contact relationships it appears that the Black River-Trenton contact is diachronous. In the northeastern portion of the study area the change from Black River to Trenton lithology appears to have been gradual with short periods of nondeposition. To the southwest, a short period of nondeposition at the end of Black River time appears to have been followed by a quick change to Trenton deposition. Although this explanation of the relationships fits the overall transgressive nature (east to west) of the strata, it is certainly oversimplified. Attempts to resolve this problem are hampered by a lack of cores which contain the contact zone, especially from the northwesternmost portion of the state. As additional cores containing this contact become available, it is hoped a better understanding will emerge. At present, because only the Seneca County core cited above has a corresponding geophysical-log suite (Wickstrom and others, 1985) even the log character of the different contacts cannot be determined and contrasted.

TRENTON LIMESTONE

The Trenton Limestone, the principal subject of this report, was first named in 1838 by Vanuxem, who applied the name to rocks forming Trenton Falls in Trenton Township, Oneida County, New York. As originally defined, the Trenton Limestone contained rocks now included in the underlying Black River Group. In 1842, Vanuxem redefined the boundary to the position now commonly accepted. Since then, the term Trenton has been applied in various areas as a member, formation, group, and/or stage name.

The name Trenton was first introduced in Ohio nomenclature as both a formation and a group by Newberry in 1869. Orton (1888) suggested that the dolomite in northwestern Ohio might correlate with the Galena Dolomite of Wisconsin and used the term Trenton in the sense of a group: "We are therefore safe in referring this 550 feet of stratum of the Findlay well to the Trenton, including both the Galena or uppermost, the Trenton proper and the Birdseye divisions" (Orton, 1888, p. 116). Present usage separates the Black River Group (the "Birdseye") from the Trenton, but includes the dolomitized portions (the Galena) of the formation.

In general, the Trenton Limestone consists of whole or fragmented fossils set in a fine, dark-gray to light-brown matrix. Thin to very thin gray or black shale beds and stylolites are common throughout the formation. Secondary dolomitization has occurred in the formation in particular beds and areas. Bentonite layers, commonly only a few inches thick at most, are found in particular beds. The lithology of the Trenton is described in greater detail in a later section of this report.

The Trenton Limestone ranges in thickness from less than 40 feet in parts of Champaign and Miami Counties to approximately 300 feet in parts of Ottawa and Lucas Counties (fig. 10). In contrast to the underlying Black River Group, the depositional strike of the Trenton is dominantly northeast-southwest. The thickness changes rapidly along a southwest-northeast band from Darke County to Ottawa County.

Three depositional environments of the Trenton Limestone have been modeled in the study area: platform, platform margin, and open shelf. For the most part, the rock types composing each of these depositional environments occur in definable vertical and lateral zones which also may be referred to as lithologic facies; thus the facies

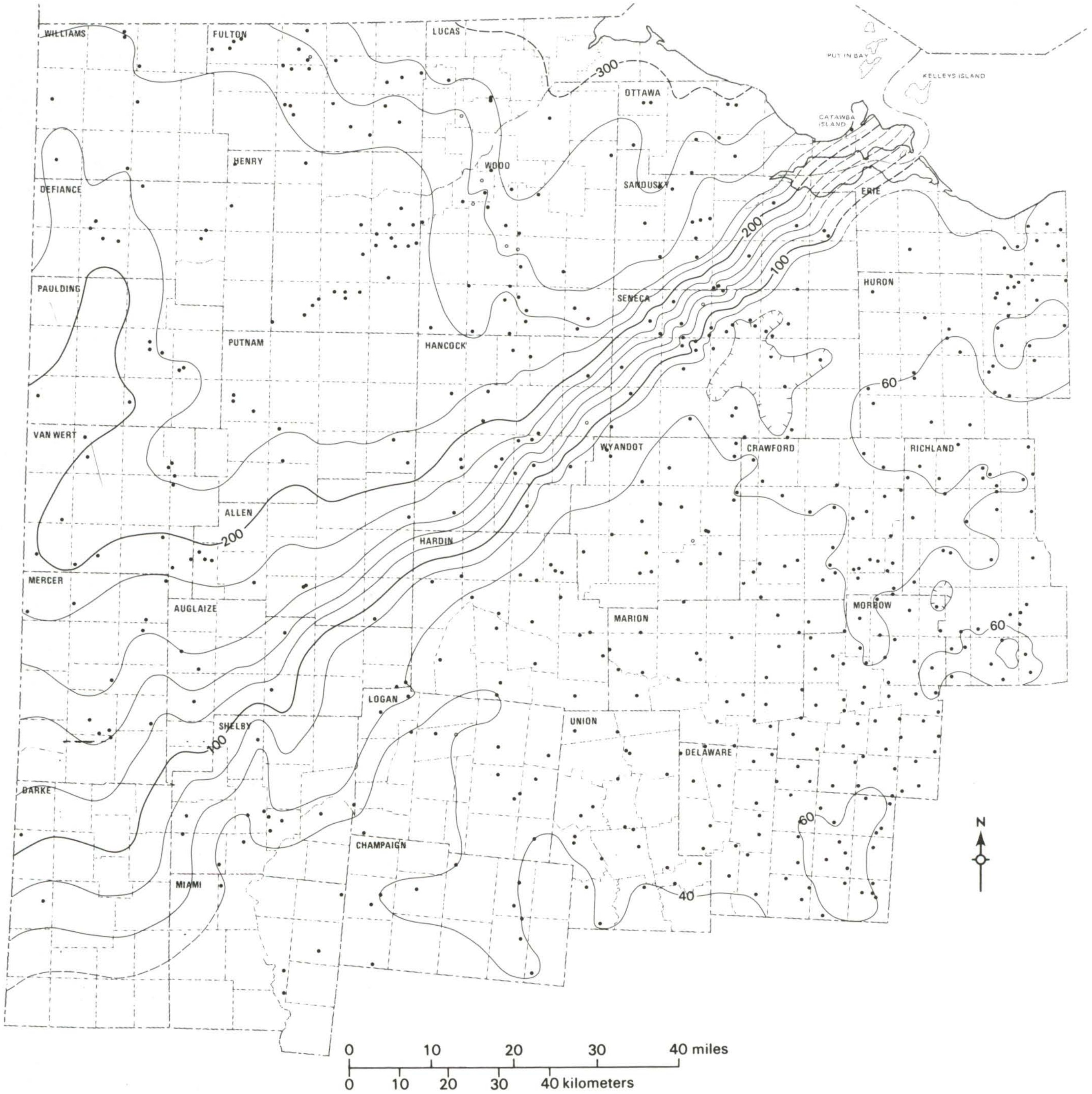


FIGURE 10.—Isopach map of the Trenton Limestone. Contour interval 20 feet.

of this report will be referred to by their depositional-environment names. These facies are discussed at length in a later section of this report.

BENTONITES OF THE BLACK RIVER GROUP AND TRENTON LIMESTONE

Bentonite layers ranging from about 2 millimeters to several centimeters in thickness occur in two main zones in the Black River Group and the Trenton Limestone; bentonites also occur in the Point Pleasant Formation. The thickest bentonite observed in the study area is approximately 4 centimeters. These bentonites, known as K-bentonites because of their potassium content, are of potentially great stratigraphic importance as they are the result of volcanic ash falls, which represent very brief intervals of geologic time and were deposited over very wide geographic areas.

Bentonite beds occur throughout the Black River and are especially abundant in the upper section of the unit to the south and east (see pl. 1, cross section D-G). Although some bentonites may be useful as marker beds locally (see Stith, 1979), lateral continuity of the individual beds is difficult to determine over long distances. Many of the bentonitic (and argillaceous) layers which are abundant in the southeastern portion of the study area disappear or lose definition to the north and west. This relationship has led to numerous errors in correlations across the area because many workers mark the contact between the Trenton and the Black River solely on the position of a bentonite kick on geophysical logs.

The first zone of bentonites is in an interval roughly 20 feet thick straddling the contact between the Black River Group and the Trenton Limestone. As many as 10 bentonite layers have been observed in as many feet in the core in Seneca County, Liberty Township. This zone is of particular interest because of its potential usefulness in locating the Black River-Trenton contact.

The second zone of bentonites is near the top of the Trenton Limestone. Only one unequivocal bentonite layer has been observed in a core from this zone (see Wickstrom and others, 1985), although a few layers may be present in other wells as evidenced by multiple characteristic "kicks" on geophysical logs. This upper bentonite zone appears to correlate to a bentonite zone in the upper Point Pleasant Formation observed in core and outcrop from southwestern Ohio and in geophysical logs across western Ohio.

Although seemingly constrained in defined zones of the Trenton and Black River rocks, the bentonites are difficult to use as stratigraphic datums. A particular bentonite layer may or may not exist in wells which are located relatively close to one another. The absence may be due to the action of currents and waves washing and mixing the bentonites on the sea floor. However, on a regional basis the bentonites are still the best stratigraphic markers in the Trenton-Black River carbonate interval. With care one should be able to pick the correct bentonite "kick" on geophysical logs within ±15 feet. The upper bentonite of the Trenton-Black River contact zone has been used as the datum on the stratigraphic cross sections for this report (pl. 1). This bentonite is equivalent to the Pencil Cave bentonite of Kentucky terminology and the α marker bed of Stith (1979). In wells in which the bentonite(s) appear to be absent, detailed correlation is required to determine the position of the datum.

Huff (1983) and Kolata and others (1987) have conducted in-depth analyses of the Ordovician K-bentonites using chemical fingerprinting methods for regional correlation. As their work is brought into this area, it may enable us to tie cored sections together and aid in correlating the subsurface strata with outcrop equivalents on a larger regional scale.

The source for the volcanic ash of the bentonites was probably far to the east and southeast, originating from active island-arc volcanism associated with the Taconic Front (Cisne and others, 1982) (fig. 11). The location of these source vents aids in explaining the disappearance of these bentonites as one goes farther north and west.

It is of great interest to note the stratigraphic positions of the various bentonite layers in relation to reconstructing the tectonic history of the area. The position and frequency of the bentonites may be indicative of increasing tectonic activity. At the end of Black River deposition and in the beginning of Trenton deposition, an increase in the frequency of bentonites is readily observable. This increase marked the change from shallow, subtidal-to-intertidal deposition (Black River) to deeper, more normal marine deposition (Trenton) as well as a change in the predominant depositional strike. This change is probably the result of increased tectonic activity (plate collision) related to the Taconic Orogeny. As this pulse of compression progressed, it triggered increased volcanic activity from the bentonites' source vents and subsequently modified the shape of the "proto-Appalachian basin" and deepened the water in its central portion, where the Point Pleasant was deposited.

A similar scenario may have occurred toward the end of Trenton depositional time when, once again, we find a number of bentonite layers. This tectonic pulse, however, appears to have been quicker and of larger magnitude, as it effectively ended continuous carbonate deposition of the Trenton and introduced continuous, deeper, mixed carbonate and clastic deposition represented by the Cincinnati group.

POINT PLEASANT FORMATION

The Trenton Limestone grades upward and laterally to interbedded limestones and calcareous shales of what in this report is called the Point Pleasant Formation (fig. 6). The thickness of the Point Pleasant (fig. 12) is reciprocal compared to the thickness of the Trenton Limestone (fig. 10). Correlation shows these interbedded limestones and calcareous shales to be equivalent, at least in part, to an interval originally called the Point Pleasant Beds by Orton (1873). Orton (1873) introduced the name Point Pleasant Beds for 50 feet of the stratigraphically lowest rocks exposed in the state along the Ohio River near the town of Point Pleasant, in Clermont County. The Point Pleasant Formation is overlain by the Kope Formation of the Cincinnati group (fig. 6).

Cressman (1973), working in north-central Kentucky, has published a detailed interpretation of the Trenton Limestone equivalent, the Lexington Limestone. In his report he has shown that the upper members of the Lexington Limestone "die out" to the north through an intertonguing/facies relationship with the Clays Ferry Formation (Cressman 1973, pl. 10). On the same cross section he has shown the basal members of the Lexington (the Curdsville, Logana, and Grier Members) continuing into Ohio, although he did not differentiate the Lexington north of the Ohio River. In his outcrop area, Cressman (1973) depicts strata equivalent to the Point Pleasant in Ohio intertonguing with the Clays Ferry Formation and calls these the Point Pleasant Tongue of the Clays Ferry Formation. It is possible in southwestern Ohio to differentiate the Lexington into, in ascending order, the Curdsville and Logana Members, a middle undifferentiated section, and the Point Pleasant Tongue (Stith, 1986) (fig. 6). In southeastern Indiana, the Curdsville and Point Pleasant have been recognized as the lowermost and uppermost members, respectively, of the Lexington Limestone (Shaver and others, 1986).

Stith (1986) has demonstrated that the Point Pleasant Tongue of the Clays Ferry Formation can be correlated in the subsurface from Mason County, Kentucky, to Delaware County, Ohio. Cross sections A-H and D-G (pl.1) illustrate that this correlation can continue (although the same well is not used for control in Delaware County) into the platform-margin facies of the Trenton Limestone in northwestern Ohio.

It does not appear practical to continue the subdivision

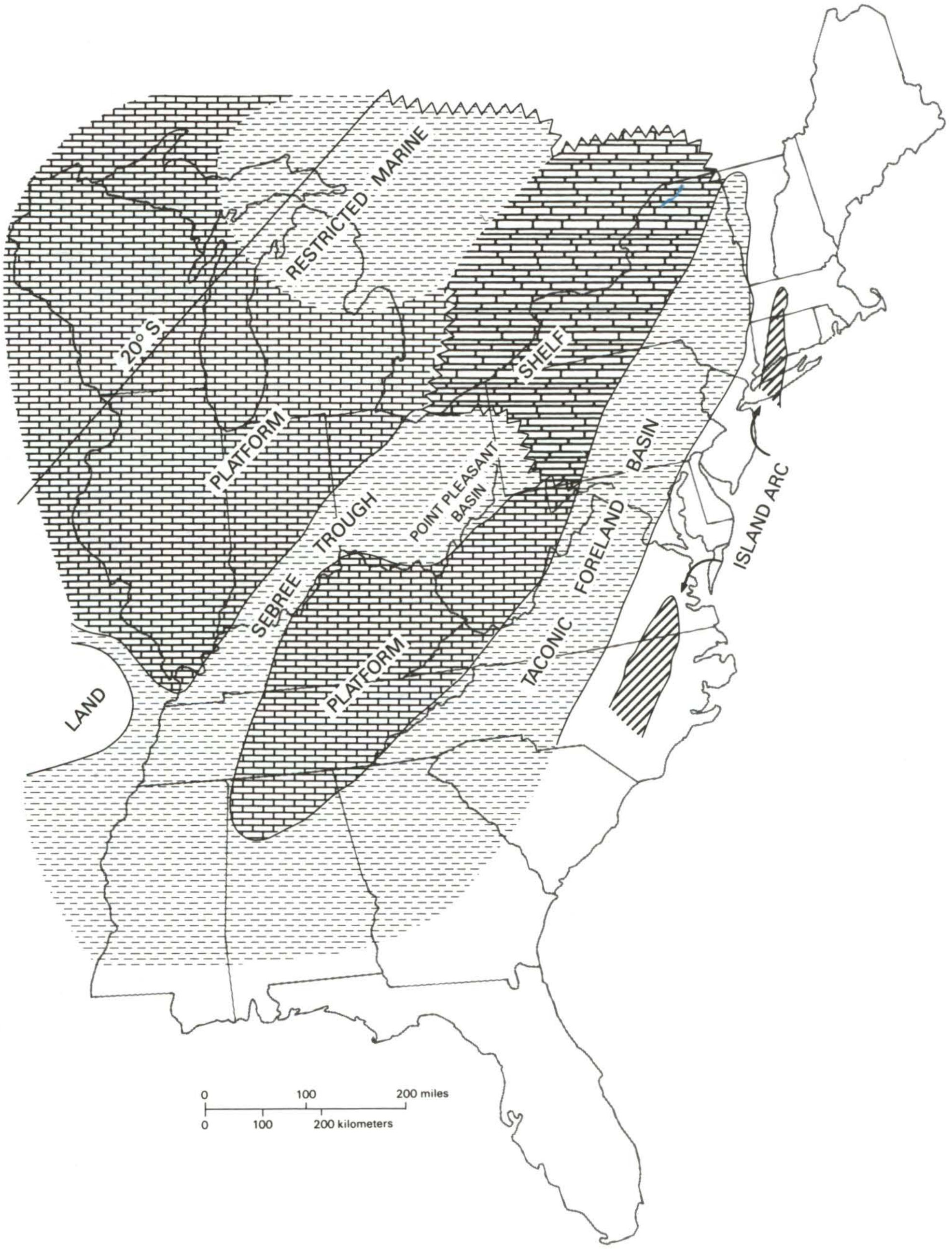


FIGURE 11.—Regional reconstruction of major depositional and tectonic elements present during late Trenton/Point Pleasant depositional time. The northeastern United States was undergoing initial phases of the Taconic Orogeny, causing the platform to founder along its eastern edge (modified from Keith, 1985).

of the Point Pleasant/upper Lexington strata into members and tongues in the subsurface of Ohio. Although such subdivision is possible in wells situated very close to the outcrop area, correlations using geophysical logs farther north from the outcrop indicate continued intertonguing and facies changes in the upper Lexington/Clays Ferry-Point Pleasant interval. With current well control it is not possible to map these changes sufficiently to warrant extension of the surface subdivisions (or introduction of new units) into the subsurface. However, the total stratigraphic interval between the top of the basal facies of the Trenton (the Curdsville Member of the Lexington Limestone) and the base of the Kope Formation does retain a characteristic, correlatable log signature as an overall package (pl. 1; Stith, 1986, pl. 2). Therefore, it is herein suggested that the interval from the top of the relatively clean limestone of the Trenton (Curdsville Member of the Lexington Limestone) to the base of the predominantly shale strata of the basal Cincinnati group (Kope Formation), as illustrated on the cross sections (pl. 1), be called the Point Pleasant Formation in the subsurface of Ohio.

On the stratigraphic cross sections (pl. 1), the top of the Point Pleasant is shown with dashed lines. Using this contact and correlations with other geophysical logs, an isopach map of the Point Pleasant has been constructed (fig. 12). Because of the difficulty of consistently picking the top of this formation on logs, not all wells which penetrated this interval could be used in the construction of the isopach map. Therefore, an isopach map of the combined Point Pleasant Formation and Cincinnati group (fig. 13) was constructed to provide a better perspective of the interval overlying the Trenton Limestone using a similar amount of control as the other maps of this report.

In northwestern Ohio the Point Pleasant Formation ranges in thickness from zero along an arcuate band from Sandusky County to Mercer County to approximately 200 feet on the eastern edge of the study area (fig. 12). The normal progression of thickening through this area is interrupted by four main sites of anomalous deposition separated by a series of northwest-trending zones of thinning. These sites will be addressed later in this report in the discussion of structure.

As it is observed in continuous cores and sample cuttings from northwestern Ohio, the Point Pleasant Formation has interbedded, gradational contacts with both the underlying Trenton Limestone and the overlying Kope Formation. Overall, the Point Pleasant consists of interbedded dark, argillaceous limestones, brown to black calcareous shales, and brachiopod coquina layers. Toward the top of the formation the relative amount of limestone decreases and the shale becomes light to dark gray.

In much of Ohio the basal portion of the Cincinnati group has been referred to by many drillers and some authors (for example, Prouty, 1983; Coogan and Parker, 1984) as the "Utica Shale." Until recently the equivalency between any shales of western Ohio with the Utica Shale of New York has been hypothetical. Work in progress by Bergström and Mitchell (1987 and personal communication) indicates that biostratigraphically diagnostic graptolite zones in rocks equivalent to the Point Pleasant Formation, as defined herein, can be tied into the Utica Shale of New York. Study of graptolites from additional cores over a larger area is underway (S. M. Bergström, G. A. Schumacher, and E. M. Swinford, personal communication). Once this work is completed the relationship of the Point Pleasant and "Utica" rocks in Ohio may be delineated.

On the basis of the relationships observed, it seems clear that the basal Curdsville Member of the Lexington Limestone of Kentucky is continuous northward into Ohio, where it becomes the basal facies of the Trenton Limestone of this study. The rocks of the Clays Ferry Formation, the Point Pleasant Tongue of the Clays Ferry Formation, and the Logana and Grier Members of the Lexington Limestone as defined by Cressman (1973) appear to be stratigraphically equivalent to the upper Trenton in northwestern Ohio and are herein called the Point Pleasant Formation.

SEBREE TROUGH FILL

Schwalb (1980) described a northeast-trending feature in western Kentucky as being a "trough-like, clastic filled, depression." He named the feature the "Sebree Valley," after a small town in western Kentucky. This feature is thought to extend continuously from western Kentucky, through southeastern Indiana (Keith, 1985), and into northwestern Ohio (figs. 11, 12). Keith (1985) has called this feature the "Kope Trough." Bergström and Mitchell (1987), acknowledging the precedence of Schwalb's term, have called it the "Sebree Trough," which is the preferred name in this report.

In western Kentucky and southern Indiana the Sebree Trough is defined by an area in which shales rest directly on the carbonates of the Black River (Schwalb, 1980; Keith, 1985). Although the Trenton does thin across some areas of the trough, no evidence currently exists showing shales resting directly on the Black River Group in Ohio. The trough in the area of this investigation is defined by the contrasting sediments of the Point Pleasant Formation. In the Sebree Trough, slightly to moderately calcareous, dark- to light-gray shales are the dominant lithology of the Point Pleasant. Minor amounts of brown shales and interbedded limestones also are present; fossils are scarce relative to deposits outside the trough. To the south and east, the Point Pleasant contains numerous dark, fossiliferous limestones and the shales are typically black and organic rich. This change across the trough may be seen graphically by means of the geophysical-log signatures on cross sections A-H and D-G (pl. 1). Although the lithology of the Point Pleasant changes, correlation across the trough is possible on the basis of good marker beds and on the base of the Kope Formation. Therefore, the rocks of the Sebree Trough are considered part of the Point Pleasant Formation in this report.

CINCINNATI GROUP

In northwestern Ohio, the Trenton Limestone and the Point Pleasant Formation are overlain by interbedded limestones and shales of the Upper Ordovician Cincinnati group (Orton, 1873). Where it is exposed at the surface in southwestern Ohio, this group may be subdivided, as shown in figure 6. Extension of such a detailed subdivision into the subsurface of Ohio has not been attempted for this study. However, preliminary correlations suggest a great deal of intertonguing, and facies changes occur in the post-Kope interval across this area. Correlations do allow the extension of the basal Kope Formation into northwestern Ohio, where it overlies the Trenton with sharp contact and the Point Pleasant with gradational contact as discussed above.

The basal portion of the Cincinnati group is composed of light- to dark-gray shales and silty shales which are slightly to very calcareous and laminated in part. This lithology grades upward into light-gray to green calcareous shales intermixed and interlayered with fine- to medium-crystalline fossiliferous limestones and dolomites. Bedding varies widely from irregular to nodular to wavy. In the eastern portion of the study area the shales and carbonates grade upward into red shale of the Queenston Shale. To the west the Queenston Shale is absent, and the shales and carbonates grade into limestones and dolomites at the top of the Ordovician.

The Cincinnati group thickens from slightly less than 700 feet in the extreme western portion of the study area to approximately 950 feet on the east. However, to better illustrate the total thickness of interbedded shales and limestones overlying the Trenton Limestone, the isopach map (fig. 13) of the combined Point Pleasant Formation and Cincinnati group was constructed.

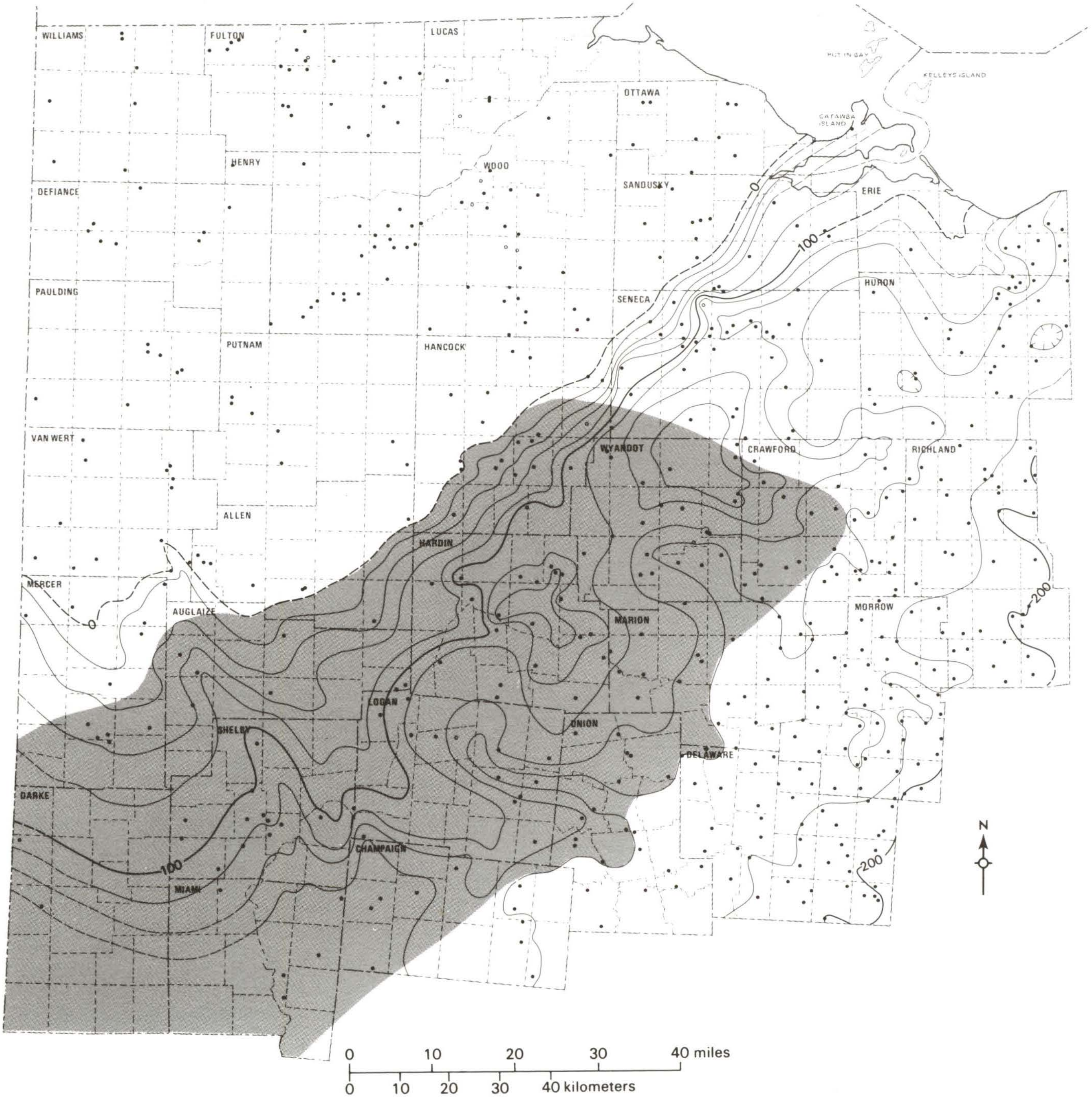


FIGURE 12.—Isopach map of the Point Pleasant Formation. Contour interval 20 feet. Patterned area is the approximate limit of the Sebree Trough.

The depositional environments represented in the Cincinnati group were highly variable both vertically and laterally. Tobin and Pryor (1981), working in the Cincinnati, Ohio, area, have summarized these environments. The Cincinnati group is interpreted to represent a shoaling-upward storm-dominated sequence. The Kope Formation represents the deepest (below wave base) part of a gently sloping ramp. Tobin and Pryor (1981) further propose (p. 54) that the cyclic bedding (interbedded limestones and shales) is a result of "alternating periods of clear-water carbonate sedimentation and periods of muddy-water shale sedimentation" brought about by major storms.

ORDOVICIAN-SILURIAN CONTACT

The Ordovician-Silurian systemic contact is thought to be unconformable in Indiana (Pinsak and Shaver, 1964; Laferriere and others, 1986) on the basis of faunal evidence. Although Janssens (1977a) found no physical evidence of an unconformity in his study area, he assumed the faunal evidence cited by Pinsak and Shaver (1964) was valid as well in northwestern Ohio. We also have found

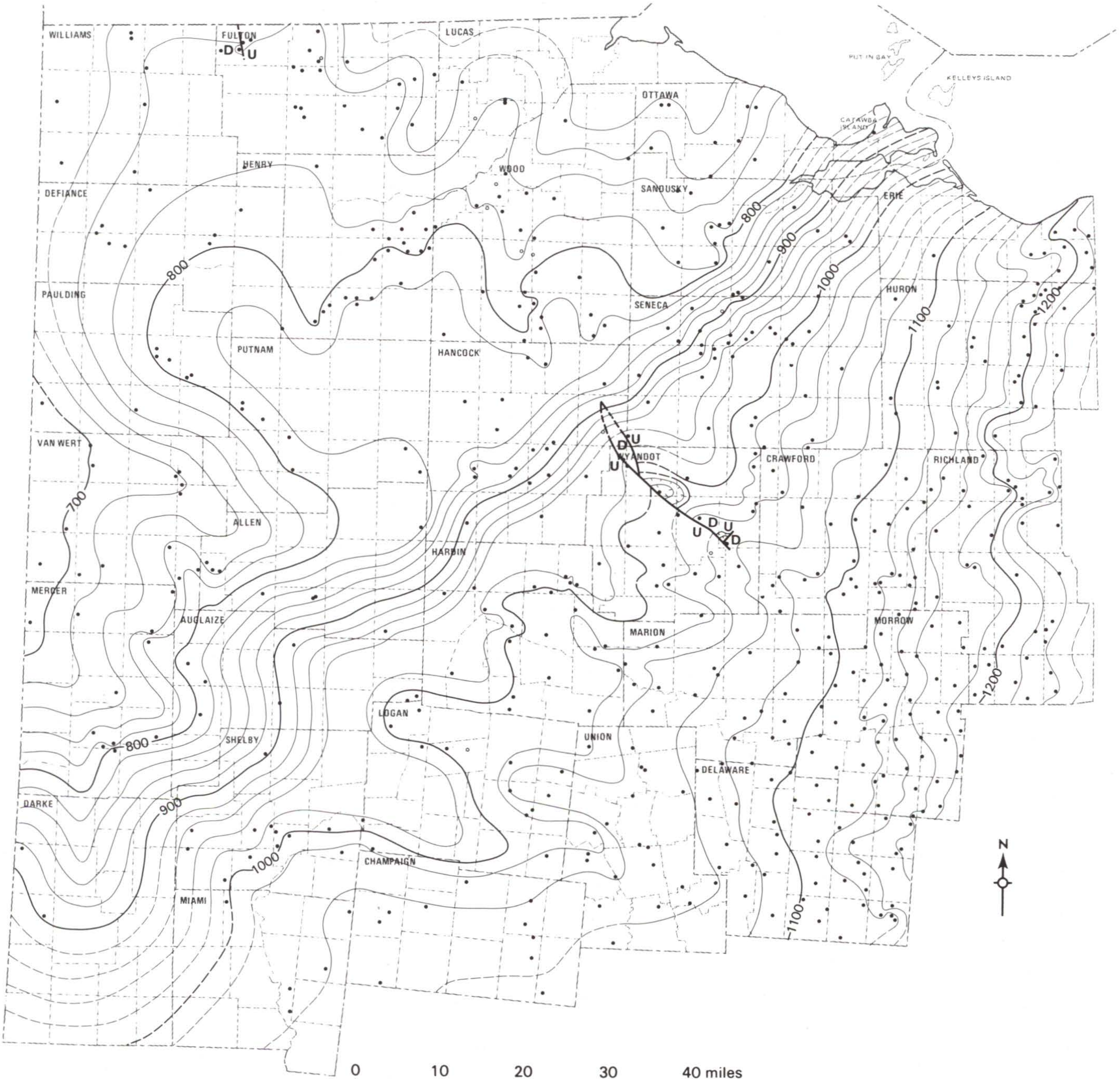


FIGURE 13.—Isopach map of the combined Point Pleasant Formation and Cincinnati group. Contour interval 20 feet.

no physical evidence of an unconformity in our study of this contact in the core from Seneca County, Liberty Township. In this core the contact across the boundary is gradational. A detailed faunal examination of this boundary in northwestern Ohio is called for in the future.

In examining this contact and the immediately overlying Lower Silurian units, we have come to the same basic conclusions reached by Janssens (1977a). The sub-Lockport (Lower Silurian) formations which are individually discernible in the eastern portion of the study area become lithologically indistinct to the west (pl. 1, cross sections A-H, E-K). This change takes place from east to west through a series of facies changes and/or pinchouts as the shales of the Rochester Shale and Cabot Head Formation disappear to the west and the carbonates of the Brassfield and Dayton Formations and the Lockport Group coalesce. The red Upper Ordovician Queenston Shale also disappears in a zone roughly coincident with the changes in the Lower Silurian units.

In the western third of the study area, as much as 200 feet of carbonates of the Whitewater and Saluda Formations at the top of the Upper Ordovician sequence can be correlated to the Maquoketa Group in Indiana (units C and D of Gray, 1972) (pl. 1, cross section A-H, E-K). To the east these carbonates thin and their stratigraphic position is represented largely by shales. The boundaries of this change have not been mapped as part of this study; however, it appears that this lithologic change is in a reciprocal relationship with the coalescence of the Lower Silurian carbonates mentioned above.

These changes in the Upper Ordovician and Lower Silurian section make it increasingly difficult to reliably pick the Ordovician-Silurian boundary as one correlates from east to west. Moreover, the apparent coincidence in the position of these lithologic changes supports the theory of a Late Ordovician carbonate shelf centered over eastern Indiana and western Ohio (Droste and Shaver, 1983); the Queenston Shale interval possibly represents a deeper, clastic-dominated facies.

LITHOLOGY AND DEPOSITIONAL ENVIRONMENTS OF THE TRENTON

GENERAL LITHOLOGIC CHARACTERISTICS

In general, the Trenton Limestone consists of whole or fragmented fossils set in a fine, dark-gray to light-brown lime-mud matrix. The relative abundance of fossil fragments (grains) compared to mud ranges from mudstone (mostly mud with less than 10 percent grains) to wackestone (mostly mud with greater than 10 percent grains) through packstone (mud and grains but mostly grain supported) to grainstone (little or no mud and wholly grain supported). The most common macrofossils are brachiopods, bryozoans, crinoids, and ostracodes. These fossils are the best indicators of faunal and facies changes in the unit. Trilobites, pelecypods, and gastropods are present, but are less common. Evidence of pressure solution in the form of stylolites occurs throughout the formation and is most abundant in the wackestone and packstone layers. Thin to very thin gray or black shale layers are common in the wackestones and packstones and locally may become quite abundant. Pyrite is common in the Trenton and may be finely disseminated, occur as fossil replacements or discrete blebs, or be localized along stylolites, shale layers, and fracture surfaces.

FACIES AND PRIMARY DEPOSITIONAL ENVIRONMENTS

The lithologies, textures, sedimentary structures, and biota in the Trenton Limestone have been used to model its deposition in three primary facies/depositional environments: open shelf, platform margin, and platform (fig. 14A). These facies are interpreted to be the result of a marine transgression from southeast to northwest. As a result of the transgressive nature, exact boundaries cannot be applied to these facies, as they grade from one to another both vertically and laterally (fig. 14B). Therefore, the contacts shown should not be viewed as definite limits.

Various idealized models for carbonate sedimentation and classification of carbonate buildups have been proposed (see Wilson, 1975, for review); most of these are based on modern carbonate sedimentation models. The vast extent of the early to mid-Paleozoic epeiric seas prevents these strata from fitting neatly into such models because such environs no longer exist. The terminology presented herein should not, therefore, be taken in a strict literal sense. The authors chose to use the idealized terminology of Wilson (1975), although other systems of classification such as those of Ahr (1973) or Read (1985) could be applied.

Open-shelf facies

A relatively thin basal facies of the Trenton Limestone apparently extends across the entire study area and constitutes all of the Trenton interval in the southeastern part of the study area (fig. 14). This facies is the most important for reconstruction of the overall Trenton sedimentation framework. The rocks of this interval are transitional between the shallower, restricted environment postulated for the Black River Group below and the shallow, open-marine platform environment common to the upper facies of the Trenton to the northwest. In the southeastern part of the study area, this unit records the transition from the Black River environment to the shallow, subtidal, open-shelf environment postulated for the Trenton and then grades upward into the deeper water, basinal sediments of the Point Pleasant Formation (fig. 14).

The open-shelf facies ranges from approximately 20 to 100 feet in thickness and consists predominantly of wispy to nodular-bedded, gray to light-brown bioclastic limestone. Wackestone to packstone are the major components; minor amounts of mudstone and grainstone are interlayered (fig. 15A). Extensive bioturbation has homogenized this facies in many sections.

Whole to partially abraded brachiopods and bryozoans are the major fauna observed. Scattered crinoid fragments and trilobites are common. Abundant ostracodes have been noted in samples from near the top of the formation to the south and east.

Light-gray to black chert is common in this lower facies as irregular blebs, fossil replacement, and layers ranging from a few tenths of an inch to a few inches thick. The cross cutting of original bedding and replacement of fossils indicate the chert is secondary. The chert may be a result of migration of silica from the bentonites of this interval, although a direct relationship remains to be proven.

Toward the top of this facies is a bryozoan-rich interval of skeletal wackestones to packstones (fig. 15B). In this zone brachiopods and echinoderms, which are the dominant fauna throughout the rest of the formation, are conspicuously rare or missing and the percentage of lime mud is comparatively much greater. This zone begins as thin (2-5 inches) layers in the central portion of the study area and thickens to the west. Because cores are required for accurate determination of the zone, its exact limits cannot presently be mapped. Fara and Keith (1989, fig. 2) have recognized this interval as a separate "bryozoan

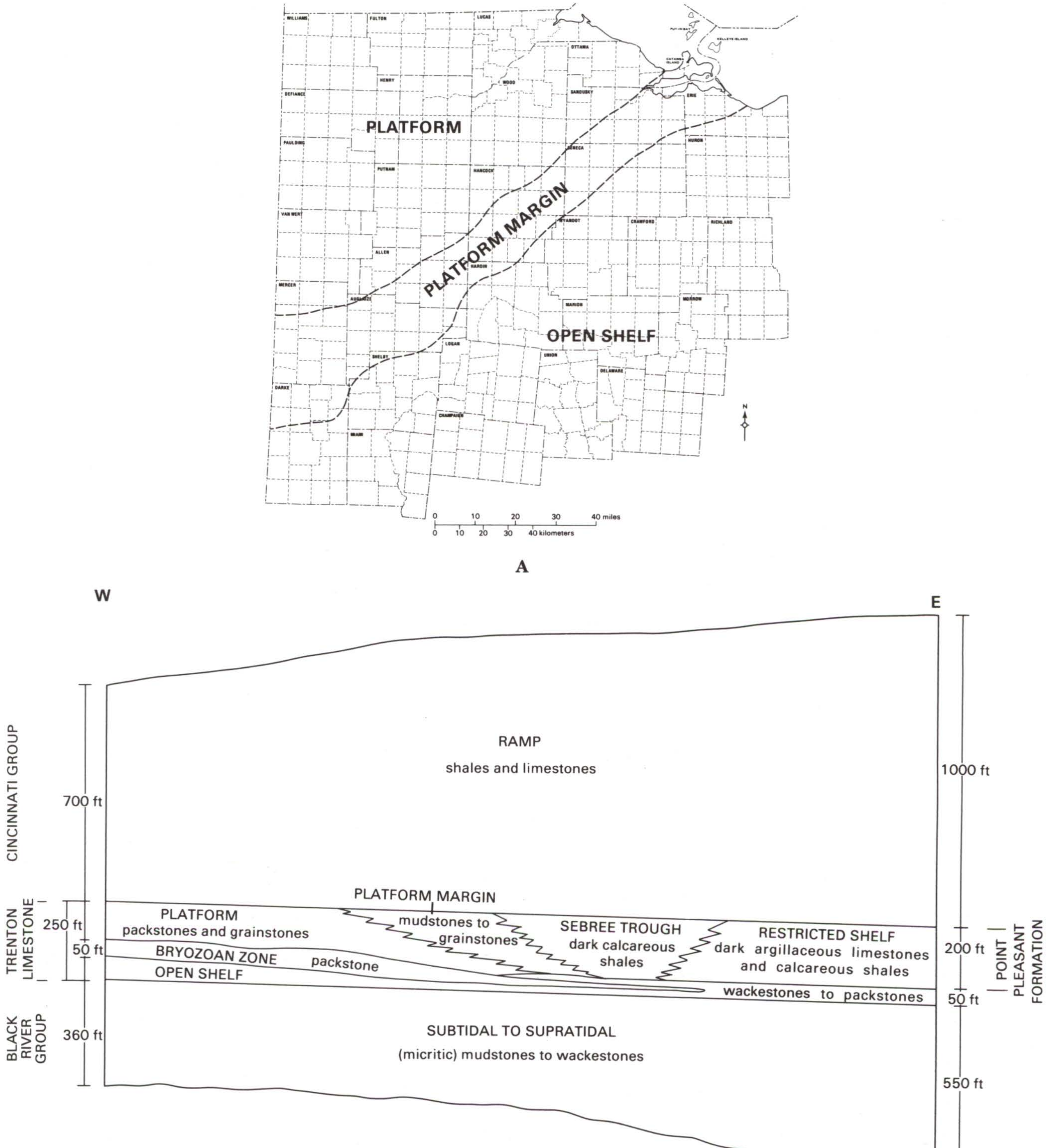


FIGURE 14.—Areal distribution (**A**) of the facies in the Trenton Limestone of northwestern Ohio and schematic, generalized east-west cross section (**B**) across study area illustrating relationships between facies and formations discussed in text. Datum = top of the Black River Group.

mound facies" in Indiana, where it is approximately 50 feet thick.

In the southeastern portion of the study area the upper part of this facies contains abundant dark-gray to black lime-rich mud. Within the lime mud are beds rich in whole brachiopod shells. These brachiopod-rich (coquina) beds range in thickness from a few inches to several feet and in some instances may be noted on gamma ray logs as the last "good" limestone kick at the top of the Trenton. These rocks grade upward into the Point Pleasant Formation, in which dark, organic shale is dominant.

We interpret the lower facies to indicate deposition in a normal-marine, subtidal, open-shelf environment. The interlayered character of the different textural limestone types probably indicates a combination of periods of storm-induced, higher energy deposition and calm-water deposition on minor topographic highs and lows which shifted about on the ancient sea floor.

The bryozoan-rich interval to the north and west and the increased amount of dark lime mud toward the top of the unit to the south and east record a lower energy, deeper water (below wave base) environment and transgression of the seas. The dark organic-rich character of the sediments and the abundant ostracodes common to the southeast indicate a lower oxygen content and more restricted circulation of the waters.

Platform facies

The platform facies, the second primary facies of the Trenton, overlies the basal open-shelf facies in the northwestern part of the study area (fig. 14) and constitutes the bulk of the Trenton thickness (approximately 100 to 225 feet). This facies consists predominantly of light- to dark-brown grainstones and packstones, which are commonly massively bedded (fig. 15C). Minor amounts of wackestone that is commonly wavy bedded, dark shale as partings and thin layers, and stylolites also occur in this facies, but to a much lesser degree than in the other two primary facies of the Trenton.

The dominant fossils observed include brachiopods and crinoids; bryozoans and trilobites are rare and scattered. The fossils are generally well abraded, and individual pieces range in size from microscopic to nearly whole specimens up to 2 inches across. Clear to white sparry calcite cement is common. Generally, the brachiopod and crinoid debris is so abundant that it forms thick sequences of brachiopodal-crinoidal grainstone. However, small sections have been noted which are rich in lime mud and shale. Near its base, this facies grades into the bryozoan mound zone of the open-shelf facies.

We interpret the rocks of the platform facies to have been deposited in shallow, open, normal-marine conditions common to carbonate platforms (Wilson, 1975). During most of its depositional time, currents and wave action were strong enough to winnow out carbonate muds and break and abrade the fossils. The thick sequences of crinoidal and brachiopodal grainstone in this facies probably represent platform-edge sands and local bars which shifted about on the shallow sea floor. The interlayered wackestone and shaly intervals represent brief periods of lower energy/deeper water or simply protected areas upon the platform.

Samples in the uppermost portion of the Trenton in parts of Williams and Fulton Counties contain a larger percentage of shale and may indicate an area which, toward the end of Trenton depositional time, experienced more restricted, deeper water conditions far back from the platform edge ("lagoonal"?). This area also may be indicative of the deepening (transgression) of the waters which ended Trenton deposition.

Platform-margin facies

The third primary facies of the Trenton, the platform margin, occurs along a zone of rapid thickening from Darke County to Ottawa County (fig. 14). This facies is highly variable in both thickness and rock types. The rock types range from lime mudstone to grainstone. All of the fossil assemblages common to the other Trenton facies can be found in the platform margin (foreslope of Wilson, 1975). The facies is characterized by scour features, lag concentrates of fossils, and lithoclasts (fig. 15D).

We propose that the platform of the Trenton in northwestern Ohio developed somewhat penecontemporaneously with basinal (Point Pleasant) deposition to the south and east and resulted in a very gentle slope on the platform margin. In essence, the margin was a transition zone between the deeper basinal water to the southeast and the shallower platform to the northwest. The diverse lithology and sedimentary features of this facies are the result of deposition in an area having high susceptibility to sea-floor disturbance by waves and storms. Much of the observed fauna were probably washed into this setting from outside the facies.

Contrary to what some earlier authors (Calvert, 1974; Henderson and Timm, 1985) have stated, there are no known reef buildups along the platform margin of the Trenton. Examination of samples and cores from this zone shows no evidence of such a buildup. Moreover, the optimal conditions conducive to reef growth (*i.e.,* steep break in slope and clear tropical waters) do not appear to have been present at this location. Lastly, the authors are aware of only one possible biohermal accumulation in the Ordovician, proposed by Read (1980), and that was deposited in a very different tectonic setting. In the core from Seneca County, Liberty Township, another depositional texture has been observed in the upper 50 feet of the Trenton (Wickstrom and others, 1985). A cross-bedded carbonate sand is interlayered with the lime mud and brachiopod-rich wackestone common to the open-shelf facies. This bed may represent a local wave-dominated shoal.

DOLOMITE IN THE TRENTON

In addition to the three primary facies of the Trenton, the original limestone has been dolomitized. Intercrystalline, interparticle, moldic, and vuggy porosity has developed in association with the dolomitization. Thus, the location of dolomitized sections is of prime concern when exploring for hydrocarbon reservoirs in the Trenton. All of the dolomite observed is secondary in nature, as evidenced by replaced and obscured fossils, crystal size and habit, and strong fabric selectivity (Davies, 1979), as well as the lack of any primary facies suggestive of supratidal deposition.

Dolomite, where present in appreciable quantity, in the Trenton is easily differentiated from limestone on geophysical logs. On neutron log curves, dolomite is distinguished by a marked deflection to the left relative to limestone, whereas on bulk density curves the deflection is to the right.

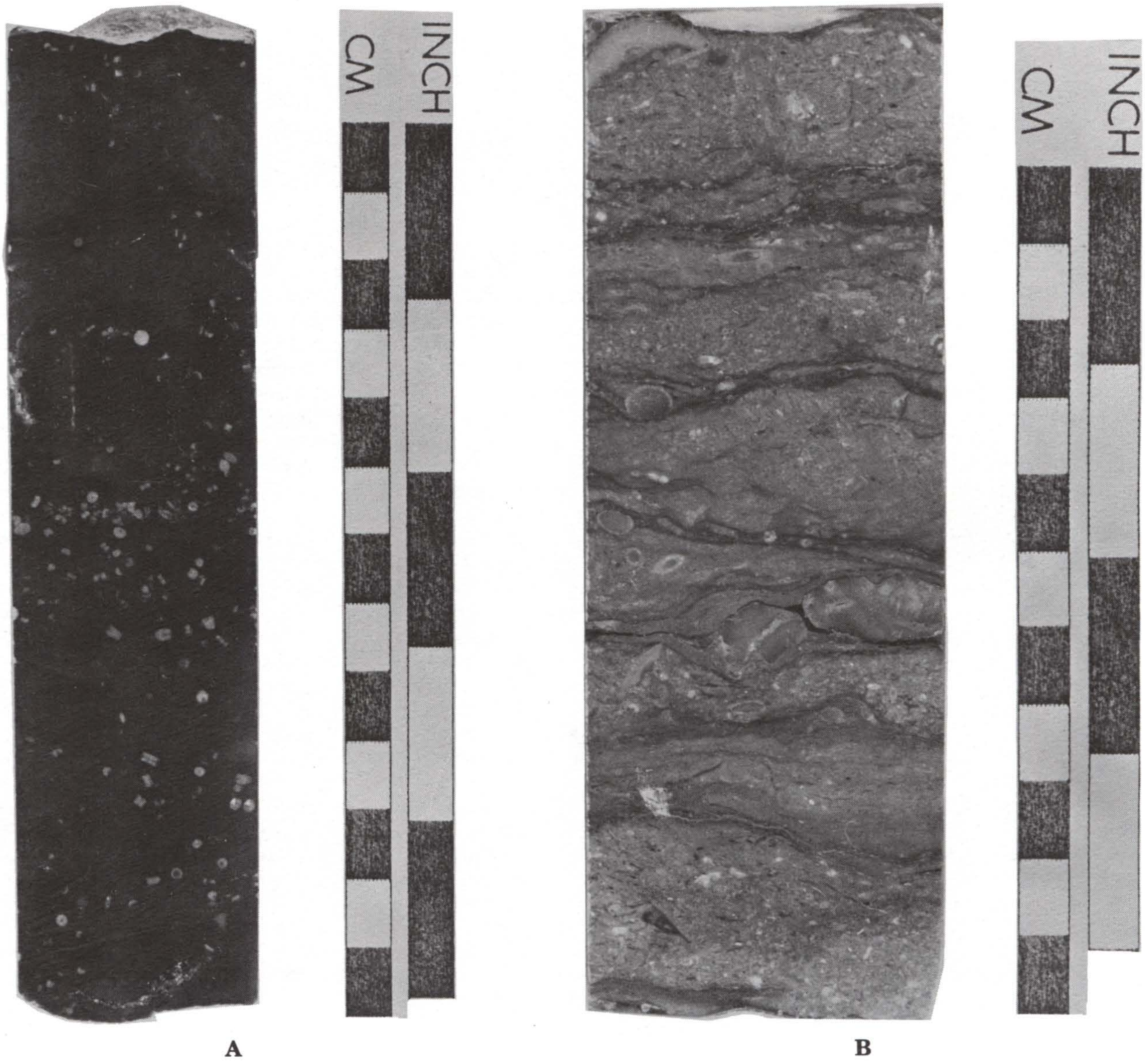
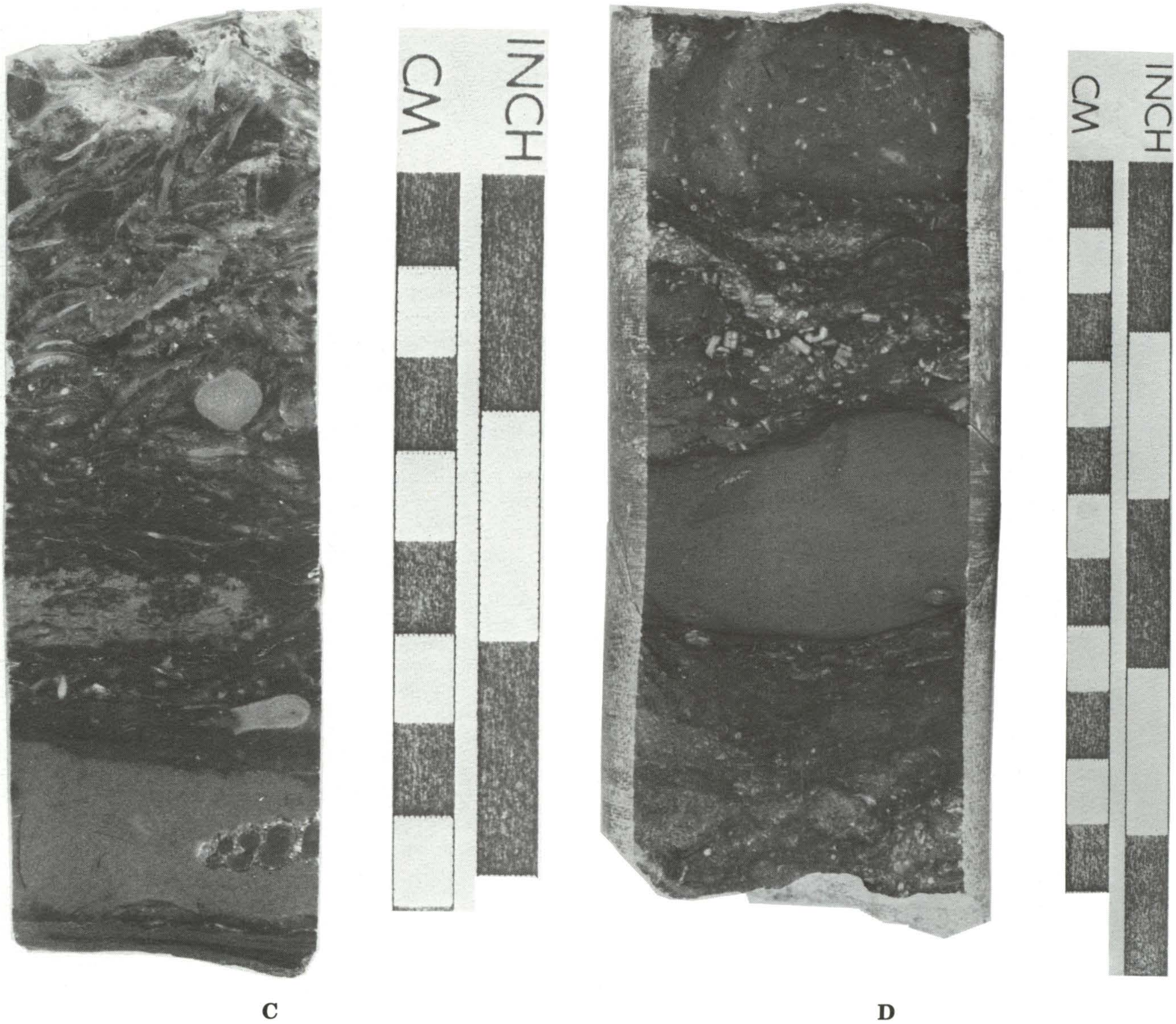


FIGURE 15.—Photographs of core slabs showing the common limestone textural types in the primary facies of the Trenton Limestone in northwestern Ohio. **A,** wackestone/mudstone of the open-shelf facies; OGS core #2580, Liberty Township, Seneca County, depth 1,526 feet. **B,** bryozoan packstone of the upper open-shelf facies; Marathon

Three types of dolomite, cap, fracture, and regional, have been described from the Trenton in Michigan and Indiana (Taylor and Sibley, 1986; Budai and Wilson, 1986; Keith, 1985; Fara and Keith, 1989). Taylor and Sibley (1986) have characterized these dolomite types using petrographic and chemical analyses of the Trenton in the Michigan Basin. Their basic findings appear valid over a large portion of northwestern Ohio as well, on the basis of petrographic and textural similarities. Cap and fracture dolomite have been identified in northwestern Ohio (fig. 16), but the presence of regional dolomite is questionable. In addition, there is a possible fourth type of dolomite in northwestern Ohio. For purposes of discussion, this type is called facies dolomite.

Cap dolomite

Cap dolomite is present in many wells in northwesternmost Ohio, principally in the platform-facies area (see fig. 14). It occurs at the very top of the Trenton Limestone and may reach thicknesses in excess of 50 feet. The cap dolomite is generally fine grained and has interlocking crystals and very little if any preserved porosity. Pyrite is common in the dolomitized cap and as a thin veneer on top of the formation. Fossils are completely to partially obscured, and thin shale streamers and stylolites are common. In Michigan (Taylor and Sibley, 1986) and Indiana (Fara and Keith, 1989), cap dolomite is relatively high in iron (ferroan dolomite) and managanese content.



Resources core TWC-4, Crane Township, Wyandot County, depth 1,523.5 feet. **C,** grainstone of the platform facies; OGS core #2549, Portage Township, Wood County, depth 1,336 feet. **D,** wackestone of the platform-margin facies; J & J Operating, Inc., permit no. 228, Big Lick Township, Hancock County, depth 1,313 feet.

Fracture dolomite

The second type of dolomite in the Trenton is closely associated with fractures and fault zones. This dolomite type is ferroan in the Michigan Basin area studied by Budai and Wilson (1986). The fracture dolomites are coarsely crystalline, with little or no original limestone texture preserved; typically, large saddle dolomite crystals line fractures and vugs. In cores located along such fractures, several generations of mineralization and brecciation have been observed (fig. 17A). Secondary minerals in these cores include dolomite, calcite, silica, pyrite, marcasite, magnetite?, selenite, sphalerite, and galena. The number of individual mineral types generally increases with depth, indicating an ascending origin for the mineralizing fluids (see discussion under Dolomitization models).

The lack of continuous cores prevents the authors from determining how extensive such mineralization may be in deeper units such as the lower Black River and the Knox. This type of mineralization has led to speculation that the Cambrian-Ordovician rocks of northwestern Ohio may contain economic deposits of sulfide minerals similar to Mississippi Valley-type deposits (Botoman and Stieglitz, 1978). Several exploration efforts have been directed toward such deposits in recent years; however, no economic concentrations have yet been discovered.

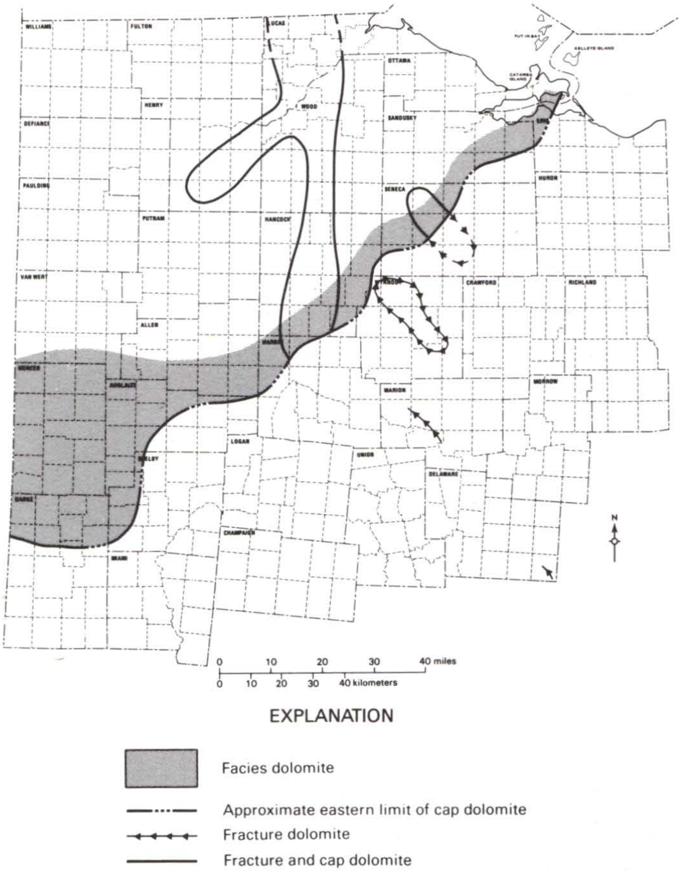


FIGURE 16.—Distribution of dolomite types in the Trenton Limestone in northwestern Ohio.

In the center of some of these fracture zones, replacement and late-stage mineralization in the Trenton have proceeded so far as to virtually seal any porosity which may have been developed in earlier stages (fig. 17A). In such sections, fracture, breccia, and vuggy porosity is rarely observed, and even the smallest fractures have been infilled with late-stage sparry calcite and dolomite. Any vugs in these zones are commonly lined with baroque, xenotopic dolomite crystals. Gregg and Sibley (1984) attribute this dolomite type to epigenetic fluid migration. Stieglitz (1975) has noted the occurrence of sparry dolomite and its association with fractures or structural features in the Trenton.

Farther from the main fracture zone, the amount and types of mineralization, the total thickness of replaced section, and the frequency of fractures decrease. Porous and permeable dolomites and dolomitic limestones (fig. 17B) occur in these areas. Typically this trend continues through an interfingered dolomite-limestone section until the section is once again composed of all primary limestone. This dolomite/fracture association is illustrated diagrammatically in figure 18. This association has been observed in cores from along the Bowling Green Fault Zone in Portage Township, Wood County; from Crane Township, Wyandot County; and from Harlem Township, Delaware County. This association doubtlessly occurs in many other areas, although cores were not available.

The lateral extent of mineralization, replacement, and solution-porosity enhancement away from such features appears to be dependent upon the magnitude of the fracture system. Along the Bowling Green Fault Zone the extent is on the order of miles. However, the extent of the fracture trend in Delaware County may be only hundreds of feet.

Regional dolomite

The existence in Ohio of any regional dolomite as described by Taylor and Sibley (1986) and Fara and Keith (1989) is questionable. Taylor and Sibley (1986, fig. 3) show regional dolomite only in southwestern Michigan, and Fara and Keith (1989, fig. 2) show it thinning dramatically from north-central to eastern Indiana. Scattered wells along the western edge of Ohio contain interlayered limestone and dolomite sequences which may represent the eastern limit of the regional dolomite type. However, no cores are available from this area for detailed analysis, and well cuttings are ambiguous. As described by Fara and Keith (1989), the regional dolomite is coarsely crystalline and nonferroan.

Facies dolomite

Along the platform margin (fig. 14), which coincides with the main arcuate body of the Lima-Indiana oil and gas trend, the possibility exists for a rather distinct type of dolomite—facies dolomite. In well cuttings, this dolomite is fine to coarsely crystalline. The lack of any cores located unequivocally in the platform-margin area prevents us from characterizing it in any detail. However, the geologic setting and the known voluminous production along this trend set facies dolomite apart from the other dolomite types. The distinctions between this dolomite type and the others will be dealt with at greater length in the next section on dolomitization models.

DOLOMITIZATION MODELS

The processes of dolomitization have been a subject of great debate for many years among earth scientists. It is of little surprise, therefore, that several hypotheses have been proposed to account for the origin of the dolomite in the Trenton in northwestern Ohio. Maxey (1979) attributed a portion of the dolomite in northwestern Ohio to primary deposition. Rooney (1966) ascribed much of the dolomitization at the top of the Trenton to subaerial exposure and the effects of karstification. Stieglitz (1975) suggested the dolomitization is post-Cincinnatian in age and proposed a system similar to the Dorag dolomitization model of Badiozamani (1973). Evidence for and against previously suggested dolomitization models and those which appear viable are discussed below.

Primary precipitation of dolomite

Maxey (1979, p. 48, fig. 15) suggested that dolomitization of an area in the west-central part of the platform facies of the Trenton was the result of a "tidal flat, tidal channel model of dolomite deposition." The dolomites of this area are similar to those across the entire platform facies, that is, they contain shale interbeds and, replaced and partially obscured fossils and appear to be fabric selective. These features plus the fact that the fossil assemblage represents a more open-marine environment argue for a replacement

FIGURE 17.—Photographs of core slabs showing examples of dolomitization of the Trenton Limestone along fracture zones. **A**, heavily fractured and dolomitized limestone with little or no preserved porosity; OGS core #2549, Portage Township, Wood County, depth 1,140 feet. **B**, dolomitized limestone with good preserved porosity; OGS core #2581, Bloom Township, Wood County, depth 1,160.8 feet.

origin for the dolomite. In addition, the absence of any appreciable amounts of associated evaporites, or even evaporite ghosts, indicates that sabkha or other restricted-circulation environments in which primary dolomite may be deposited did not occur to any appreciable degree in the Trenton of northwestern Ohio.

Dorag (mixed-water) dolomitization model

Badiozamani (1973) proposed a model in which a fresh-water mass interacting with a saline-water mass produced replacement dolomite in the Ordovician strata of Wisconsin. Using Badiozamani's model as a basis, Stieglitz (1975) suggested the formation of a ground-water lens related to a post-Cincinnatian regression of the sea as a possible explanation for the dolomitization at the top of the Trenton. Davies (1979, p. 9) stated that "Corollaries of the mixed-water dolomitization models are that the development of a fresh-water zone may be related to tectonic highs . . . ."

It is possible that, if a post-Ordovician/pre-Silurian regression and exposure took place, a water table or lens of fresh water was established at the contact between the Trenton Limestone and the Cincinnati group. However, it seems a formidable task to introduce the volume of water required for dolomitization through over 750 feet of largely impermeable shales and limestones. A version of the Dorag model may still be viable, under a different timing scheme, to explain a portion of the dolomitization (largely the cap

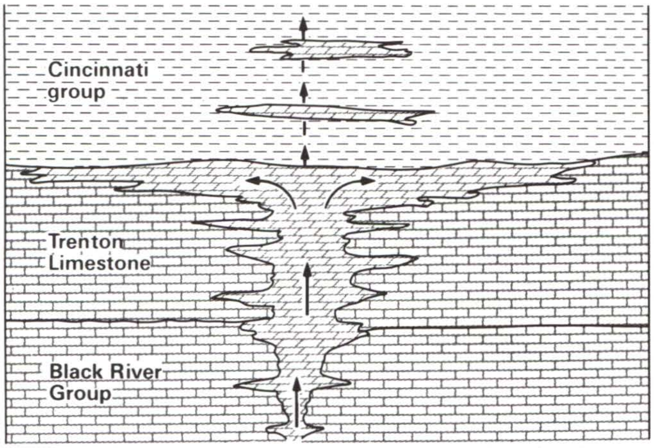


FIGURE 18.—Diagrammatic model of dolomitization along fracture trends in the Black River Group and Trenton Limestone of northwestern Ohio. Fractures and faults act as conduits of migration for ascending fluids. As the fluids cool and react with the host rock, dolomite and other secondary minerals precipitate.

dolomite) in the Trenton; isotopic analyses would greatly aid any further discussion.

Subaerial exposure and effects of karstification

Rooney (1966) hypothesized an unconformity at the top of the Trenton Limestone in northwestern Ohio and eastern Indiana and ascribed much of the dolomitization to the effects of this exposure surface. If the Trenton had been subaerially exposed prior to deposition of the Cincinnati group, features indicative of emergence such as caliche and/or an erosional surface topography should be present. Such features have not been observed in the Trenton. Further, the large amount of relief on the Trenton surface reported by Rooney (1966) in the Kentland Quarry of Indiana has subsequently been interpreted by the Indiana Geological Survey as a fault surface (Brian D. Keith, personal communication, 1985).

Keith (1985) and Fara and Keith (1989) have proposed that the upper Trenton surface represents a submarine corrosion surface and have presented evidence from cores in Indiana to support this hypothesis. Cores which contain this contact in Ohio exhibit the same general features as reported in Indiana—very small amount of relief (<3 cm), bands of pyrite and phosphate mineralization, and pebbles of Trenton lithology (fig. 19A). Contact zones which do not have these features are invariably from cores along fault zones, where greater relief and mineralization would be expected, or are from the area in which the Trenton is overlain by the Point Pleasant Formation, where the contact is gradational (fig. 19B).

In short, the Trenton Limestone-Cincinnati group contact in northwestern Ohio resembles more a mineralized hardground surface than a subaerial unconformity. Hardgrounds are thought by most researchers (for example, Bathurst, 1971; Kennedy and Garrison, 1975) to represent short interruptions in sedimentation (diastems) and periods of submarine exposure rather than subaerial unconformities.

Shale dewatering

Davies (1979) discussed the arguments presented by Illing (1959) and Jodry (1969) for dolomitization of permeable reefal limestones by waters derived by compaction of adjacent or enclosing shales. McHargue and Price (1982) discussed, in detail, dolomitization of carbonates associated with argillaceous sediments in which the conversion of smectite to illite provides a source for both iron and magnesium. The lithostratigraphic relationships exhibited in northwestern Ohio suggest that shale dewatering may be responsible for at least two types of dolomite (facies and cap) in the Trenton which may be closely related to one another in timing and genesis. This dolomitization model may explain the bulk of the dolomite in the Trenton in northwestern Ohio and be responsible for much of the extent of the giant Lima-Indiana oil and gas trend.

The Trenton Limestone is directly overlain by shales of the Cincinnati group in the platform-facies area; this area is also the only area in which cap dolomite is common in the Trenton in Ohio. This same stratigraphic relationship exists in Indiana (Keith, 1985) and Michigan (Taylor and Sibley, 1986) where the Trenton contains cap dolomite. This interdependence supports a shale-dewatering model for the Trenton cap dolomite in which fluids expelled from the overlying shales during compaction migrated downward into more permeable limestone.

Another possible variation of this model is that the fluids responsible for dolomitization were expelled from the shales of the Cincinnati group and/or the Point Pleasant Formation and their equivalent units in deeper portions of the surrounding basins and migrated upward to the edges of the subsiding basins. This scenario of migration would best define the genesis of the "facies dolomite" trend. Cap dolomites are typically higher in iron content than the other dolomite types. Therefore, reason suggests that at least a partial difference in the source fluids existed. The simplest explanation appears to be that the overlying Kope Formation supplied at least a portion of the fluids for the cap dolomite and was not a major contributor of dolomitizing fluids for the other types of dolomite to any appreciable degree.

The "facies dolomite" trend in northwestern Ohio occurs along the platform margin where the Trenton thickens dramatically (figs. 10, 14, and 16). This area was in a unique position to receive fluids which migrated out of the deeper portions of the Appalachian Basin. Here the Trenton appears to be equivalent to the Point Pleasant Formation. As the Point Pleasant sediments were compacted during progressive burial in the Appalachian Basin, the expelled fluids would be expected to migrate updip (see pl. 1, structural cross sections A-H, D-G). The updip migration would put these fluids in contact with the platform-margin- and platform-facies limestones of the Trenton. An additional point is that the giant Lima-Indiana oil and gas trend (fig. 2) largely coincides with the zone of this lithofacies change. In this scenario the early high-magnesium connate fluids could have allowed dolomitization of the "leading edge" of the thick deposits of the Trenton, thereby opening channels of porosity and permeability, which later migrating hydrocarbons filled.

Admittedly, the introduction of a fourth dolomite type along this trend is speculative; however, the geologic position of the facies dolomite is markedly different than that of the other dolomite types. Detailed petrographic and geochemical analyses are needed along this trend to aid in the determination of its genesis. The area of occurrence of this dolomite type contains many geologic complexities; it is likely that dolomitization along this zone was not caused simply by shale dewatering and migration to the facies change. Structural trends such as the Logan-Hardin, Union, Auglaize, and Anna-Champaign Faults, which will be discussed later, may reveal that this dolomitization process was at least enhanced by the presence of faults which are situated both parallel and perpendicular to the facies dolomite trend.

Dolomitization by ascending fluids

As already stated, dolomitization as well as other secondary mineralization is prevalent in the Trenton along

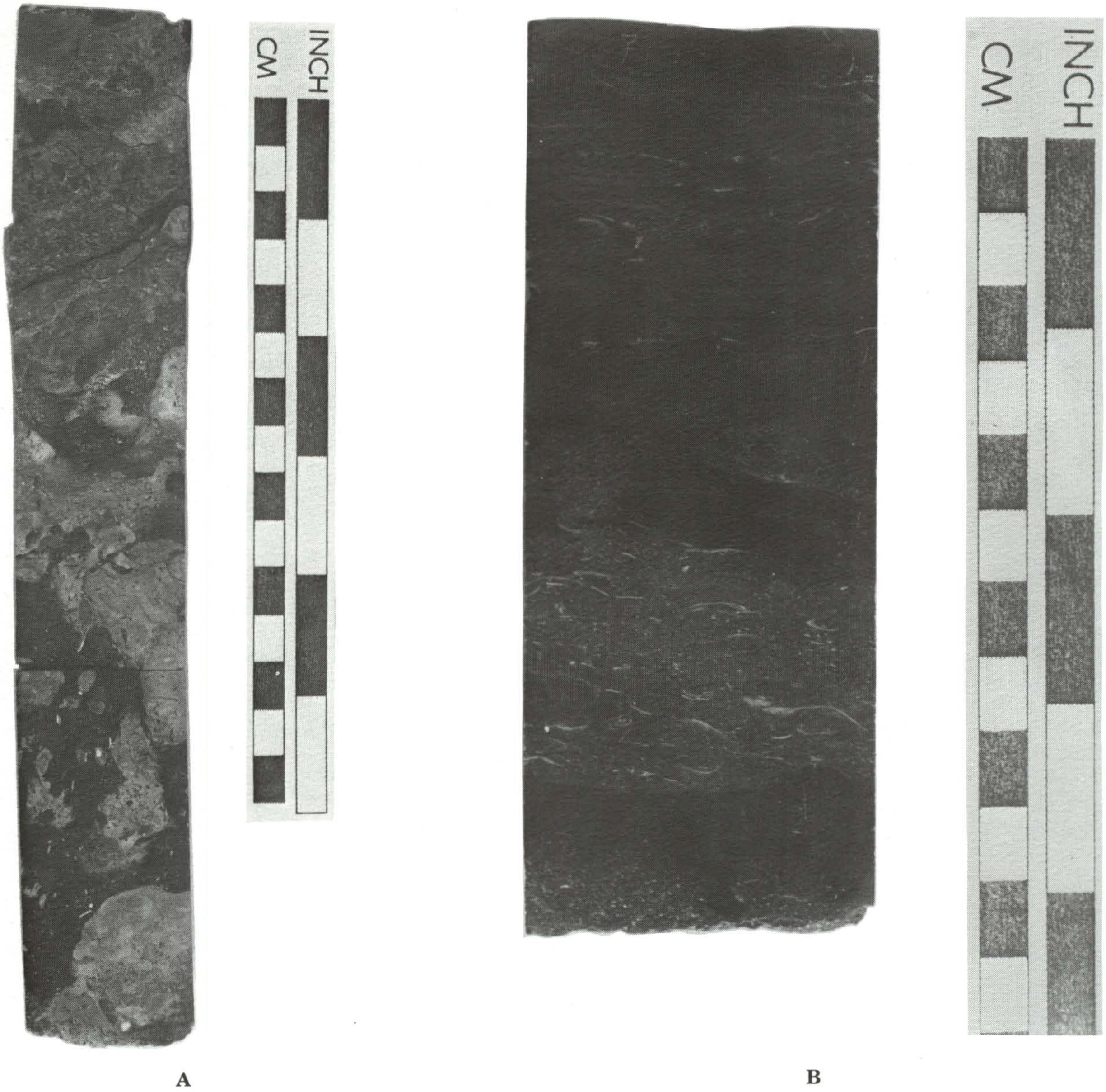


FIGURE 19.—Photographs of core slabs showing the contact between the Trenton Limestone and the overlying shales. **A**, sharp contact with heavy pyrite mineralization and dolomitization at the contact zone; OGS core #2549, Portage Township, Wood County, depth 1,107.5 feet. **B**, gradational contact characterized by alternating bands of dark calcareous shale and brachiopod-rich limestone layers; Marathon Resources core TWC-4, Crane Township, Wyandot County, depth 1,512.2 feet.

fault and fracture zones. The diversity of mineral types and textural and chemical differences call for a separate dolomitization mechanism for this fracture dolomite. Cores from along these zones indicate that the types of mineralization increase with depth, suggesting ascending fluids as the transport medium, as illustrated in figure 18. Preliminary strontium and oxygen isotope analyses (proprietary data) from dolomites along such fractures indicate high temperatures of formation (100-120 degrees Celsius), which point to ascending, epigenetic fluids. Textural and chemical analyses of the baroque dolomites common to the fracture zones of the Trenton in the Michigan Basin (Gregg and Sibley, 1984) also indicate an epigenetic source. Many Trenton reservoirs have been located along fracture zones, both in the carbonate buildup of the platform and platform-margin facies and in the shelf facies. The most prolific production from the Lima-Indiana trend was from the area along the Bowling Green Fault Zone. Fracture-associated reservoirs, such as the Harlem gas field in Delaware County (see fig. 28), are the only known hydrocarbon traps producing from the Trenton in the southeastern third of the study area.

The ultimate source for these fluids remains undetermined at present. The two most probable sources for these fluids are (1) low- to moderate-temperature (epigenetic) hydrothermal fluids emanating from deep-seated igneous bodies, and (2) saturated connate brines expelled from shales and other sedimentary rocks from deeper in the basin. The aeromagnetic map of Ohio (Hildenbrand and Kucks, 1984a) displays an abundance of anomalous areas related to the Precambrian basement in northwestern Ohio (see fig. 5). A number of these anomalies have been interpreted (W. H. Hinze, personal communication, 1984; Lucius, 1985) to represent plutonic bodies. If this interpretation is correct, these bodies would be a very good source for the metals in the Trenton mineralized zones. This source, however, is heavily dependent upon the time of emplacement of these bodies and other factors. Many more specific chemical analyses will be required to allow a better interpretation.

In summary, there are a number of models by which the origin of the dolomite in the Trenton may be explained. All of the dolomite in the Trenton (and most in the Black River) can be interpreted as postdepositional and indicates diagenetic events involving some scale of fluid movement. On the basis of observed relationships and available data, the authors believe that the majority of the dolomite can be attributed to a combination of shale-dewatering and epigenetic fluid migration along fractures. However, the exact composition and origin of the fluids as well as the exact timing of the different events remain questionable.

STRUCTURE

Structural cross sections (pl. 1) across the study area and structure contour maps on top of the Knox Dolomite (fig. 20), Trenton Limestone (fig. 21), and Cincinnati group (fig. 22) have been constructed. Portions of the following discussion were published previously (Wickstrom, 1990) but are included here for completeness.

The Findlay Arch (see fig. 3) is the dominant positive structural feature in the study area and, in part, separates the Appalachian and Michigan Basins. The crest of the arch is 15 miles wide in Hancock, Seneca, and Wyandot Counties. Northeastward it broadens to as much as 40 miles in Lucas and Ottawa Counties. The Findlay Arch extends for approximately 40 miles in Ohio and plunges northeastward at a rate of 15 feet per mile. The east limb of the arch dips toward the Appalachian Basin at a maximum rate of 25 feet per mile; the west limb is bounded by the Bowling Green Fault Zone; west of this fault, dip may locally exceed 200 feet per mile into the Michigan Basin. To the south the Findlay Arch is bounded by the the Outlet Fault Zone (see fig. 23).

The Indiana-Ohio Platform, a broad, structurally high area characterized by nearly flat-lying strata, dominates the central and southwestern portions of the study area. This feature, as defined by Green (1957), underlies nearly 10,000 square miles in Indiana and Ohio and separates the Appalachian, Illinois, and Michigan Basins. This area is more the result of differential subsidence in the surrounding basins than of arching or uplift.

The Indiana-Ohio Platform in the central and southwestern portion of the study area constitutes the structurally highest part of the area. Some closure is evident. Although well control is quite limited in the southwestern third of the study area, the contours drawn on the top of the Knox Dolomite (fig. 20) in that area generally resemble a paleodrainage pattern. If this interpretation is correct, it is most likely that drainage on this surface developed during the time of the post-Knox erosional unconformity.

The position of this pattern coincides with the proposed position of the failed Precambrian rift zone near Anna (Shelby County) discussed earlier; this rift zone may have been the underlying structure controlling this drainage. Moreover, this pattern aligns well with one of the anomalous areas of thinning on isopachs maps of the Point Pleasant Formation (fig. 12) and the combined Point Pleasant-Cincinnati group (fig. 13). Using a combination of these trends, the Anna-Champaign Fault of Kiefer and Trapp (1975) has been redefined as shown on figure 23. Lastly, the pattern mapped on the Knox is also coincident with bedrock stream valleys buried by glacial deposits and called the Teays River system (Stout, Ver Steeg, and Lamb, 1943). The coincidence of structural, thickness, and drainage anomalies in the same area may be good indication of a deep-seated structure which has been reactivated periodically throughout the Paleozoic.

BOWLING GREEN FAULT ZONE

The Bowling Green Fault Zone is another major structural feature in northwestern Ohio and has been mapped on all the structure maps in this report. This feature was first noted by Orton in 1886, who referred to it as the "Findlay Break." Since then, it has been interpreted by various authors as a high-angle normal fault, a high-angle reverse fault, a monocline, or simply as the "Bowling Green structure." The Bowling Green Fault Zone is well expressed on the aeromagnetic map of Ohio (Hildenbrand and Kucks, 1984a) (see fig. 5) as a linear trend composed of small, negative, elongate anomalies running north-south from Hancock County to Lucas County. The position of the fault zone can also be noted on the geologic map of Ohio (Bownocker, 1920) where the contact between the Silurian and Devonian bedrock turns north-south along the fault rather than following the general arcuate northeast trend of the other bedrock contacts in that area.

On the basis of cored sections, seismic and well data, and quarry exposures along the trend, we interpret the Bowling Green structure to be a complex fault zone of considerable magnitude with the upthrown side to the east (pl. 1, structural cross section B'-J'). In Ohio, the fault zone extends at least 45 miles from central Hancock County northward through Wood and Lucas Counties (figs. 20-23). The trend of the fault zone is sinuous, ranging from N6°W to N20°E to N26°W. Total displacement across the zone is approximately 500 feet in Ohio, but it is difficult to determine how much is due to folding west of the fault versus actual vertical offset along most of its length. At the position of a proprietary seismic profile made available to the Ohio Geological Survey, the faulting is interpreted to be reverse in nature with approximately 250 feet of displacement on the Trenton surface (fig. 24). Reliable well control in Hancock County suggests approximately 100 feet of displacement there. Secondary (and tertiary?) faulting and folding are associated with this fault zone as can be seen on the structure maps and the seismic profile. The

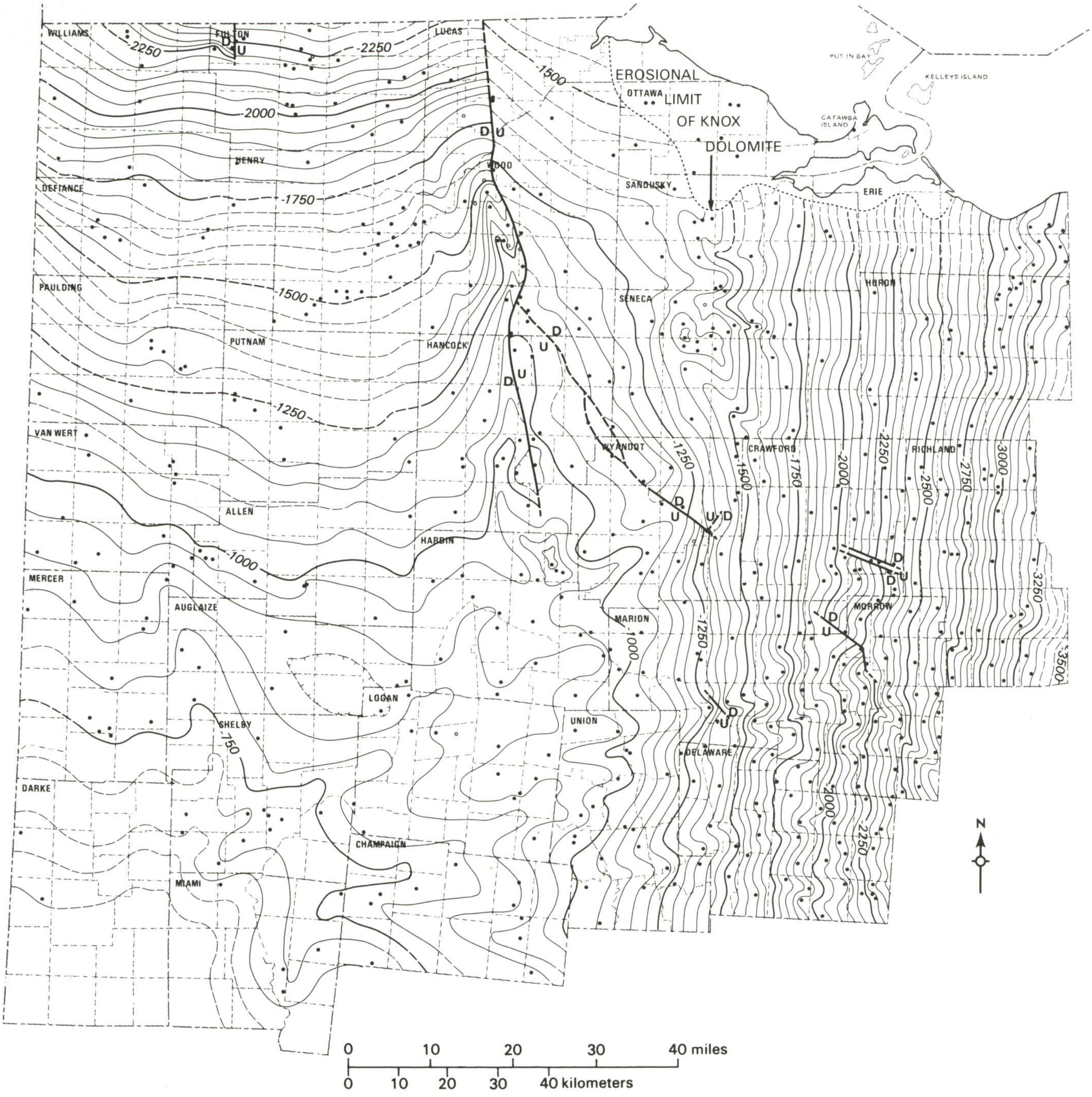


FIGURE 20.—Structure contour map drawn on top of the Knox Dolomite. Contour interval 50 feet. Erosional limit in north-central part of map after Janssens (1973).

Bowling Green Fault Zone extends northward into southeastern Michigan, where it is the structure credited with the reservoir development of the Deerfield field. Displacement in this area is thought to be approximately 500 feet (R. J. DeHaas, personal communication, 1985).

Because of the varying trend of the fault, changing offset along its length, associated folding, and a number of secondary faults (of which the Outlet Fault Zone may be the largest), the Bowling Green Fault Zone is interpreted to be the principal disturbed zone in a complex wrench-fault system, as depicted in figure 25. The basic mechanics of this type of fault system have been discussed by Wilcox and others (1973); an excellent overview is provided by Christie-Blick and Biddle (1985). In this type of fault system, lateral (strike-slip) and vertical offsets are common along the principal disturbed zone as well as the associated faults. Present data do not allow determination of the amount (if any) of lateral movement along the Bowling Green Fault Zone, although along a zone of this magnitude it may have been considerable.

We have interpreted the largest bend in the fault trace to represent a restraining bend (as described by Wilcox

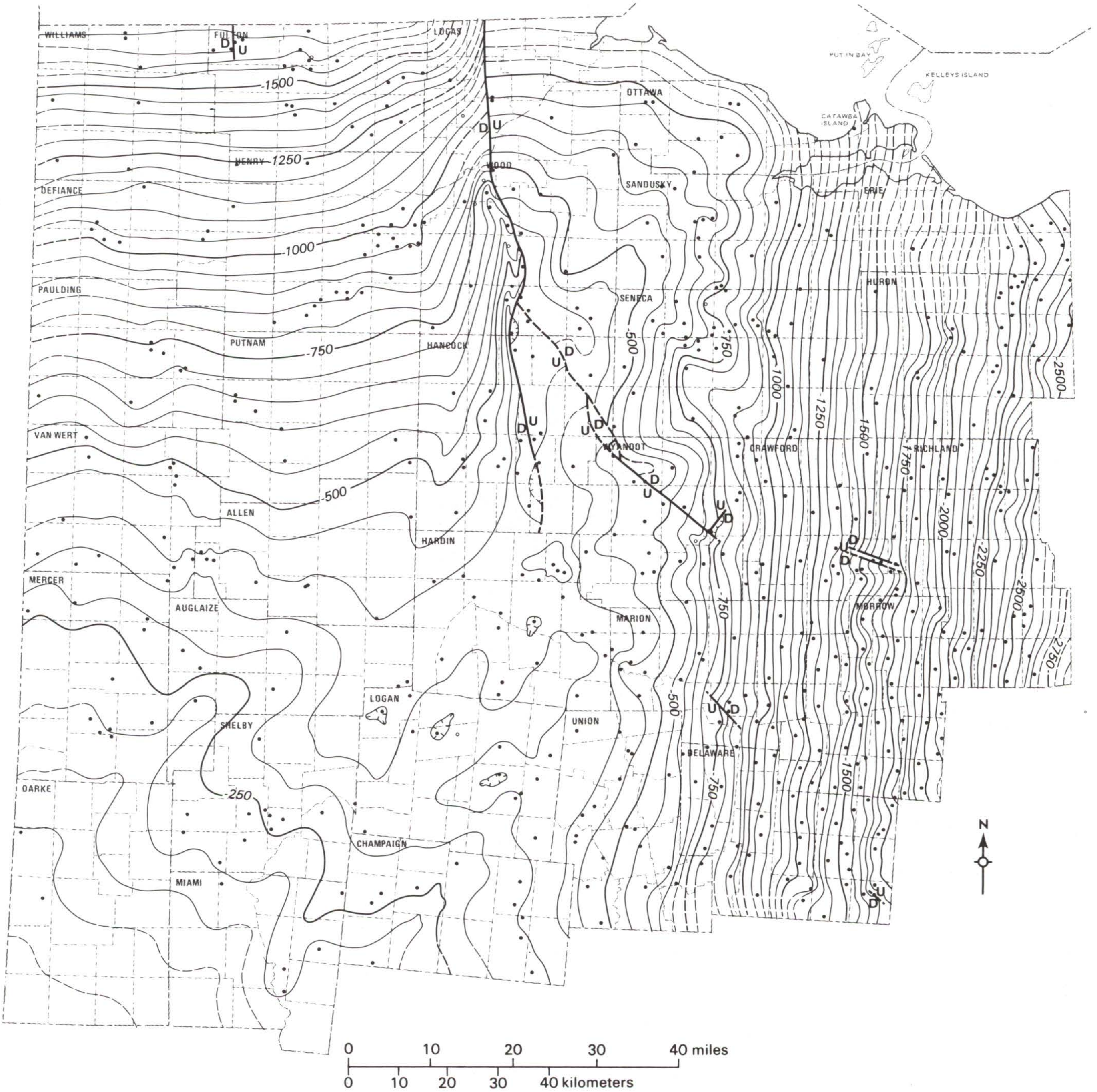


FIGURE 21.—Structure contour map drawn on top of the Trenton Limestone. Contour interval 50 feet.

and others, 1973) (fig. 25) along which the most prominent associated folding has occurred (figs. 20-22). This sequence of folding appears to contain elements of both a compressional and a drag nature. The oil and gas fields (compare fig. 28) located along this sequence of folds had some of the highest initial and cumulative production figures of any areas in the entire Lima-Indiana trend.

Detailed (1:62,500 scale) mapping (unpublished, Ohio Division of Geological Survey) along the faults, using historic drillers' records and modern geophysical logs, reveals a very shattered, unpredictable surface which is thought to be the result of a complex zone of primary and secondary, synthetic and antithetic faults (fig. 25). Available cores and samples from this area indicate a large amount of brecciation.

Presently available data suggest that there have been at least three episodes of movement along the Bowling Green Fault Zone: Precambrian, Ordovician, and Silurian(?) or later. Evidence for a Precambrian episode is the position of the Bowling Green Fault Zone coincident with the location of the late Precambrian Grenville Front. The seismic profile in figure 24 also may be interpreted

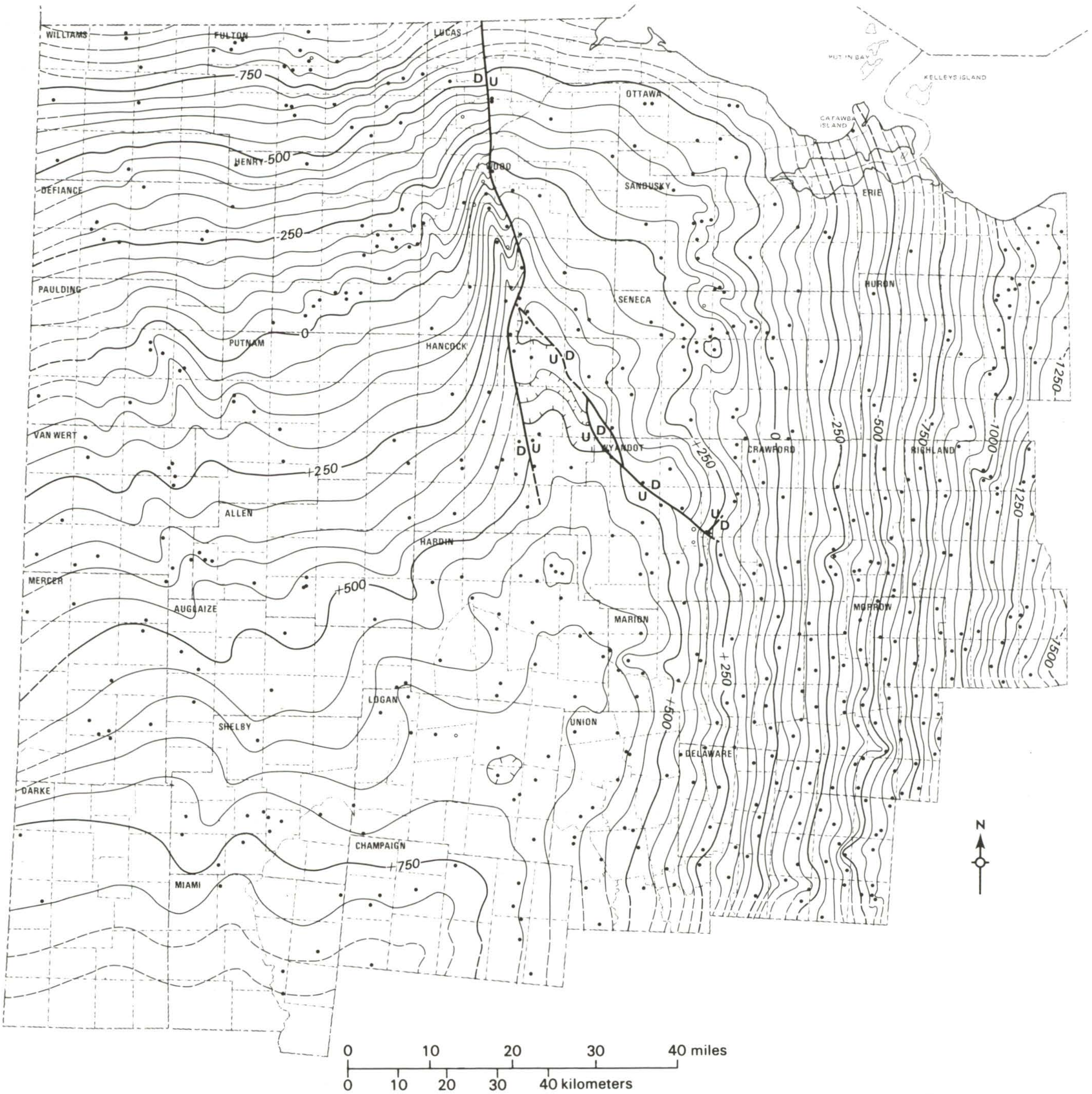


FIGURE 22.—Structure contour map drawn on top of the Cincinnati group. Contour interval 50 feet.

to support Precambrian movement on the Bowling Green Fault Zone.

An Ordovician episode of faulting along this zone is evident in the seismic profile (fig. 24). A reflection horizon, identified by an arrow in figure 24, in the basal Cincinnati group terminates in the anticlinal structure west of the Bowling Green Fault Zone. To the east, this same reflection horizon terminates in the fault zone. This evidence may indicate that the fault and associated anticline existed before deposition of the basal Cincinnati group, and, therefore, that an episode of faulting occurred during, or slightly after, deposition of the upper Trenton Limestone. This episode of faulting was probably in response to the increasing intensity of the Hudson Valley phase of the Taconic Orogeny as proposed by Titus (1989).

In exposures (figs. 26, 27) of the Bowling Green Fault Zone, the Silurian bedrock is folded and faulted, indicating an episode of activity along this zone during late Cayugan (Silurian) time and/or later.

In addition to the vertical displacement along the Bowling Green Fault Zone, at least two lines of evidence suggest there have been lateral components of movement: (1) the apparent drag direction of the folding on the west

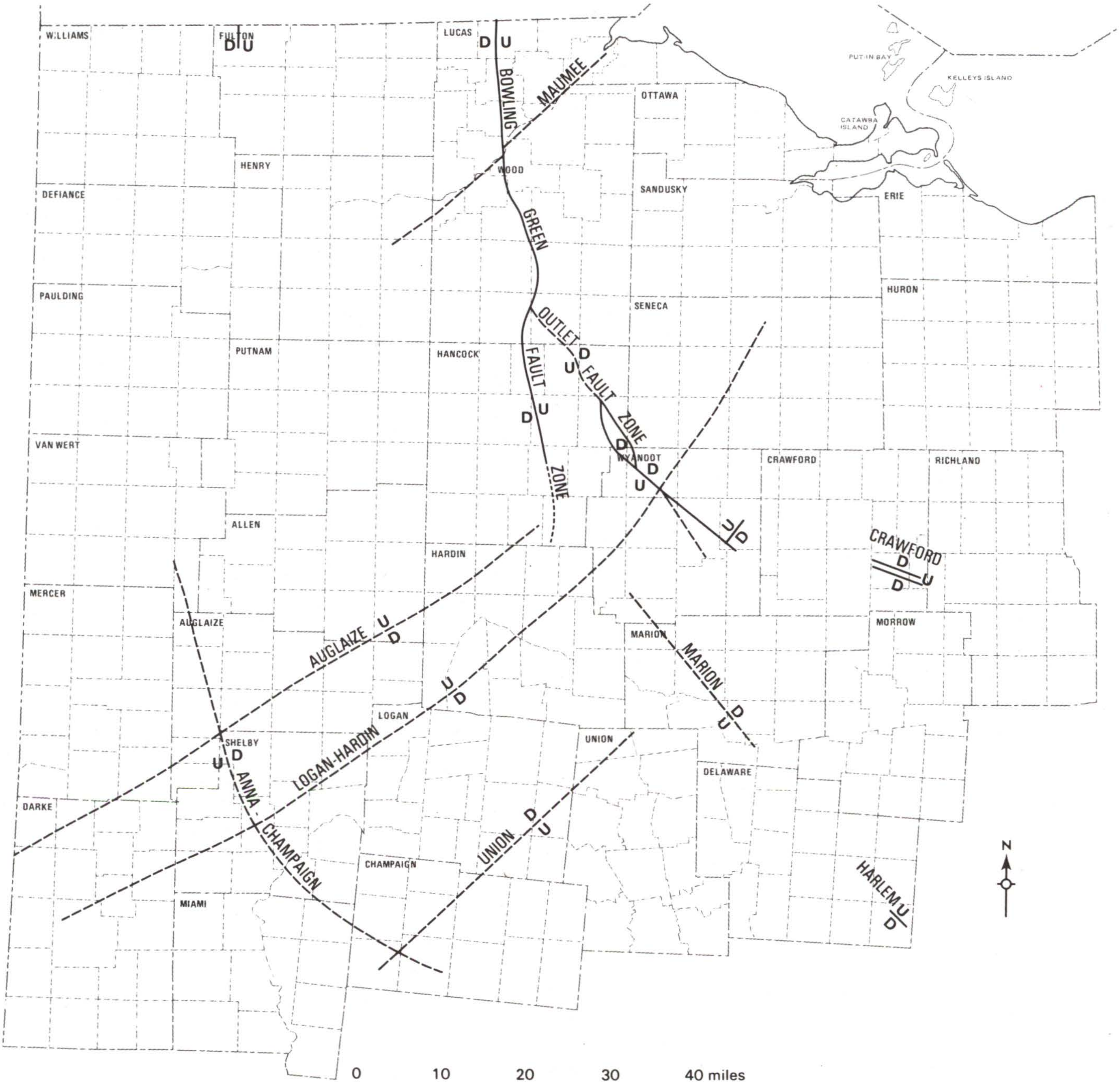


FIGURE 23.—Mapped (solid lines) and inferred (dashed lines) faults in northwestern Ohio. See text for discussion.

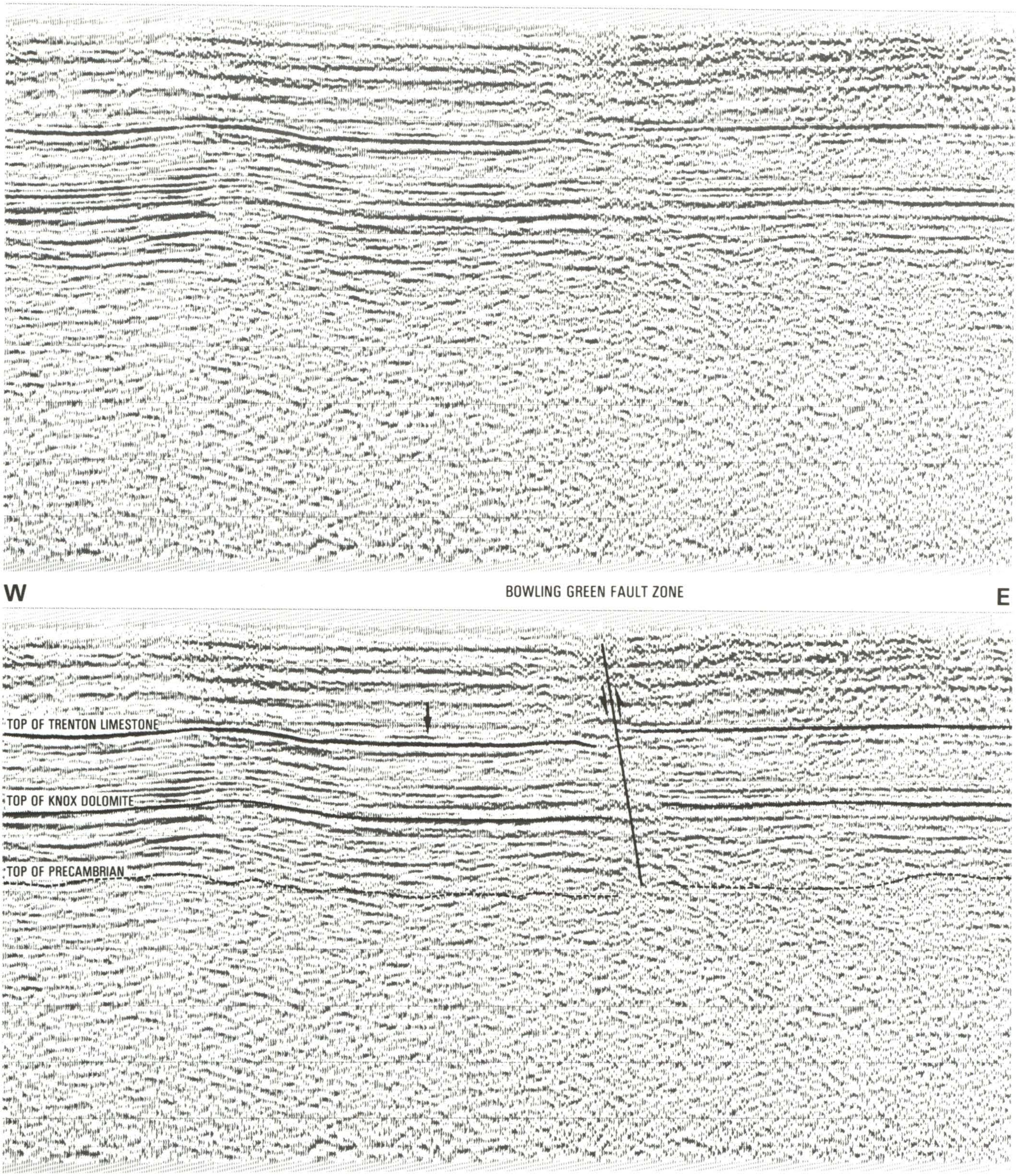


FIGURE 24.—East-west seismic profile across the Bowling Green Fault Zone in central Wood County, Ohio. Top, uninterpreted; bottom, interpreted. Arrow points to reflection horizon used as timing indicator. Portion of line shown is approximately 3.5 miles in length and extends vertically from 0 to 1.0 second. The original, nonexclusive seismic line is the property of, and proprietary to, CGG American Services, Inc., and is used here with permission.

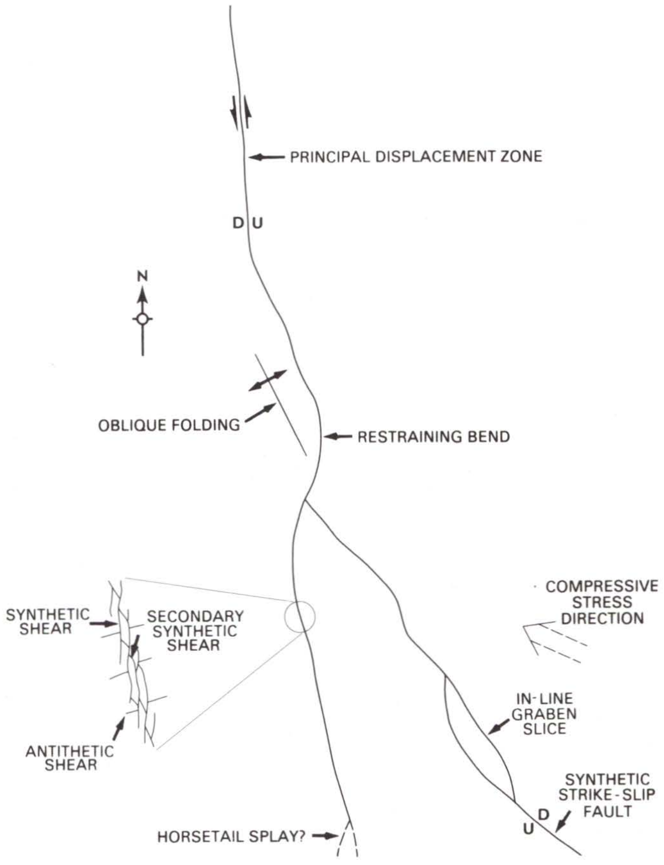


FIGURE 25.—Diagram showing relationships of Bowling Green Fault Zone, Outlet Fault Zone, and associated folding and compressive stress direction, movement directions, and wrench-fault terminology.

side of the fault (figs. 20-22) and (2) of the shift of the present-day Maumee River (and location inferred Maumee Fault of figure 23) as it crosses the position of the fault zone. Both lines of evidence support a left-lateral displacement along this zone, although each of them probably represents widely separated reactivation events. Left-lateral movement along the Bowling Green Fault Zone would fit the regional tectonics of the Taconic Orogeny, which, in this area, would have had compressive forces originating from the east-southeast (fig. 25). Much detailed work along this zone is needed before additional analysis of its movements can be made.

Although the Bowling Green Fault Zone is not depicted as a fault on the isopach maps of this report, it has influenced deposition. An anomalous thinning of the Black River Group at the southern end of the Bowling Green Fault Zone is coincident with associated anticlinal highs and areas of closure on the Trenton and Knox structure maps, and may indicate smaller scale movement during the late Cambrian. In addition, the isopach map of the combined Cincinnati group-Point Pleasant Formation has anomalous contours crossing this fault zone. The thickness of the Trenton Limestone does not appear to have been affected, further supporting the post-Trenton timing of the Ordovician episode of movement.

OUTLET FAULT ZONE

Another major structural feature mapped during this investigation is the large northwest-trending fault system running from Wyandot County to Wood County. This feature is named the Outlet Fault Zone, after a stream originating in northwestern Wyandot County. Large quantities of oil and gas were found along this zone in Wyandot County in the 1930's (the Carey, Upper Sandusky, and Tymochtee fields; see fig. 28) and from its northern extension as part of the Lima-Indiana trend. In Wyandot County this fault system can be fairly well documented with existing well logs and records. However, along the northern portions of this system reliable well data become scarce, and lineaments and old drillers' records must be used to define it.

Detailed analysis of the movement along this system or determination of the exact intersection with the Bowling Green Fault Zone cannot be made using existing data. However, we believe this system is related to the Bowling Green Fault Zone (fig. 25); the Outlet Fault Zone is interpreted as a large synthetic (Reidel) shear zone. The

FIGURE 26.—Photograph of the surface expression of the Bowling Green Fault Zone; gouge zone in the north wall of the France Stone Co. Waterville quarry, Waterville Township, Wood County. Photo taken during summer 1985 and courtesy of France Stone Co.

sense of folding and nature of displacement in the upthrown block between the two faults (fig. 21) also support a direct relationship.

Examination of cores and drilling records from this area show that the Trenton has been extensively fractured and brecciated, although the width of the breccia zone is much smaller than that associated with the Bowling Green Fault Zone. Here the zone is on the order of a few hundred to a thousand feet wide. Vertical displacement ranges along its length from approximately 20 feet to over 100 feet. As with the Bowling Green Fault Zone, lateral displacement, if any, cannot be determined. Associated folding in this system undoubtedly is far more intense than shown on the maps.

Deposition of the overlying Cincinnati group, and perhaps the Point Pleasant Formation, was affected by this fault system, as may be seen on figures 12 and 13. However, thicknesses of the Trenton Limestone (fig. 10) and Black River Group (fig. 8) apparently were not influenced by this fault, further supporting a late Ordovician time of movement.

INFERRED FAULTS

Unpublished studies by Kiefer and Trapp (1975), Heidorn (1975), Quick (1976), Krupa (1980), and McPhee (1983) have postulated the existence of a number of northeast-trending faults or fractures in northwestern Ohio which had not been recognized previously. These postulated faults have been reevaluated in this investigation and our interpretations are shown on figure 23. Also shown on figure 23 are a number of additional, inferred areas of faulting that have been noted in the course of this investigation: the Union, Marion, and Maumee trends.

Although well control alone does not allow exact definition of these faults, structural trends do exist on all the mapped surfaces in support of their placement (figs. 20-22). These structural trends, along with isopach trends,

FIGURE 27.—Aerial photograph taken during drought of 1934 showing fault and fracture traces in the bed of the Maumee River along the Bowling Green Fault Zone. Southern edge of the France Stone Co. Waterville quarry is in upper right of photo. Forst Road bridge over the river is oriented N-S. Photo courtesy of the Ohio Historical Society.

lineament analysis (unpublished file maps, Ohio Division of Geological Survey), and analysis of proprietary seismic data, have been used to place these faults (fig. 23). Many of these faults are reflected in anomalies on the gravity and magnetic maps of the state (Hildenbrand and Kucks, 1984a, 1984b), indicating deep, Precambrian influence. In addition, the epicenters of recent small-magnitude earthquakes have been located on or very close to a number of these trends (D. H. Christensen, University of Michigan Seismology Lab, written communication, 1988). Direct evidence of movement of Paleozoic strata along these zones is, for the most part, lacking. Therefore, the exact positions and sense and amount of displacement are speculative at present.

The positions of the Auglaize, Logan-Hardin, and Union Faults may be the most important to understanding the geologic history of northwestern Ohio. As depicted by the original authors (Heidorn, 1975; Quick, 1976; Krupa, 1980), the Auglaize and Logan-Hardin Faults tie into the Bowling Green Fault Zone to the north and terminate against the Anna-Champaign Fault to the south. The positions of the Auglaize, Logan-Hardin, and Union Faults as mapped in this report (fig. 23) closely correspond to the positions of anticlinal-synclinal trends which appear on all of the structure maps of this report. As currently mapped, the northwesternmost fault, the Auglaize Fault, may indeed tie into the Bowling Green trend. However, the platform margin of the Trenton, the northeastern flank of the Findlay Arch, and the southeastern edge of the Lima-Indiana trend all align in the Hancock-Seneca-Sandusky County area and indicate this fault continues to the northeast. The Logan-Hardin and Union fault trends also appear to extend farther northeast and may terminate in the Outlet Fault or continue farther still. These northeast-oriented fault trends are just that—trends; the authors believe that future drilling and seismic profiles will reveal many individual faults along these trends.

These faults may represent a down-to-the-basin, northeast-trending series of blocks. The area of these faults is coincident with the position of the Sebree Trough (fig. 12). The Trenton platform deposits are north of the Auglaize Fault, and the position of the platform margin of the Trenton is coincident with this fault. Furthermore, the lithologic changes in the Point Pleasant described previously are coincident with the positions of the Auglaize and Union Faults. Between these two faults the Point Pleasant is composed almost totally of gray to black shales with only minor carbonate content. South and east of the Logan-Hardin Fault the Point Pleasant is composed of interlayered limestone and calcareous gray to black shale common to the Point Pleasant throughout much of the rest of the state. This lithologic transition may be seen on the stratigraphic cross sections (pl. 1). These relationships may indicate some form of downwarping or faulting along this zone contemporaneous with Trenton-Point Pleasant deposition.

The potential cross-cutting relationship of this fault set with the Bowling Green and Outlet Fault Zones suggests that the northeast-trending set predated the northwest-trending set. The down-to-the-basin, graben style of the northeast-trending fault set also indicates extensional rather than compressive tectonics. On the basis of these observations, we hypothesize that the major (extensional) movement along this set of faults occurred during Cambrian or early Ordovician time, with lesser (compressive) reactivation in the middle to late Ordovician.

The above discussion calls for downthrown blocks in an area that is the structurally highest portion of the study area according to the structure maps (figs. 20-22). This reversal in topography can be explained by the later subsidence of the surrounding basins, which left this area as a crown or high between them. Indeed, the proposed faults responsible for the establishment of the trough in the Ordovician may have been essential factors in setting up the boundaries of the basins at this location.

OTHER STRUCTURES

A large area of structural closure and nosing is roughly centered over the Seneca-Sandusky County line on all the structure maps (figs. 20-22) of this report. This area is also located over the largest amplitude magnetic and gravity anomaly in Ohio (see Hildebrand and Kucks, 1984a, 1984b). Lucius (1985) has interpreted this geophysical anomaly to represent a large, mafic, plutonic pendant situated at a very shallow depth in the Precambrian. A continuous core drilled into this anomaly has revealed that the upper Precambrian is composed of a mafic gabbro (Wickstrom and others, 1985). Investigation (Wickstrom, 1987) of the Precambrian and the Mount Simon Sandstone (Cambrian) over this anomaly reveals it to be a structurally high area on the Precambrian surface (over 200 feet of relief) and that the Mount Simon thins to zero over this high.

This location appears to represent another example of a Precambrian structure being reactivated through time. It shows clearly on all the structural horizons considered, and the character and magnitude of the associated structures change with depth (see figs. 20-22). Shearrow (1987) has shown faulting in this area which is coincident with the Tiffin oil and gas field in central Seneca County.

In addition to the larger structural features described above, small structural noses and faults are present in the eastern half of the study area (figs. 20-22). Some of these (Marion, Harlem, Crawford) may prove to be systems as large as the Outlet Fault Zone. In this area the Paleozoic strata are dipping into the Appalachian Basin, and the structural noses are related to areas of terracing. Local northwest-oriented faulting also is apparent on the Trenton and Knox structural surfaces. The anomalous zones of thickening and thinning noted on the isopach maps of the Point Pleasant and combined Point Pleasant/Cincinnati group may be related to these northwest-trending structural features.

Structures of this type have been receiving attention in recent years with some success. The gas field in Harlem Township, Delaware County, and the successful wells in Pleasant Township, Marion County, have found reserves in fault/fracture-associated features in the Trenton-Black River interval. It is probable that additional reserves will be discovered in analogous features of northwestern Ohio.

Areas of structural terracing, with some associated fracturing, have also been noted as the Trenton descends into the Michigan Basin. The Bryan field of Williams County appears to be an example of this type of structure. The fault shown (fig. 23) in Gorham Township, Fulton County, is mapped solely on the basis of two wells, thus its extent and orientation are uncertain.

SUMMARY OF STRUCTURAL GEOLOGY

In summarizing the structural geology of the Upper Cambrian and Ordovician rocks of northwestern Ohio, two intriguing facts, which lead to much conjecture, are apparent: (1) many of the structural complexities of this area lie in the "arches" region between the Appalachian and Michigan Basins; (2) the frequency of structural anomalies is higher to the east of the proposed Grenville Front boundary line than to the west.

This first item may seem overly obvious. However, the idea begs for a better understanding of the timing of subsidence events and other tectonic factors in each of the basins as well as the mechanisms of why the boundaries of each basin are in their respective positions. Knowledge of the underlying principles may lead to prediction of yet undiscovered structures.

The second item may have far-reaching applications for future exploration efforts. Most of the structural anomalies east of the Grenville Front appear to have their roots in the Precambrian. To the east of the front line lies a zone within the Grenville Province that is thought to contain many plutonic bodies and thrust sheets, which are the probable controlling factors. Better modeling of these known Precambrian-rooted structures by way of detailed exploration surveys will give us the tools necessary to find analogous, undiscovered structures.

GEOLOGIC HISTORY

On the basis of the information presented above, the Middle and Upper Ordovician strata of northwestern Ohio are believed to represent a thick transgressive sequence bounded below by the Cambrian-Ordovician Knox unconformity and above by a post-Ordovician unconformity, although physical evidence for the latter is lacking. The following paragraphs capsulize the proposed geologic history of this transgressive sequence in the study area.

1. Following erosion of the Knox unconformity surface, a brief interval of mixed clastic and carbonate sedimentation represented by the Wells Creek Formation occurred as shallow seas once again covered the area.
2. The Black River Group was deposited in a widespread, shallow, epeiric sea. Environments of deposition were subtidal to intertidal (Stith, 1979). Depositional strike was dominantly north-south and the seas transgressed from east to west.
3. Following deposition of the Black River Group, the epeiric sea covering the area became relatively deeper and more normal marine in nature. This change is represented by the basal, subtidal, open-shelf facies of the Trenton Limestone. The increase in the number of bentonites at the top of the Black River and the base of the Trenton indicates that the Taconic Orogeny was beginning to increase in intensity to the south and east.
4. Cessation of deposition of the basal Trenton facies marked a major change in the depositional configuration of the area. At this time depositional strike changed from north-south to northeast-southwest (figs. 8, 10). This change appears to have been the result of downwarping of the proto-Appalachian Basin to the southeast, probably related to an early pulse of the Taconic Orogeny (Vermontian phase?). This change brought about a relative shallowing of the waters to the northwest, resulting in the deposition of the thick carbonate buildup of the platform facies of the Trenton. South and east of this carbonate buildup, the water was deeper, circulation was restricted, and the Point Pleasant Formation was deposited (figs. 12, 13). The northeast-trending Auglaize, Logan-Hardin, and Union Faults were probably reactivated at this time. These faults established the northeastern limits of the Sebree Trough and may be responsible for the depositional differences between the Trenton and the Point Pleasant.
5. Titus (1989) has proposed that a second, more intense pulse of the Taconic Orogeny (the Hudson Valley phase) was responsible for the end of Trenton deposition in New York. It seems probable that this same phase was responsible for the end of Trenton deposition regionwide. Available evidence indicates this pulse was responsible for the activation of the Bowling Green Fault Zone as well as the associated Outlet Fault Zone and, perhaps, the other smaller, dominantly northwest-oriented structural features of the area.

The Hudson Valley phase is marked by a rapid subsidence and/or rise in sea level, which resulted in a westward migration of Utica Shale deposition. In northwestern Ohio the westward-migrating sea swept across the area of Point Pleasant deposition and overwhelmed the carbonate production of the Trenton platform. Deposition of the Cincinnati group shales and limestones continued until the late Ordovician/early Silurian carbonate shelf established itself in this area.

OIL AND GAS PRODUCTION

HISTORICAL DEVELOPMENT OF THE LIMA-INDIANA OIL AND GAS TREND

The Lima-Indiana oil and gas trend, which was extensively drilled in the late 1800's and early 1900's, extends in a broad curve for 185 miles from Toledo, Ohio, southwestward to Indianapolis, Indiana (see fig. 2). The Ohio portion of the trend is 120 miles long and ranges from less than 1 mile wide to as much as 20 miles wide (fig. 28). More than 60 individual fields have been named along the trend in Ohio, but there are few distinct breaks between them. The principal reservoir rock in all of these fields is the Trenton Limestone.

Because the Lima-Indiana trend was the first true giant oil and gas field discovered in North America, it is of great interest in this investigation. The history of the development of this trend is a rather lengthy, yet absorbing story. The nation's oil and gas drilling, refinery, and transportation industries were in their infancy in the late 1800's. The country was steadily increasing its industrial base, for which inexpensive fuels were a must. Having such a large reserve of oil and gas beneath it at this critical time provided a boom to the economies and populations of the cities and towns of northwestern Ohio.

Compiling the diverse types of historical information on this era is a task worthy of its own study. The authors relied on two main sources of information: Edward Orton (1886, 1888, 1889, 1890), who was the State Geologist during the development of these fields and who documented much of the geology, production, and human side of the story, and J. J. Arpad (1985), who has produced a documentary film which, in large part, deals with the history of this development. In addition, a biography of J. D.

Rockefeller (Winkler, 1929) is a helpful reference for anyone interested in this era. The following paragraphs attempt to capsulize this dramatic time period as it pertains to the oil and gas production. Much of this information is taken directly from these sources or is paraphrased.

Commercial quantities of hydrocarbons were first discovered in the Lima-Indiana trend in 1884, just 25 years after Colonel Drake's famous first well of 1859 at Titusville, Pennsylvania. The development of the Lima-Indiana trend came at a time when production from the early fields of Pennsylvania was declining and thus shifted the focus of the petroleum industry to northwestern Ohio. Ohio was the second major stop on the early oil trail which led from Titusville to Texas. As George Whitney wrote in the *Oil City Derrick* newspaper, "the oil world moved 300 miles westward."

Production from the Ohio portion of the Lima-Indiana

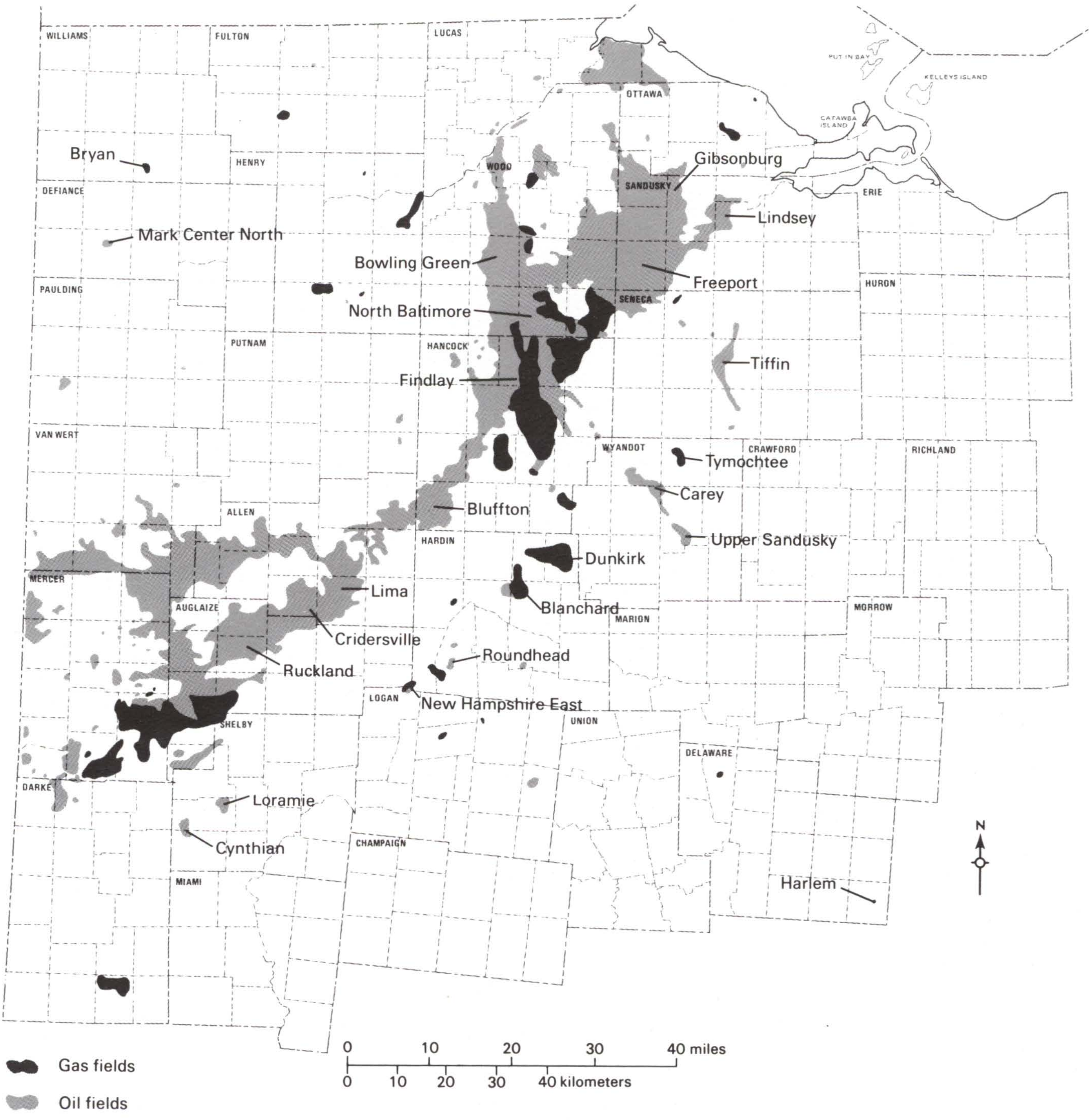


FIGURE 28.—Oil and gas fields of northwestern Ohio (modified from DeBrosse and Vohwinkel, 1974). Only names of fields discussed in the text are shown.

trend rose rapidly from negligible quantities in 1885 to over 1 million barrels of oil in 1886 and reached peak production in 1896, when over 20 million barrels were brought out of the ground. Unfortunately, production declined almost as rapidly as it grew; by 1906 annual production was down to 10 million barrels and fell to less than 1 million barrels in 1934. Figure 29 charts the oil-production history. Because much of the gas from the Lima-Indiana trend was piped directly from the wells into towns and factories for use, without any gauging, it is impossible to report annual gas-production figures. Cumulative production and the number of wells drilled also are difficult to determine because of a lack of records. However, estimated figures are 500 million barrels of oil, 1 trillion cubic feet of gas, and 100,000 wells for the entire Lima-Indiana trend. The Ohio portion of the trend produced roughly 380 million barrels of oil from about 76,000 wells.

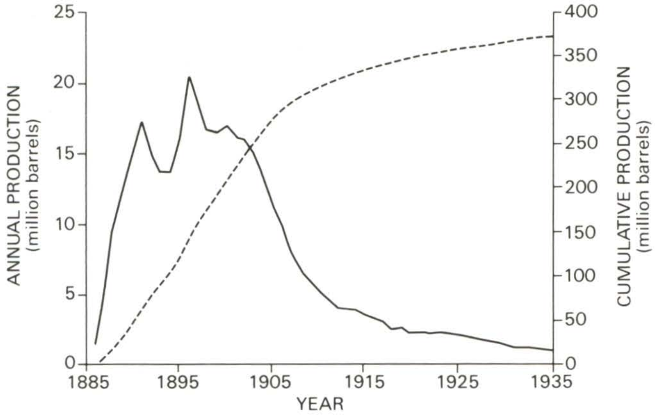


FIGURE 29.—Annual (solid line) and cumulative (dashed line) production of oil from the Ohio portion of the Lima-Indiana trend. Data for graph taken from Janssens (1977b).

The development of the Lima-Indiana trend initially began as a natural gas boom, followed shortly by an oil boom. However, these events were distinct and will be discussed separately.

The gas boom in northwestern Ohio centered around the city of Findlay in Hancock County. Early Indian legends tell of ritual fire ceremonies performed in the area. Flames were ignited when a lighted torch was held to some rock crevices. The leaping flames were then read by a medicine man who foretold the future. More direct evidence comes from the first white settlers in the area in the 1830's. Residents were constantly plagued by the natural gas seepages and high sulfur levels in their water wells. Finding good supplies of potable water was a difficult task.

In October 1836 a farmer named Aaron Williamson was digging a water well on his property south of Findlay. At 10 feet he hit plenty of water and his helpers stopped work and went to supper. Upon returning after sunset they lighted a bark torch to check the side walls for slumping. At that instant there was a minor explosion as gas from this shallow excavation ignited. It burned for three months until rain and snow put it out.

The first practical use of natural gas in the area was recorded in 1838. A man named Daniel Foster lived in a cabin along Main Street in Findlay. In the summer of that year he began digging a well but struck a strong "vein" of gas at a depth of 8 feet. He abandoned it as a water well but decided to use the gas. He inverted a sugar kettle over the well and ran a wooden conductor pipe under it to his house. At a point near the chimney he drilled a hole and inserted a gun barrel into the conductor pipe. In the fireplace the gun barrel had been drilled with holes and the end was plugged with a cork. The gas was used for light, heat, and some cooking. Reportedly, Foster and the subsequent owner of the house used this flame until the house was connected to a commercial gas line in the late 1880's. Despite Foster's demonstration of the utility of gas, it did not cause great excitement in the village. The pioneers had a difficult time making a living without having to fool with a substance they knew nothing about. More often the gas seepages were considered a nuisance and occasionally a hazard. People were injured when trying to ignite the "burning water" for the amusement of friends.

More than any other individual, Dr. Charles Oesterlin was responsible for the opening of the gas field in northwestern Ohio. Dr. Oesterlin was a German-educated physician who had come to Findlay in the 1830's. Aside from medicine he was an amateur scientist primarily concerned with geology. He decided he would make a study of these gas seepages mostly for purely scientific reasons. He studied books on geology and took field trips in and around Findlay and Hancock County to study the rock formations in local quarries. In the 1870's, while serving as Findlay's representative in the Ohio General Assembly, Oesterlin studied geology at the Ohio State University. He discussed the seepages with his professors, including Dr. Edward Orton, the State Geologist. Dr. Orton had studied the fields in Pennsylvania and eastern Ohio and was of the strong opinion that no gas or oil could exist in the Trenton Limestone of northwestern Ohio.

Despite Orton's discouraging pronouncements, Oesterlin came away convinced that there must be an immense volume of gas trapped below the upper strata of limestone to cause gas to seep through the cracks in the porous rock. Until 1884, however, he couldn't find anyone to back his idea of drilling to the Trenton Limestone to tap his theoretical gas reservoir. In that year the Findlay Natural Gas Company was formed by selling stock to local citizens. Their first drilling venture was on Dr. Oesterlin's farm east of Findlay. They found a strong gas seep at only 7 feet in May 1884, so they stopped and hired a professional driller from Bradford, Pennsylvania, to drill the well. The drilling finally commenced in September 1884. The drillers were prepared to go 2,000 feet if necessary to find the gas source. By November 1, they had already found gas at three levels: 314 feet, 516 feet, and 618 feet. At this third level the gas was strong enough to shoot a flame 6 feet high when ignited out of the 7-inch casing. When this occurred the stock in the Findlay Natural Gas Company soared, and crowds gathered daily to watch the progress. The top of the Trenton was penetrated at 1,092 feet on November 16. More than 3,000 people gathered to watch; to satisfy the crowd the drillers ran a pipe to the top of the derrick and ignited it. The flambeau could be seen for miles at night, fueling even more excitement. The company's stock prices exploded and speculation became rampant. On December 5, 1884, the well had reached 1,648 feet and began to encounter salt water. Drilling stopped and the well was shot with 30 quarts of nitroglycerine. The resulting blast when the gas was ignited could be seen 15 miles away. This first gas well produced about 250,000 cubic feet per day, and set off a drilling spree all over northwestern Ohio.

The Findlay Natural Gas Company and other gas companies continued to drill wells, even though there was no market for the gas or infrastructure to transport it. Throughout 1885 eight more wells were drilled around Findlay, each seemingly more spectacular than the last. Estimated production was as much as 4 million cubic feet of gas. The most spectacular of the gas wells was the 13th, drilled in early 1886. This well was located on the bank of the Blanchard River, which flows through Findlay, on the lot of the Karg Slaughter House. On January 20, 1886, the city was awakened by a frightening roar as the Karg well came in at 1,146 feet, blowing 20 to 50 million cubic feet of gas per day. The gas escaped with such a ferocious roar that the drillers were afraid to light it.

Gas saturated the city for five days before the well could be brought under control, and not a fire was lit in Findlay during that time. A 10-foot-high standpipe was erected 200 feet away and hooked into the well. When lit the flame shot more than 100 feet in the air and was plainly visible 25 miles away in Bowling Green. The great flambeau burned for four months before the well could be brought under control. During this time it became a major tourist attraction and was reported in all the national newspapers. It proclaimed to the world the arrival of a great new field and marked the beginning of a period of rapid development.

Responding to the amazing abundance of gas, the civic leaders of Findlay decided to "boom" the town. They hired C. C. Howells, a professional publicity person, who had just successfully boomed Wichita, Kansas, as a cattle town. Howells set out to create all the hoopla of a wildwest show—then America's number one form of entertainment.

First, he ran advertisements all over the country that Findlay was offering free gas to manufacturers who could locate here. Next, he had 19 arches built across Main Street, each festooned with blazing gas jets in multicolored glass globes (fig. 30). Each arch had a banner bragging

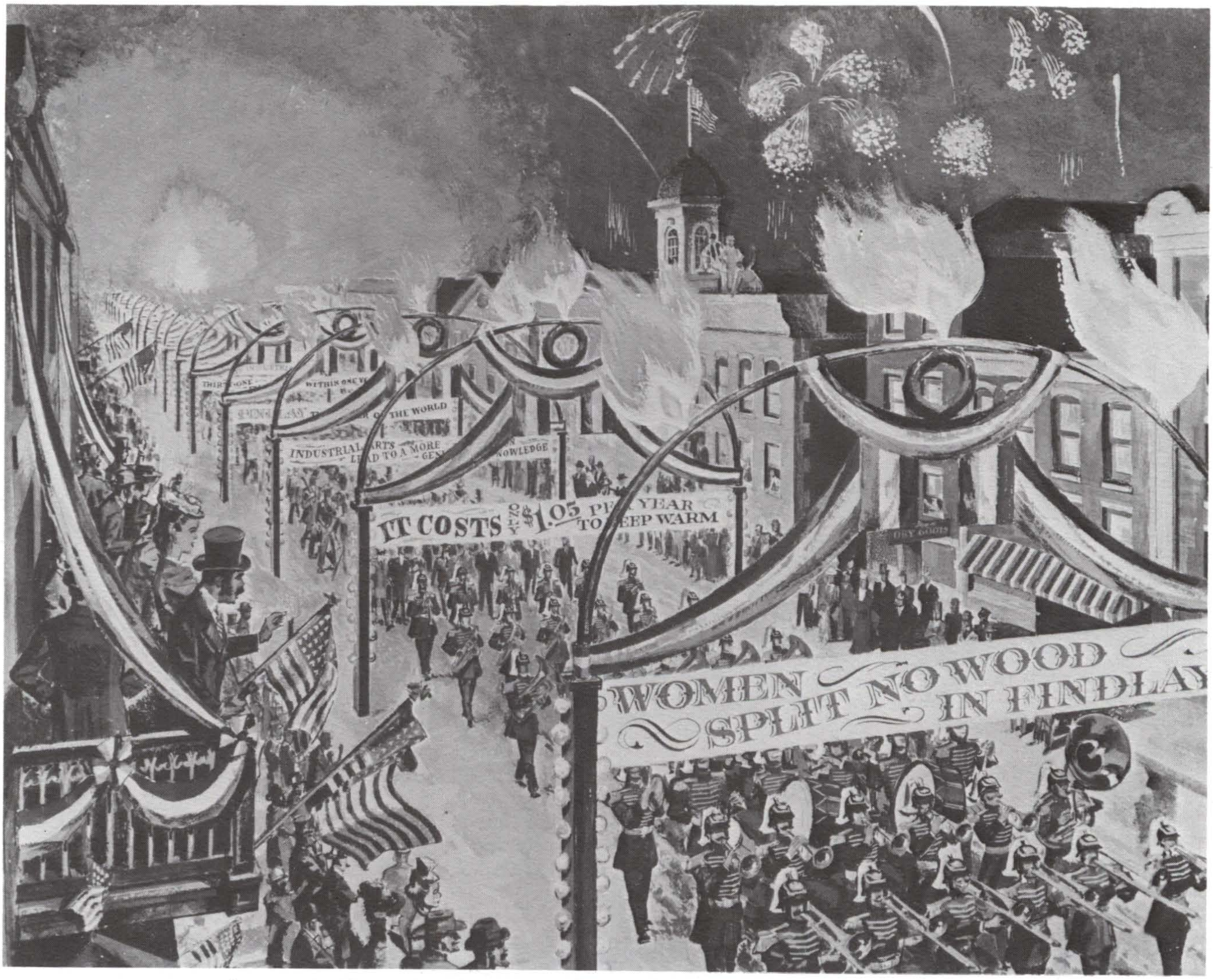


FIGURE 30.—Street scene during Findlay's (Hancock County) June 8-10, 1887, gas boom celebration. Illustration provided by Ohio Historical Society.

about the city's virtues: "Findlay - the center of the world," "Women split no wood in Findlay," etc. Then he had three of the largest gas wells piped to the north end, center, and south end of town. Each was fitted to a 60-foot-high standpipe which was burned continuously to show how abundant gas was and to make sure the city would never see night. To entertain prospective industrialists and investors Howells had a huge convention hall built on the banks of the Blanchard River facing the Karg well. He named the hall "The Wigwam." Finally, to bring all of this to a climax, he put on a three-day celebration, June 8-9-10, 1887. The celebration was complete with marching band, drill teams, equestrian troops, military units, politicians, sports teams, singers, dancers, lecturers—all peppered with 100-gun salutes and similar fanfare. More than 30,000 people from all over the United States attended the event.

The end result of Howells' hoopla were 50 new industries locating in Findlay, including many glass factories; a quadrupling of the population, creating an attendant real estate and housing boom; and a massive infusion of outside capital into the town.

All of the splendor made the people of Findlay overlook the negative aspects of the boom: millions of cubic feet of gas were wasted to promote the boom; numerous sets of gas lines in the streets—most above ground and leaking—caused a stench and constant danger of explosion; once a well was turned into the town lines it was permitted to flow continuously—no one bothered to turn off the gas—so stoves, lights, etc., continued to burn indefinitely. Then there were the saloons, fighting, thieving, and prostitution that accompanied any sort of boom.

Findlay absorbed all of this and became an industrial town. Almost all of the small towns in northwestern Ohio that were in the newly discovered gas field tried to mimic Findlay's boom, but none were quite as successful.

Some people were appalled at the tremendous waste of natural gas, but no one could control the boom. In 1888, the Bowling Green newspaper quoted Edward Orton, who predicted the gas in northwestern Ohio would not last another 10 years. The news was met with delight because nearly everything the state geologist had said about the Trenton had turned out vice versa. However, for once he was right—within three years all the glass factories in Bowling Green and North Baltimore had to close for lack of fuel. By 1891 northwestern Ohio's gas boom was over, just seven years after the first large discovery.

The oil boom in northwestern Ohio began a year after the gas boom, but it lasted much longer. It began when Benjamin Faurot, a Lima businessman, took a railroad excursion to Findlay in early 1885 to see wells there. Being a civic leader, he did not want a rival town to get the better of Lima; he returned home and announced "if Findlay can get gas, so can we." He put together a group of investors and hired a Pennsylvania driller to drill for gas on his property. The gas would be used to manufacture strawboard, which had recently revolutionized the packaging and shipping industry. On May 9, 1885, the drillers reached the Trenton but there was no gas, only a show of oil. Discouraged, Faurot decided to shoot the well with explosives before abandoning it. To his astonishment and that of the spectators the well flowed 200 barrels oil per day briefly before settling down to about 25 barrels per day.

This was the first oil well in northwestern Ohio and marked the opening of the Lima field. The gas excitement in Findlay was now matched by growing oil excitement in Lima as derricks sprang up all over the city. The Citizens Gas Company, another local prospecting company, completed the second well at Lima in December 1885, and it produced oil in greater quantities than Faurot's, about 40 barrels of oil per day.

Meanwhile Faurot gave up the strawboard paper business and with a group of investors started the Trenton Rock Oil Company to prospect for oil—not gas—and the oil boom was on. By 1886, the company had drilled 250 wells from Lima southwest through St. Marys and into Indiana, producing a plentiful supply of crude.

The discoveries in Lima initially did not cause a great stir in Pennsylvania because the Lima crude had a high sulfur content. When refined it produced a yellowish kerosene which smelled like rotten eggs when burned, gave off less light, and left a sulfurous crust on wicks. One year's operation of the Lima field convinced the oil world that northwestern Ohio contained a great quantity of oil but its poor quality made it virtually worthless. Because of the poor quality, development of the field was left to locals, who had insufficient capital to provide transportation and storage facilities. The oil was used initially to generate steam for surrounding communities.

By this time, the Standard Oil Company, under John D. Rockefeller, operating initially out of Cleveland, Ohio, had monopolized the refining and transportation of crude oil from the Pennsylvania fields. The Lima-Indiana trend, however, caused a big problem for the company. The Trenton crude could not be refined into an illuminating oil that met the standards the company had set for its kerosene. At the same time, it couldn't afford not to buy the Trenton crude for fear of losing its monopoly in the refining business. On Rockefeller's advice, Standard's board of directors decided to buy the crude and store it until the company could find a way to refine it into an acceptable product. The National Transit Company, which was Standard Oil Company's distribution subsidiary, surveyed the scene in northwestern Ohio and quickly formed the Buckeye Pipeline Company to buy up the production.

On May 11, 1886, one year after Faurot's discovery well, the Buckeye Pipeline Company entered the Lima area with tank cars and started to buy oil at 40 cents a barrel at the well. They also began erecting storage tanks (which had been disassembled in Pennsylvania), and on June 2, 1886, the first oil was run into the tanks.

Then, in late 1886 and early 1887, great oil "gushers" started coming on in southern Wood and northern Hancock Counties. The Fulton well, drilled near North Baltimore, between Bowling Green and Findlay, in December 1886, was the first, but was to be only the smallest tip of the iceberg. The well was initially drilled to a depth of 1,194 feet searching for gas. The owners decided to drill another 200 feet and at nearly 1,400 feet they hit a boomer which came on at 500 barrels a day. Two months later the Henning well flowed 2,000 barrels a day. Then, five months later, in the spring of 1887, the Slaughterhouse-Beds well, drilled near Cygnet, came on at 5,000 barrels a day. In September 1887, the Ducat, the Potter, and the Foltz wells all came in gushing more than 10,000 barrels a day each. For the next two years enormous gushers came on regularly—some supposedly produced as much as 50,000 barrels per day—and startled the oil industry with each new discovery.

When these gushers came in there was no way to collect that much oil. It didn't make sense to provide storage and pipelines in advance because a well might be dry. So gushers were allowed to flow free until storage facilities were built or until they could be capped off. When that happened the fields would be knee deep in oil, which would run off into ditches and rivers. At best the flowing well would be directed into an open earthen pit or a hastily made lake.

In response to this deluge, Standard reduced its price until it hit 15 cents a barrel. But still excitement mounted, for even at 15 cents a barrel some of these wells could bring in over $1,500 a day, and it cost only $1,200 to drill the wells.

The producers around Lima couldn't compete on 15-cent oil. Their wells tended to produce only 50 to 100 barrels a day—$15 worth at best. Thus 14 independent Lima-area oil producers formed a combine, trading their wells and leases for stock in the company. They called their combine the Ohio Oil Company, which was the predecessor of the modern Marathon Oil Company. They took their production off the market until Standard would pay at least 40 cents a barrel.

Meanwhile Standard Oil Company took more aggressive steps to deal with the excitement. First, it built a refinery at Lima, named the Solar Refining Company, to permit its chief refining specialist, J. W. Van Dyke, and the recently hired Canadian scientist Herman Frasch to work out the sulfur problem. Then Standard redoubled its storage and pipeline efforts, creating the Cygnet Pipeline Company and Connecting Pipeline Company to handle the gushing Wood County crude. Next, the Manhattan Oil Company was created near Gallatea (north of Findlay) to market an inferior grade of kerosene. Ownership of the refinery was hidden so it couldn't be traced back to Standard. Finally, John D. Rockefeller proposed that Standard do what he had always said it should never do—go into the production end of the industry to stabilize the situation.

The plan was to buy up all of the leases and producing wells and take the field out of production. They tried to do it secretly, but word quickly spread that Standard was buying everything in sight. In 1889 Standard bought the Ohio Oil Company, its only real competitor in the area, and so owned 75 percent of the Lima-Indiana trend.

Standard was ready to shut down the field when two things happened. First, Frasch and Van Dyke perfected the sweetening stills to refine the sulfur out of the crude, so there was no need to shut the field completely down. Second, and more importantly, in 1889 the Pennsylvania Supreme Court ruled that the old "common law of mineral rights" was not applicable in the case of gas and oil rights. Instead the "common law of hunting rights" applied. The court invoked the "law of capture," the common-law principle that migratory wildlife belongs to the person who can capture the game on his property.

This decision meant you didn't own the oil and gas under your property until you brought it to the surface and captured it. If your neighbor could drill a hole and capture it on his property it was his. Suddenly the situation had changed. If Standard tried to control production by shutting down its 75 percent of the field, the independent producers who owned the other 25 percent could pump it dry. Thus, to maintain its 75 percent control, Standard drilled, pumped, and sold the Lima-Indiana crude as fast as it could to get rid of the production.

The end result was an appalling waste of a major natural resource. No one bothered with geology. Everyone practiced "close-ology," which meant getting a well as close as you could to a known producer then pump it faster than the neighboring well. When you obtained a lease you first drilled offsets to existing wells in adjacent leases and then drilled on your perimeter to protect your supply. In the better producing areas the derricks were stacked almost on top of one another (see cover photo).

In this atmosphere of dog-eat-dog competition the Lima-Indiana trend quickly reached its peak production of 20 million barrels per year (see fig. 29). Ohio was the leading oil-producing state in the nation from 1895 to 1903. By 1910, however, the fields were largely depleted.

The excitement in the Lima-Indiana trend died down abruptly in 1901 when news of the Spindletop well of Texas reached Ohio. That phenomenal gusher near Beaumont, Texas, came roaring in at 100,000 barrels a day, and the focus of the oil industry shifted permanently to new fields in the midcontinent and the southwest. The new gusher glutted an already oversaturated market and the price of oil dropped to 3 cents a barrel; the barrel was worth more than the oil it contained. Wells in Ohio could no longer pay their way, and the oil companies shut down and abandoned all but the best producers. The Standard Oil Company produced the Lima-Indiana trend until 1911, when the government broke the Standard trusts into 32 separate companies. After 20 years the Ohio Oil Company was again an independent producing company, and it continued operating wells in the field until 1937. Since that time there has been little activity by the major oil companies in northwestern Ohio.

The Lima-Indiana trend produced prolifically for only about 20 years, but its development came at an important time. It bridged the period between the decrease in production from the Pennsylvania fields and the development of the midcontinent and southwestern fields. It also came at a time when new inventions such as the internal combustion engine were increasing the need for fuels and lubricants. Thus, the Lima-Indiana trend provided the nation with an ample supply of cheap petroleum products at a time when shortages could have greatly slowed technological development.

TRAPPING MECHANISMS

A number of hydrocarbon trapping mechanisms in the Trenton Limestone of northwestern Ohio are dependent on the structure, lithology, and facies described in earlier sections. Coogan and Parker (1984) briefly discussed six types of trapping plays in the Trenton: (1) anticlinal traps, (2) faulted anticlinal traps, (3) updip facies change, (4) fractured reservoirs, (5) porosity-permeability traps, and (6) minor structural noses. All of these trap types are valid for the Trenton, some with variations from the original description, and generally in some combination. Some of the major occurrences of petroleum in the Trenton are discussed below, with consideration of the trapping mechanisms. See figure 28 for location of fields; field names are from DeBrosse and Vohwinkel (1974).

The most prolific producing area of the Lima-Indiana trend was in Wood and Hancock Counties peripheral to the Bowling Green Fault Zone. The northern field of this area is aptly named the Bowling Green field; the southern is the Findlay field. It is estimated that roughly 60 percent of all the oil produced from the Lima-Indiana trend came from these two counties (Marathon Oil Company, personal communication, 1983). Average recoveries for most of the Ohio Trenton reservoirs were generally below 1,000 barrels per acre. However, in Wood and Hancock Counties recoveries were extremely high, reaching as high as 14,000 barrels per acre on some isolated leases.

Most of this oil was produced from reservoirs associated with the Bowling Green Fault Zone. The fault zone placed the Trenton reservoir rock against the impermeable shales of the Cincinnati group on one side of the fault and against the tight impermeable limestones of the Trenton on the other side (structural cross section B'-J', pl. 1), thereby preventing any further lateral migration of the hydrocarbons. Vertical migration of hydrocarbons was inhibited by both the tight dolomite and other secondary mineralization at the top of the formation and the overlying shales. The porous gouge zones of the fault planes allowed migration of the hydrocarbons into the traps. The best production along the fault zone was on the western, downthrown, side. Here, production was magnified by a combination of fracture/fault-associated porosity enhancement and a series of faulted/fractured anticlines and synclines (fig. 21).

East and southeast of the Bowling Green Fault Zone, production was associated with the Outlet Fault Zone and the upthrown block between it and the Bowling Green Fault Zone. The fields along these features include the North Baltimore, Tymochtee, Carey, and Upper Sandusky fields and the gas-bearing portion of the Findlay field. Trapping along the Outlet Fault Zone is very similar to that along the Bowling Green Fault Zone but at a smaller scale, that is, fault/fracture-enhanced porosity along with associated (tertiary) folding (fig. 21). The dominant oil production appears to follow the fault zone very closely (compare figs. 21 and 28). Because of the lack of records, it is difficult to say whether the best production was from the upthrown or downthrown side of the Outlet Fault Zone.

The dominant gas production in this area is situated on structural highs which are related to the faulting. The Tymochtee gas field is located on a tertiary anticlinal fold related to the (secondary) wrench faulting of the Outlet Fault Zone. The gas "cap" of the Findlay field appears to be situated on the upthrown block between the Bowling Green and Outlet Fault Zones and, therefore, is at least partially fault bounded.

The Gibsonburg and Freeport oil fields, located mostly in Sandusky County, are examples of a combination of an updip facies change and anticlinal traps. The southeastern edges of these fields are located along the platform margin (figs. 10 and 14) where the Trenton grades into the Point Pleasant. The authors agree with Cole and others (1987) that the Point Pleasant was the principal source rock for the hydrocarbons in the Trenton and that the petroleum migrated updip across this facies change. The remainder of the Gibsonburg and Freeport fields is located on the crest of the Findlay Arch, which provides structural closure for the trap.

Many of the other fields which form the main arcuate body of the Lima-Indiana trend are thought to be the result of an updip facies trap in combination with a porosity-permeability trap. Included in this list are the Bluffton, Lima, Cridersville, and Ruckland fields in Hancock, Allen, and Auglaize Counties. Also, the northeasternmost field of the trend, the Lindsey field, which is contiguous with and slightly northeast of the Freeport field, is included in this trap classification. As discussed in other sections of this report, it is believed that fluids migrating out of the deeper portions of the basin were responsible for the secondary dolomitization and porosity enhancement of the Trenton along this trend (facies dolomite). Later-migrating hydrocarbons infilled the porosity that was created. Further migration to the northwest was inhibited by the porosity-permeability change from the dolomite to the primary limestone of the Trenton. Again, the overlying shales provided the necessary vertical seal.

It is quite possible that this arcuate trend is further enhanced by the Auglaize Fault, which parallels it (fig. 23), and that this fault is responsible for many of the Lima-Indiana fields. As discussed earlier, the Auglaize, Logan-Hardin, and Union Faults are probably responsible for the position of the Sebree Trough in this region. The position of the Logan-Hardin Fault defines the position of another string of fields (compare figs. 23 and 28) parallel to the Lima-Indiana trend. This string includes the Roundhead, New Hampshire East, Loramie, and Cynthian fields. Furthermore, if these fault trends continue to the northeast, as we have proposed, the Logan-Hardin Fault may be responsible for the positions of the Blanchard and Dunkirk fields in Hardin County as well as the en echelon breaks in the Carey and Tiffin fields in Wyandot and Seneca Counties.

As the Trenton Limestone dips into the Michigan Basin in northwesternmost Ohio, structural terracing forms yet another trap type. Here, minor flexures, or changes in dip, form small terraces in which hydrocarbons may accumulate. Examples of this type of trap are found in the Mark Center North field in Defiance County and the Bryan field in Williams County.

The recent gas development in the Harlem field in Delaware County is located along a northwest-southeast-trending fracture system (Wickstrom and Gray, 1985). Along this fracture, dolomitization and porosity development have occurred in the entire Trenton-Black River section at scattered intervals. The orientation and nature of this fracture system are very similar to those developed in the Upper Sandusky and Carey fields in Wyandot County and as modeled in figure 25. Some of the other small structural noses in the eastern portion of the study area on the structure maps (figs. 20-22) appear to be fracture related when mapped at a larger scale.

Since the early 1900's, drilling activity in northwestern Ohio has been low and sporadic. Most operators have been small independents working in and along the fringes of the old fields where the reservoir pressures and the hydrocarbon returns are typically low. However, in the last decade there has been renewed interest in the Trenton, sparked by discoveries in southern Michigan and the Harlem field in Delaware County, Ohio. It is probable that more fracture systems such as these are present to the southeast of the old Lima-Indiana trend. However, because displacements are small or lacking, detailed geophysical and possibly geochemical exploration methods will undoubtedly be required to locate these features.

RESERVOIR CHARACTERISTICS

Reservoir characteristics in the Lima-Indiana trend varied widely. Hydrocarbons were generally found in porous dolomite zones in the upper 100 feet of the Trenton. However, along fracture/fault zones, the entire Trenton-Black River interval consists of dolomite in many wells. Individual pay zones were generally less than 16 feet thick and were highly discontinuous both vertically and laterally. According to some proprietary core reports, porosities average only 4 to 6 percent but are extremely variable, ranging from 1.5 to 14 percent. Permeabilities also are extremely variable, ranging from 0.3 to 9,000 millidarcys, although most records from producing intervals show permeabilities range from 100 to 400 millidarcys.

Visual inspection of cores and data from proprietary core reports indicate that this high variability in porosity and permeability is due to a dual-porosity system. One type of porosity consists of a system of small interconnected capillaries resulting from interparticle, intercrystalline, and perhaps moldic porosity with fair to good permeability. The second type of porosity is the result of large macroscopic vugs which, of themselves, have low permeability. Production from a reservoir with porosity of the first type should follow a somewhat normal progression of good initial production followed by a slow decline of reservoir pressure and production. Production from reservoirs with large amounts of the second type of porosity may be overly skewed towards the front end. Very large amounts of initial production are typical of these reservoirs, and, unless there is a connection to a reservoir system containing significant amounts of the first type of porosity, production generally falls off to uneconomic levels very quickly, sometimes in only a few days.

SECONDARY AND UNCONVENTIONAL RECOVERY

Since the early 1900's operators have discussed the possibility that large amounts of oil are left in place in the Lima-Indiana trend and that this oil was ripe for secondary recovery operations. Such speculation was fueled by the very fast, unsophisticated manner in which these fields were originally produced and abandoned. Many reasoned that the residual oil saturation left in place would be abnormally high; some theorized that as much as 90 percent of the original oil was still in the ground.

Since the 1950's a number of companies have actively investigated the possibility of secondary recovery in the old Trenton fields, and at least one major attempt at water flooding has been tried. The results of these investigations and tests indicate that (1) primary recovery from the old Trenton fields was much higher than that normally expected, and (2) the nature of the Trenton reservoirs is not conducive to standard secondary recovery attempts.

Several factors, however, point toward some areas of the Lima-Indiana trend as attractive targets for secondary recovery:

- From study of the old records of production, it appears as though the primary drive force for these fields was simple solution gas drive with, perhaps, a small component of water drive. Under normal conditions, primary recovery from fields with simple solution gas drive does not exceed approximately 20 percent of the oil in place.
- Reservoir analysis of many old producing areas indicates an economically attractive amount of oil remaining for secondary recovery attempts (given a suitable reservoir type).
- The viscosity of the oil is sufficient to allow mobility in an artificial flood.

After consideration of the available cores, proprietary core analyses, and structure mapping, the following factors discourage secondary recovery attempts:

- The reservoir rock of these fields is too heterogeneous to allow an effective artificial waterfront to build up. As mentioned above, the rock is composed of two basic types of porosity which may or may not be in communication over substantial distances. Each of these porosity types has a large variability in the amount of associated permeability; good permeability/connectivity is essential in controlling any flood program.
- Detailed laboratory analyses (proprietary) of cores from Wood and Hancock Counties indicate that in excess of 40 percent of the original hydrocarbons in place have been produced, compared with a normal depletion of about 20 percent for solution-gas-drive reservoirs.
- Approximately 76,000 wells are thought to have been drilled in the Ohio portion of the Lima-Indiana trend, for most of which we have no modern location, and by many accounts most of these wells were either not plugged at all or were poorly plugged by today's standards. These unlocated wells both add to the heterogeneity of the reservoir and provide uncharted paths for fluids to enter or exit the reservoirs.
- Old drilling records reported many crevices. These naturally occurring voids, along with the many fractures and faults noted in records and the current mapping, add additional uncertainties to the reservoirs when considering secondary recovery attempts. These voids and fractures can act as migration paths for injected fluids. The fractures may also act as permeability barriers to migration of the fluids.

After careful examination of the factors involved in standard secondary recovery methods in the old Trenton fields, it certainly appears to the authors that the negative factors outweigh the positive factors. Indeed, the only attempt at secondary recovery known to us can only be labelled as highly unprofitable.

During the energy crisis and subsequent skyrocketing of petroleum prices in the mid-1970's to early 1980's, a few companies were investigating the possibility of mining the oil in the once-prolific producing areas (Stieglitz, 1981). The most viable technology presented involved gravity drainage of the reservoirs. In this method, vertical shafts would be cut to below the producing horizons (into the Black River). Horizontal drifts would then be constructed under the reservoir. At intervals along the drifts, enlarged drilling rooms would be cut. From these drilling rooms a series of small-diameter holes would be drilled upward in a radial pattern. The oil would then be allowed to drain into these holes and be conducted to a collection system. The system could also be enhanced by injection of steam from a series of surface wells. Adding to the plus side of the economics for such an attempt is the possibility of selling much of the tunnelled material as aggregate.

Although this technology appears viable, it is still hindered by many of the same arguments presented above for secondary recovery efforts plus additional problems which would be unique to this type of venture. Furthermore, some cost analyses for oil mining estimate that the cost of oil would have to reach $80 per barrel before such a venture would be profitable. Thus, oil mining of the Trenton holds some promise only for the unforeseeable future.

SOURCE ROCKS

For many years, operators in northwestern Ohio have assumed the overlying "Utica Shale" was the source rock for hydrocarbons in the Trenton. As discussed earlier, the use of the term "Utica" has been confusing in Ohio. When discussing source rocks, the "Utica" is generally denoted as the shale directly overlying the platform facies of the Trenton; this shale is the equivalent of the Kope Formation. Indeed, many wells drilled through the "Kope" in northwestern Ohio have encountered strong shows of oil. However, geochemical analyses of both the Kope and the Point Pleasant Formations contradict this source-rock assumption (Cole and others, 1987). The Kope does contain an appreciable amount of kerogen, but the analyses indicate the Point Pleasant to be a much better potential source rock.

The Point Pleasant Formation is in a very favorable position for the migration of liberated hydrocarbons into the Trenton reservoirs. Stratigraphic and structural cross sections (pl. 1) illustrate the updip and facies-related migration path which liberated hydrocarbons could easily follow from the limestones and dark calcareous shales of the Point Pleasant into the thick reservoir rock of the Trenton platform-margin and platform facies. Migration of hydrocarbons from deep basinal deposits of the Point Pleasant along fault and unconformity conduits also is a distinct possibility; these rocks may have served as a source for not only the Trenton but also the Black River Group, the Knox Dolomite, and perhaps other petroleum-bearing horizons. Comparison of the oil and gas fields map (fig. 28) and the Point Pleasant isopach map (fig. 12) reveals good correlation between the area of thinning and pinchout of the Point Pleasant Formation and the location of the major oil and gas fields. The possibility that the Point Pleasant Formation supplied the high-magnesium brines to dolomitize the Trenton has already been discussed. Both of these possibilities should be explored with further isotopic analyses and oil/source-rock pairings.

It is also likely that the hydrocarbons in the Trenton in northwestern Ohio had more than one source and source direction. Some analyses (Noel and others, 1987) indicate that oils from the Trenton represent two or three distinct groups, which may have come from separate source areas. The Collingwood Shale of northern Michigan and Ontario appears to be a favorable candidate as a source (Hiatt and Nordeng, 1985) which could have fed hydrocarbons from another direction than the Point Pleasant. Further source-rock analyses tied to basin thermal and subsidence histories are needed to fully evaluate these possibilities.

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APPENDIX

The following sets of well data are arranged geographically in groups of counties. The index map below shows the groups and their order. Each set of well data is accompanied by a map showing the locations and permit/file numbers of wells (solid circles) or cores (open circles) included in the data set. Not all wells listed are shown on the maps because of space limitations.

Most of the wells listed in this appendix were geophysically/electrically logged. These logs were the primary source of information used to map the various units. Three wells (Wood County, Portage Township, #2549 and Wyandot County, Crane Township, 2 and 4) were continuously cored but were not geophysically logged.

The elevations listed are those from which the logging or coring was measured.

The abbreviations that precede numbers for land subdivisions are:

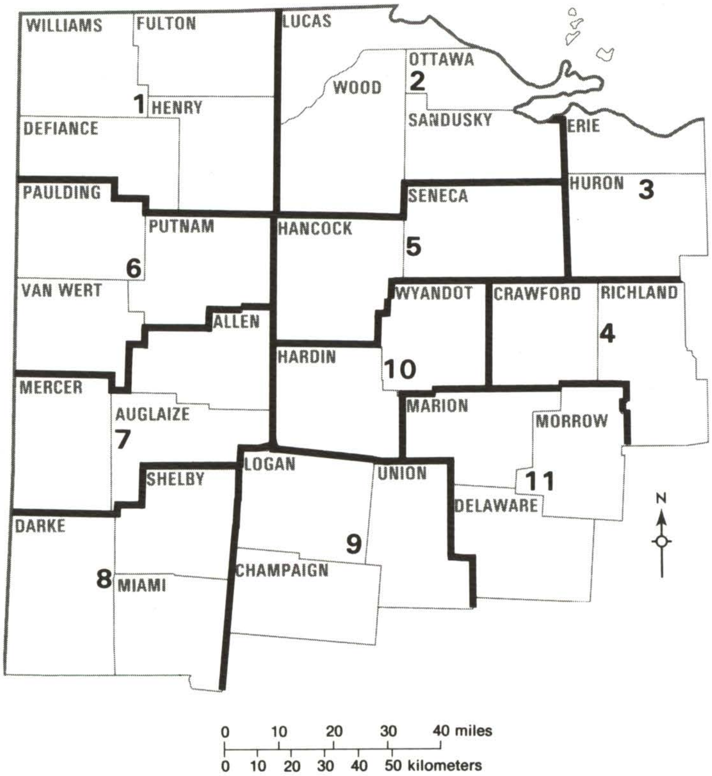
L	lot
S	section
V	Virginia Military Survey lot
¼	quarter township

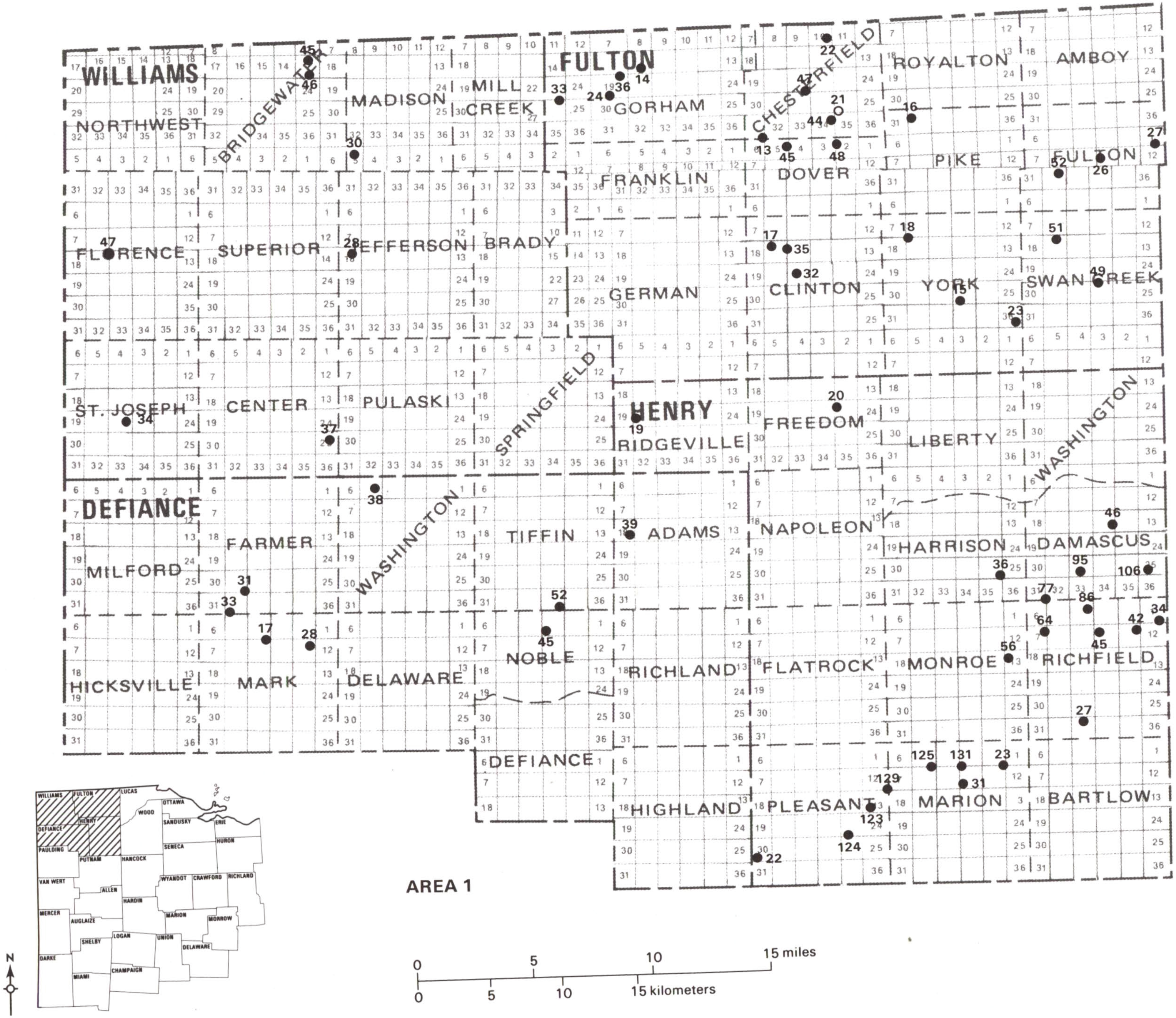
The abbreviations that follow land subdivision numbers are compass directions (East, North, South, West).

The abbreviations used for unit tops are:

ABS	unit absent in well
NDE	well or log not deep enough to encounter unit
NL	interval not logged
?	contact questionable or not discernible

The data in this appendix are available on diskette as Division of Geological Survey Digital Data File No. 1.




WILLIAMS
FULTON
HENRY
DEFIANCE
NORTHWEST
BRIDGEWATER
MADISON
MILL CREEK
GORHAM
CHESTERFIELD
ROYALTON
AMBOY
FRANKLIN
DOVER
PIKE
FULTON
FLORENCE
SUPERIOR
JEFFERSON
BRADY
GERMAN
CLINTON
YORK
SWAN CREEK
ST. JOSEPH
CENTER
PULASKI
SPRINGFIELD
RIDGEVILLE
FREEDOM
LIBERTY
WASHINGTON
MILFORD
FARMER
WASHINGTON
TIFFIN
ADAMS
NAPOLEON
HARRISON
DAMASCUS
HICKSVILLE
MARK
DELAWARE
NOBLE
RICHLAND
FLATROCK
MONROE
RICHFIELD
DEFIANCE
HIGHLAND
PLEASANT
MARION
BARTLOW
N
0 5 10 15 miles
0 5 10 15 kilometers
WILLIAMS
FULTON
LUCAS
DEFIANCE
HENRY
OTTAWA
WOOD
SANDUSKY
ERIE
PAULDING
PUTNAM
HANCOCK
SENECA
HURON
VAN WERT
ALLEN
HARDIN
WYANDOT
CRAWFORD
RICHLAND
MERCER
AUGLAIZE
MARION
MORROW
SHELBY
LOGAN
UNION
DELAWARE
DARKE
MIAMI
CHAMPAIGN

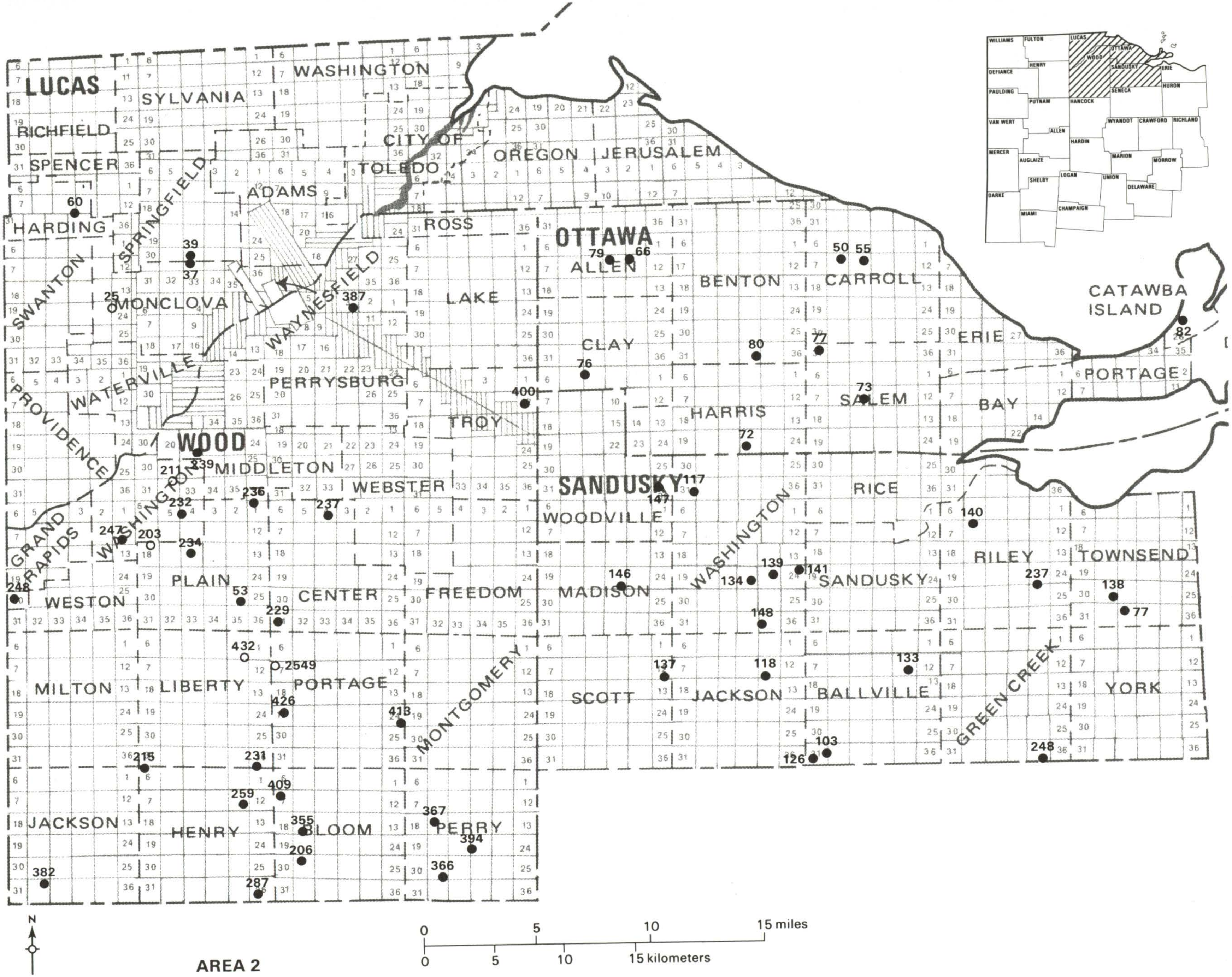
AREA 1

APPENDIX — AREA 1

Permit no.	County	Township	Land sub-division	Operator	Lease name	Eleva-tion	Depth to top (ft)					
							Cincin-nati group	Point Pleasant Fm	Trenton Ls	Black River Gp	Wells Creek Fm	Knox Dolo-mite
39	DEFIANCE	ADAMS	S18	SOHIO PET CO	HIGBEA	745	1102	ABS	1885	2116	2479	2484
31	DEFIANCE	FARMER	S29	WAND OIL	SALTZMAN	752	1070	ABS	1836	2055	2392	2398
33	DEFIANCE	FARMER	S32	JOHNSON OIL CO	MILLER	749	NL	ABS	1766	1978	2286	2310
17	DEFIANCE	MARK	S4	BROWN	GECOWETS	722	1002	ABS	1765	NDE	NDE	NDE
28	DEFIANCE	MARK	S11	BROWN	HAVER	702	NL	ABS	1742	1958	2289	2293
25	DEFIANCE	NOBLE	S3	MAUMEE VALLEY OIL & GAS	BROWN	707	970	ABS	1756	NDE	NDE	NDE
43	DEFIANCE	NOBLE	S3	GRAHAM-MICHAELIS CORP	Z T B	705	NL	ABS	1754	NDE	NDE	NDE
45	DEFIANCE	NOBLE	S3	GRAHAM-MICHAELIS CORP	HEILMAN	709	974	ABS	1764	NDE	NDE	NDE
59	DEFIANCE	NOBLE	S2	GRAHAM-MICHAELIS CORP	HARDY	705	NL	ABS	1764	NDE	NDE	NDE
52	DEFIANCE	TIFFIN	S34	GRAHAM-MICHAELIS CORP	SAUBER	702	982	ABS	1769	NDE	NDE	NDE
61	DEFIANCE	TIFFIN	S35	GRAHAM-MICHAELIS CORP	HUEFNER	709	988	ABS	1770	NDE	NDE	NDE
38	DEFIANCE	WASHINGTON	S5	SOHIO PET CO	BURGBACHER	741	1116	ABS	1884	2117	2456	2462
13	FULTON	CHESTERFIELD	S31	MCCLURE OIL CO	KEEFER	733	1528	ABS	2298	2546	NDE	NDE
19	FULTON	CHESTERFIELD	S34	COVEY & NULL	TUGGLE	797	1621	ABS	2389	2642	3018	3032
21	FULTON	CHESTERFIELD	S26	AMERICAN LIBERTY OIL CO	PENNING	814	1647	ABS	2415	2667	3046	3064
22	FULTON	CHESTERFIELD	S10	MCCLURE OIL CO	DEYO	815	1735	ABS	2498	2763	3139	3159
37	FULTON	CHESTERFIELD	S34	TALMADGE DRLG CO	TUGGLE	806	1638	ABS	2401	2654	3030	3045
38	FULTON	CHESTERFIELD	S34	LOREX INC	PFUND	813	1640	ABS	2405	2663	3032	3043
39	FULTON	CHESTERFIELD	S27	LOREX INC	RECKNER	819	1650	ABS	2415	2660	NDE	NDE
41	FULTON	CHESTERFIELD	S34	LOREX INC	WILLEMAN	812	1638	ABS	2400	2655	NDE	NDE
44	FULTON	CHESTERFIELD	S34	LOREX INC	WILLEMAN	806	1620	ABS	2388	2646	NDE	NDE
46	FULTON	CHESTERFIELD	S26	LOREX INC	SMITH	809	1640	ABS	2401	2655	3030	3045
47	FULTON	CHESTERFIELD	S21	LIBERTY PET CORP	JOHNSTON	775	NL	ABS	2383	2641	3010	3034
50	FULTON	CHESTERFIELD	S34	HATT	EBY	794	1641	ABS	2381	NDE	NDE	NDE
17	FULTON	CLINTON	S17	KUBAT	VONIER	758	1410	ABS	2186	2432	2800	2826
32	FULTON	CLINTON	S21	MAGUIRE	NOFZIGER	777	1387	ABS	2155	2397	2768	2785
35	FULTON	CLINTON	S17	ARROWHEAD EXPLORATION	VONIER	765	1422	ABS	2194	2440	2807	2835
45	FULTON	DOVER	S5	LIBERTY PET CORP	CLINGMAN	778	NL	ABS	2324	2574	2950	2974
48	FULTON	DOVER	S2N	HATT	BARHITE	800	1615	ABS	2379	NDE	NDE	NDE
26	FULTON	FULTON	S10	LIBERTY PET CORP	SLAHUNEK	723	1414	ABS	2106	2438	2794	2796
27	FULTON	FULTON	S1N	LIBERTY PET CORP	TANTIGIAN	713	NL	ABS	2121	2389	2805	2812
28	FULTON	FULTON	S32S	LIBERTY PET CORP	FAUBLE	743	1370	ABS	2136	2396	2787	2794
52	FULTON	FULTON	S32S	AN-CAR OIL CO	BRATTON	754	1408	ABS	2172	2434	NDE	NDE
14	FULTON	GORHAM	S17	MCCLURE OIL CO	THOMAS	785	1680	ABS	2437	2692	NDE	NDE
24	FULTON	GORHAM	S19	MCCLURE OIL CO	GAMBLE	820	1695	ABS	2477	2734	3161	3182
33	FULTON	GORHAM	S26W	LIBERTY PET CORP	STEINEM	835	1684	ABS	2449	2699	3056	3070
36	FULTON	GORHAM	S19	MCCLURE OIL CO	ERBSKORN	810	1692	ABS	2441	2692	3056	3064
16	FULTON	PIKE	S32	DUNN	KIRKENDALL	771	1625	ABS	2358	2620	?	3004
12	FULTON	SWAN CREEK	S22	OHIO OIL CO	MUNN	680	1220	ABS	1936	NDE	NDE	NDE
49	FULTON	SWAN CREEK	S27	LIBERTY PET CORP	STOREHOLDER	690	1179	ABS	1911	2163	2560	2573
51	FULTON	SWAN CREEK	S17	HOUSEKNECHT OIL PROD	ZIELINSKI	722	1274	ABS	2036	2294	0	2696
15	FULTON	YORK	S27	RIXLEBEN INC	BRINKMAN	720	1247	ABS	2015	2260	2652	2662
18	FULTON	YORK	S8	COVEY & NULL	NEUSWANDER	758	1414	ABS	2183	2431	2815	2824
23	FULTON	YORK	S36	JOHNSON OIL CO	WITTENBERG	692	1162	ABS	1935	2181	2571	2576
41	HENRY	DAMASCUS	S26	GRAHAM-MICHAELIS CORP	DIBLING UNIT	678	886	ABS	1676	NDE	NDE	NDE
43	HENRY	DAMASCUS	S22	GRAHAM-MICHAELIS CORP	TONJES UNIT	678	900	ABS	1682	NDE	NDE	NDE
46	HENRY	DAMASCUS	S15	GRAHAM-MICHAELIS CORP	SHIVELY	676	911	ABS	1698	NDE	NDE	NDE
55	HENRY	DAMASCUS	S27	GRAHAM-MICHAELIS CORP	JUNGE	679	NL	ABS	1668	NDE	NDE	NDE
59	HENRY	DAMASCUS	S21	GRAHAM-MICHAELIS CORP	HOUSER	680	NL	ABS	1697	NDE	NDE	NDE
71	HENRY	DAMASCUS	S32	GRAHAM-MICHAELIS CORP	SHIDLER	681	879	ABS	1673	NDE	NDE	NDE
77	HENRY	DAMASCUS	S31	GRAHAM-MICHAELIS CORP	CONN	683	873	ABS	1667	NDE	NDE	NDE

APPENDIX — AREA 1 (continued)

Permit no.	County	Township	Land sub-division	Operator	Lease name	Eleva-tion	Depth to top (ft)					
							Cincin-nati group	Point Pleasant Fm	Trenton Ls	Black River Gp	Wells Creek Fm	Knox Dolo-mite
82	HENRY	DAMASCUS	S33	GRAHAM-MICHAELIS CORP	LANZER	682	891	ABS	1679	NDE	NDE	NDE
83	HENRY	DAMASCUS	S33	GRAHAM-MICHAELIS CORP	JOHNSON	682	NL	ABS	1683	NDE	NDE	NDE
84	HENRY	DAMASCUS	S32	GRAHAM-MICHAELIS CORP	MOWERY	683	874	ABS	1675	NDE	NDE	NDE
88	HENRY	DAMASCUS	S32	GRAHAM-MICHAELIS CORP	FREY	682	NL	ABS	1671	NDE	NDE	NDE
95	HENRY	DAMASCUS	S28	GRAHAM-MICHAELIS CORP	FRANKFATHER	683	894	ABS	1692	NDE	NDE	NDE
98	HENRY	DAMASCUS	S26	GRAHAM-MICHAELIS CORP	PROFANT	680	882	ABS	1673	NDE	NDE	NDE
99	HENRY	DAMASCUS	S35	GRAHAM-MICHAELIS CORP	RUDOLPH	680	883	ABS	1660	NDE	NDE	NDE
100	HENRY	DAMASCUS	S35	GRAHAM-MICHAELIS CORP	WEASEL	679	867	ABS	1668	NDE	NDE	NDE
106	HENRY	DAMASCUS	S25	GRAHAM-MICHAELIS CORP	ECKEL	678	NL	ABS	1663	NDE	NDE	NDE
107	HENRY	DAMASCUS	S26	GRAHAM-MICHAELIS CORP	NICKELS	678	896	ABS	1680	NDE	NDE	NDE
109	HENRY	DAMASCUS	S34	GRAHAM-MICHAELIS CORP	WELLS	680	892	ABS	1689	NDE	NDE	NDE
115	HENRY	DAMASCUS	S34	GRAHAM-MICHAELIS CORP	SHUFELT	682	869	ABS	1661	NDE	NDE	NDE
20	HENRY	FREEDOM	S23	LESH DRLG	BADENHOP	718	1192	ABS	1960	2198	2583	2597
36	HENRY	HARRISON	S26	CALLANDER & KIMBREL INC	HALL	683	922	ABS	1710	1939	2337	2349
23	HENRY	MARION	S2	M WEIKEL	LAND	706	740	ABS	1542	1777	NDE	NDE
24	HENRY	MARION	S1	M WEIKEL	BRUBAKER	706	742	ABS	1566	NDE	NDE	NDE
30	HENRY	MARION	S1	NAHABEDIAN & FAWCETT	BRUBAKER	707	735	ABS	1548	NDE	NDE	NDE
31	HENRY	MARION	S10	HATT	HITTE	713	740	ABS	1564	NDE	NDE	NDE
32	HENRY	MARION	S2	NAHABEDIAN & FAWCETT	MEYER	705	747	ABS	1560	NDE	NDE	NDE
122	HENRY	MARION	S28	OIL DEVELOPMENT CO	DULIN	710	753	ABS	1565	NDE	NDE	NDE
125	HENRY	MARION	S5	TURRILL	MAHLMAN	711	771	ABS	1587	NDE	NDE	NDE
131	HENRY	MARION	S3	PIONEER OIL CO INC	BADEN	710	748	ABS	1564	NDE	NDE	NDE
56	HENRY	MONROE	S13	GRAHAM-MICHAELIS CORP	POHLMAN	689	NL	ABS	1653	NDE	NDE	NDE
22	HENRY	PLEASANT	S30	KATEX OIL CO	HOFFMAN	732	743	ABS	1563	NDE	NDE	NDE
123	HENRY	PLEASANT	S13	TURRILL	OKULEY	723	752	ABS	1565	NDE	NDE	NDE
124	HENRY	PLEASANT	S23	TURRILL	FABER	732	774	ABS	1568	NDE	NDE	NDE
126	HENRY	PLEASANT	S23	FITZGERALD ENERGY PROD	THOMAS	728	765	ABS	1512	NDE	NDE	NDE
129	HENRY	PLEASANT	S12	FITZGERALD ENERGY PROD	MILES ET AL	717	756	ABS	1575	NDE	NDE	NDE
12	HENRY	RICHFIELD	S3	GRAHAM-MICHAELIS CORP	SCHULZE	684	851	ABS	1643	NDE	NDE	NDE
27	HENRY	RICHFIELD	S33	HATT	GROSCHNER	701	787	ABS	1600	NDE	NDE	NDE
34	HENRY	RICHFIELD	S1	CALLANDER & KIMBREL INC	STAUB	676	827	ABS	1634	NDE	NDE	NDE
35	HENRY	RICHFIELD	S9	CALLANDER & KIMBREL INC	SHEPARD	684	850	ABS	1641	NDE	NDE	NDE
42	HENRY	RICHFIELD	S11	GRAHAM-MICHAELIS CORP	SHULL	686	835	ABS	1630	NDE	NDE	NDE
45	HENRY	RICHFIELD	S10	GRAHAM-MICHAELIS CORP	WENDT	683	843	ABS	1638	NDE	NDE	NDE
64	HENRY	RICHFIELD	S7	GRAHAM-MICHAELIS CORP	MEIENBURG	685	865	ABS	1668	NDE	NDE	NDE
68	HENRY	RICHFIELD	S5	GRAHAM-MICHAELIS CORP	FOLLETT	685	868	ABS	1676	NDE	NDE	NDE
70	HENRY	RICHFIELD	S6	GRAHAM-MICHAELIS CORP	RISWOLD	682	NL	ABS	1674	NDE	NDE	NDE
75	HENRY	RICHFIELD	S4	GRAHAM-MICHAELIS CORP	SHIDLER	684	NL	ABS	1660	NDE	NDE	NDE
78	HENRY	RICHFIELD	S5	GRAHAM-MICHAELIS CORP	BARNES	681	NL	ABS	1677	NDE	NDE	NDE
80	HENRY	RICHFIELD	S5	GRAHAM-MICHAELIS CORP	JONES	681	NL	ABS	1677	NDE	NDE	NDE
86	HENRY	RICHFIELD	S4	GRAHAM-MICHAELIS CORP	NULTON	682	870	ABS	1665	NDE	NDE	NDE
89	HENRY	RICHFIELD	S5	GRAHAM-MICHAELIS CORP	JONES	683	866	ABS	1661	NDE	NDE	NDE
108	HENRY	RICHFIELD	S3	GRAHAM-MICHAELIS CORP	SCHULZE	683	848	ABS	1649	NDE	NDE	NDE
19	HENRY	RIDGEVILLE	S20	FREY	FREY	720	1192	ABS	1965	2188	2546	2562
45	WILLIAMS	BRIDGEWATER	S13	COLUMBIA GAS TRANS CORP	KOLLAR	908	1874	ABS	2618	2865	3187	3195
46	WILLIAMS	BRIDGEWATER	S13	COLUMBIA GAS TRANS CORP	COOK	915	1856	ABS	2598	2832	3166	3175
37	WILLIAMS	CENTER	S25	TAMP OIL CO	WINELANDS	779	1212	ABS	1980	2202	2550?	2560?
47	WILLIAMS	FLORENCE	S17	SOHIO PET CO	LAUTZENHEISER	917	1628	ABS	2360	2592	ABS	2888
28	WILLIAMS	JEFFERSON	S18	MCCLURE OIL CO	KASPAR	889	1588	ABS	2338	2572	NDE	NDE
30	WILLIAMS	MADISON	S5	MCCLURE OIL CO	BARNHART	868	1706	ABS	2472	2722	3070	3076
33	WILLIAMS	ST. JOSEPH	S21	WALTON OIL CO	KENNERK	848	1362	ABS	2104	NDE	NDE	NDE
34	WILLIAMS	ST. JOSEPH	S21	BEGLINGER	KENNERK	842	NL	ABS	2086	2295	2634	2648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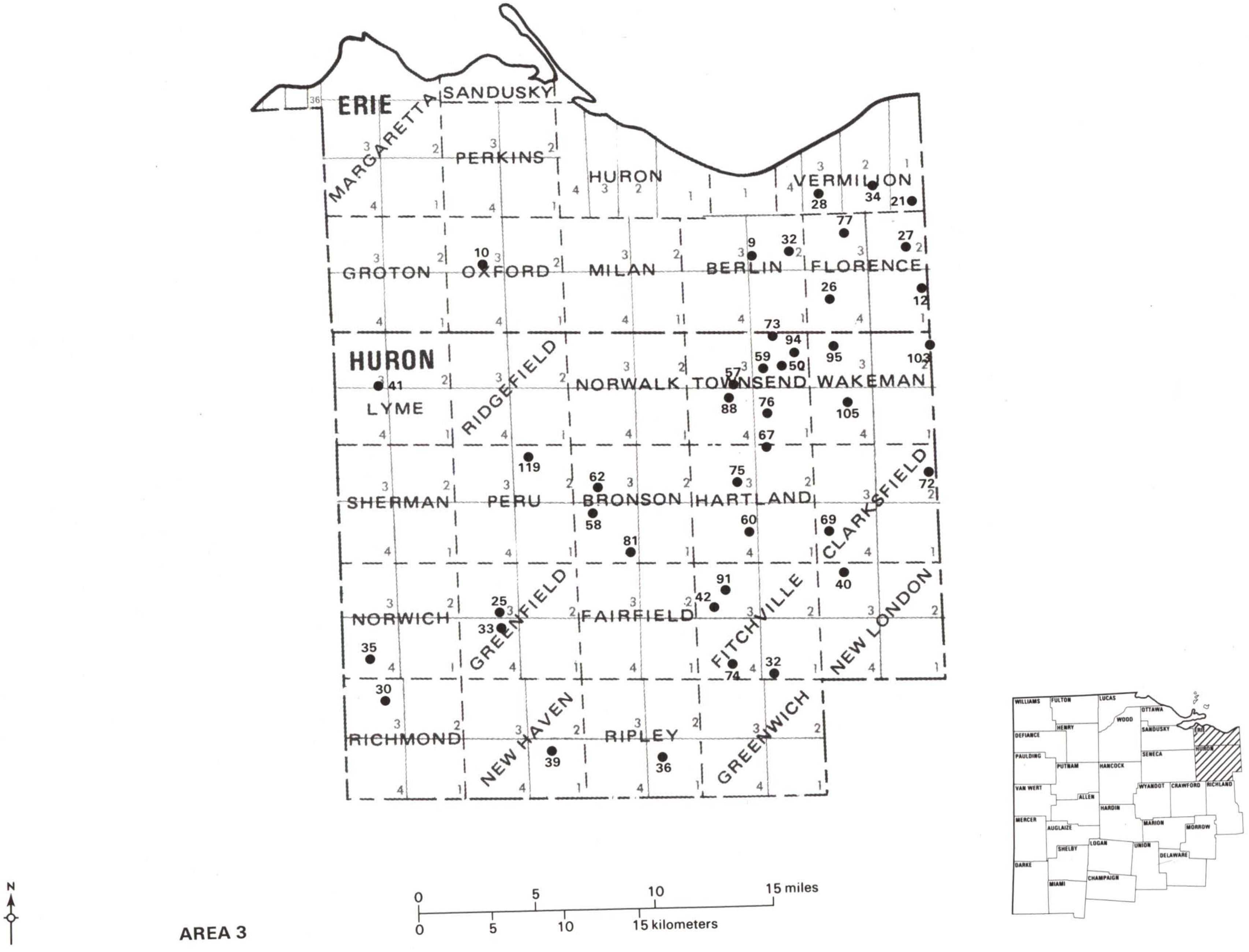
AREA 2

APPENDIX — AREA 2

Permit no.	County	Township	Land sub-division	Operator	Lease name	Elevation	Depth to top (ft)					
							Cincinnati group	Point Pleasant Fm	Trenton Ls	Black River Gp	Wells Creek Fm	Knox Dolomite
60	LUCAS	HARDING	S9	LIBERTY PET CORP	KETRING	675	1218	ABS	1975	2260	2686	2691
25	LUCAS	MONCLOVA	S23	OHIO OIL CO	MEHRING	663	998	ABS	1752	2011	NDE	NDE
37	LUCAS	MONCLOVA	S28	GEOTRONIC SURVEY CO	MANLEY	670	NL	ABS	1348	NDE	NDE	NDE
39	LUCAS	SPRINGFIELD	S28	GEOTRONIC SURVEY CO	BURCHFIELD	635	580	ABS	1340	NDE	NDE	NDE
66	OTTAWA	ALLEN	S11	D & H OIL CO	HOEFT	600	NL	ABS	1346	NDE	NDE	NDE
79	OTTAWA	ALLEN	S10	SHAFER OIL PROD	PINKERTON	607	583	ABS	1307	1590	NDE	NDE
80	OTTAWA	BENTON	S34S	SHAFER OIL PROD	KAISER	607	590	ABS	1325	1596	NDE	NDE
44	OTTAWA	CARROLL	S9	WENNER PET	MOORE	576	685	ABS	1430	1721	2267	NDE
48	OTTAWA	CARROLL	S8	WENNER PET	HEMMINGER	579	675	ABS	1410	NDE	NDE	NDE
49	OTTAWA	CARROLL	S4	WENNER PET	VELLIQUETTE	578	683	ABS	1421	NDE	NDE	NDE
50	OTTAWA	CARROLL	S8	FITZGERALD ENERGY PROD	ARNDT	579	672	ABS	1406	1701	2247	NDE
55	OTTAWA	CARROLL	S9	HORTIN & HUFFMAN INC	HEMMINGER	580	675	ABS	1417	NDE	NDE	NDE
56	OTTAWA	CARROLL	S9	HORTIN & HUFFMAN INC	MOORE	578	683	ABS	1421	NDE	NDE	NDE
58	OTTAWA	CARROLL	S9	HORTIN & HUFFMAN INC	MOORE	576	690	ABS	1433	NDE	NDE	NDE
62	OTTAWA	CARROLL	S9	HORTIN & HUFFMAN INC	HEMMINGER	577	666	ABS	1406	NDE	NDE	NDE
69	OTTAWA	CARROLL	S8	HORTIN & HUFFMAN INC	HEMMINGER	579	677	ABS	1414	NDE	NDE	NDE
88	OTTAWA	CARROLL	S27	HORTIN & HUFFMAN INC	MILLINGER	590	NL	ABS	1389	NDE	NDE	NDE
43	OTTAWA	CATAWBA ISLAND	S26	KIRKCONNELL	THAYER	592	NL	ABS	1892	NDE	NDE	NDE
64	OTTAWA	CATAWBA ISLAND	L1	WM OIL & GAS CO	MAY COMM UNIT	600	897	ABS	1906	2175	NDE	NDE
82	OTTAWA	CATAWBA ISLAND	S26	SHAFER OIL PROD	BAUMAN	601	1030	ABS	1888	2123	NDE	NDE
76	OTTAWA	CLAY	S4	SHAFER OIL PROD	RIDEOUT APARTMENT	631	545	ABS	1298	1575	NDE	NDE
70	OTTAWA	HARRIS	S2	SHAFER OIL PROD	KAISER	600	585	ABS	1319	1586	NDE	NDE
72	OTTAWA	HARRIS	S22	SHAFER OIL PROD	SHAFFER	610	560	ABS	1300	1561	NDE	NDE
73	OTTAWA	SALEM	S9	SHAFER OIL PROD	WISTINGHAUSEN	589	553	ABS	1315	1585	NDE	NDE
77	OTTAWA	SALEM	S31	SHAFER OIL PROD	MILBRODT	601	584	ABS	1321	1608	NDE	NDE
89	OTTAWA	SALEM	S33	HORTIN & HUFFMAN INC	VON EITZEN	590	622	ABS	1372	NDE	NDE	NDE
103	SANDUSKY	BALLVILLE	S31	EMME OIL CO	TOLENTO	676	510	1308	1382	1538	2059	2065
126	SANDUSKY	BALLVILLE	S31	C & E OIL CO	RECKER	675	NL	NL	1392	1555	2058	2066
133	SANDUSKY	BALLVILLE	S11	SPINDALE OIL & GAS CO	MILLER	646	NL	NL	1493	1658	2187	2208
248	SANDUSKY	GREEN CREEK	S35	GLORY OIL CO INC	ROHDE	776	NL	1772?	1918	1985	2529	2550
118	SANDUSKY	JACKSON	S11	BURRELL PET CO	GABEL	679	580	NL	1354	1597	NDE	NDE
146	SANDUSKY	MADISON	S22	MAGUIRE	ALSHIRE-MARATHON	706	NL	NL	1242	1519	2040	2055
140	SANDUSKY	RILEY	S8	ASHLAND OIL	TRICK	587	625	1404	1474	1685	2224	2234
210	SANDUSKY	RILEY	S26	OHIO LIQUID DISPOSAL	OHIO LIQUID DISPOSAL	620	742	?	1667	1819	2362	2367
225	SANDUSKY	RILEY	S26	OHIO LIQUID DISPOSAL	OHIO LIQUID DISPOSAL	618	738	1598	1667	1818	2367	2397
235	SANDUSKY	RILEY	S26	OHIO LIQUID DISPOSAL	OHIO LIQUID DISPOSAL	616	738	?	1663	1815	2360	2366
237	SANDUSKY	RILEY	S26	OHIO LIQUID DISPOSAL	OHIO LIQUID DISPOSAL	618	717	1552	1639	1795	2340	2345
137	SANDUSKY	SCOTT	S12	ASHLAND OIL	HAVEN	711	465	ABS	1241	1507	2029	2050
77	SANDUSKY	TOWNSEND	S33	EAST OHIO GAS CO	HAFF	644	892	1747	1860	1966	2498	2512
138	SANDUSKY	TOWNSEND	S29	ASHLAND OIL	WOBSER	649	878	1746	1845	1956	2488	2504
117	SANDUSKY	WASHINGTON	S31	DUNIGAN JR	AVERS	633	510	ABS	1260	1534	2053	2065
134	SANDUSKY	WASHINGTON	S22	COMMONWEALTH GAS CORP	LILLY	651	493	ABS	1286	1534	2068	2080
139	SANDUSKY	WASHINGTON	S23	COMMONWEALTH GAS CORP	WARNER	637	525	ABS	1300	1543	2032	2037
141	SANDUSKY	WASHINGTON	S24	ASHLAND OIL	MIARER	658	525	ABS	1298	1552	2078	2086
148	SANDUSKY	WASHINGTON	S35	CHIEF DRLG INC	LOGENBACH	663	530	ABS	1321	1564	2092	2098
147	SANDUSKY	WOODVILLE	S36	MAGUIRE	KERBEL	647	502	ABS	1250	1538	2046	2056
206	WOOD	BLOOM	S29	CONTINENTAL OIL CO	EBERSOLE	726	225	ABS	1043	1280	1754	1765
355	WOOD	BLOOM	S17	MOBIL OIL CORP	PATTERSON	721	259	ABS	1079	1320	1776	1796
409	WOOD	BLOOM	S7	HAMBLIN	BILS	707	290	ABS	1077	NDE	NDE	NDE
229	WOOD	CENTER	S31	SOUTHERN TRIANGLE OIL	KNAUSS	694	300	ABS	1092	1362	1826	1835

APPENDIX — AREA 2 (continued)

Permit no.	County	Township	Land subdivision	Operator	Lease name	Elevation	Depth to top (ft)					
							Cincinnati group	Point Pleasant Fm	Trenton Ls	Black River Gp	Wells Creek Fm	Knox Dolomite
237	WOOD	CENTER	S4	KIN-ARK OIL CO	CARTER	673	401	ABS	1174	1452	1941	1967
248	WOOD	GRAND RAPIDS	S30	KIN-ARK OIL CO	NEILSON	681	823	ABS	1609	1841	2265	2268
215	WOOD	HENRY	S6	GOOD & GOOD DRLG	HERRINGSHAW	698	622	ABS	1423	1666	2116	2121
259	WOOD	HENRY	S11	TRANSAMERICAN PET CORP	LEATHERS	698	348	ABS	1145	1378	1825	1833
287	WOOD	HENRY	S36	NAHABEDIAN & FAWCETT	STEVENS	736	NL	ABS	1108	1344	1799	NDE
422	WOOD	HENRY	S32	CABOT OIL & GAS CORP	BOWER	723	518	ABS	1320	1561	NDE	NDE
424	WOOD	HENRY	S20	CABOT OIL & GAS CORP	RAYLE	708	524	ABS	1331	NDE	NDE	NDE
382	WOOD	JACKSON	S32	LEASE LENDERS CORP	SOONER	717	NL	ABS	1459	1691	2118	2130
231	WOOD	LIBERTY	S36	O'NEILL	PEEK	698	352	ABS	1157	1407	1862	1880
398	WOOD	LIBERTY	S36	MAUMEE VALLEY RESOURCES	MAUMEE VALLEY RESOURCES	689	NL	ABS	1161	1405	NDE	NDE
423	WOOD	LIBERTY	S2	ANSCHUTZ CORP	KRAMER	691	526	ABS	1221	1516	1976	1986
432	WOOD	LIBERTY	S2	TEXAS GAS EXPLORATION	FEEHAN UNIT	690	496	ABS	1268	1531	1993	2000
433	WOOD	LIBERTY	S3	TEXAS GAS EXPLORATION	APPLE	693	431	ABS	1208	1466	1921	1930
239	WOOD	MIDDLETON	S21W	JRS CO	ASMUS ET AL	670	401	ABS	1168	1440	1905	1916
364	WOOD	PERRY	S22	ALLERTON RESOURCES INC	DENNIS ET AL	748	350	ABS	1173	1428	1921	1937
366	WOOD	PERRY	S29	ALLERTON RESOURCES INC	TIENAREND	744	320	ABS	1131	1370	1861	1882
367	WOOD	PERRY	S17	ALLERTON RESOURCES INC	BRENEMAN	721	332	ABS	1146	1402	1896	1905
394	WOOD	PERRY	S22	KIRBY EXPLORATION	DENNIS	752	412	ABS	1172	1418	1913	1926
387	WOOD	PERRYSBURG	S3	BRETT	BRIMACOMB	637	569	ABS	1307	1599	NDE	NDE
53	WOOD	PLAIN	S26	F-L OIL & GAS DRLG CO	FEEHAN	681	546	ABS	1321	NDE	NDE	NDE
203	WOOD	PLAIN	S18	GRANTLEY CO	SPITLER	671	634	ABS	1416	1672	2134	2143
234	WOOD	PLAIN	S16	BLACK RIVER OIL & GAS	TOBER	683	534	ABS	1309	1572	2008	2013
236	WOOD	PLAIN	S1	KIN-ARK OIL CO	SMITH	677	386	ABS	1154	1436	1904	1909
413	WOOD	PORTAGE	S24	M & M DRILLING	AURAND	686	380	ABS	1188	NDE	NDE	NDE
414	WOOD	PORTAGE	S24	M & M DRILLING	AURAND	686	387	ABS	1187	NDE	NDE	NDE
426	WOOD	PORTAGE	S19	SAGE ENERGY INC	CARPENTER	686	351	ABS	1157	NDE	NDE	NDE
2549	WOOD	PORTAGE	S7	OHIO DIV. GEOL. SURVEY	MAUMEE STONE CO	680	NL	ABS	1104	NDE	NDE	NDE
400	WOOD	TROY	S12	D & H OIL CO	SCHULTE	644	NL	ABS	1243	NDE	NDE	NDE
211	WOOD	WASHINGTON	S32	CONTINENTAL OIL CO	EULERONE	668	675	ABS	1446	1715	2170	2178
232	WOOD	WASHINGTON	S4	O'NEILL JR	FOOTE	675	NL	ABS	1364	1623	2087	2092
247	WOOD	WASHINGTON	S12	ASHLAND OIL	FREEWORTH	685	795	ABS	1573	1832	2258	2262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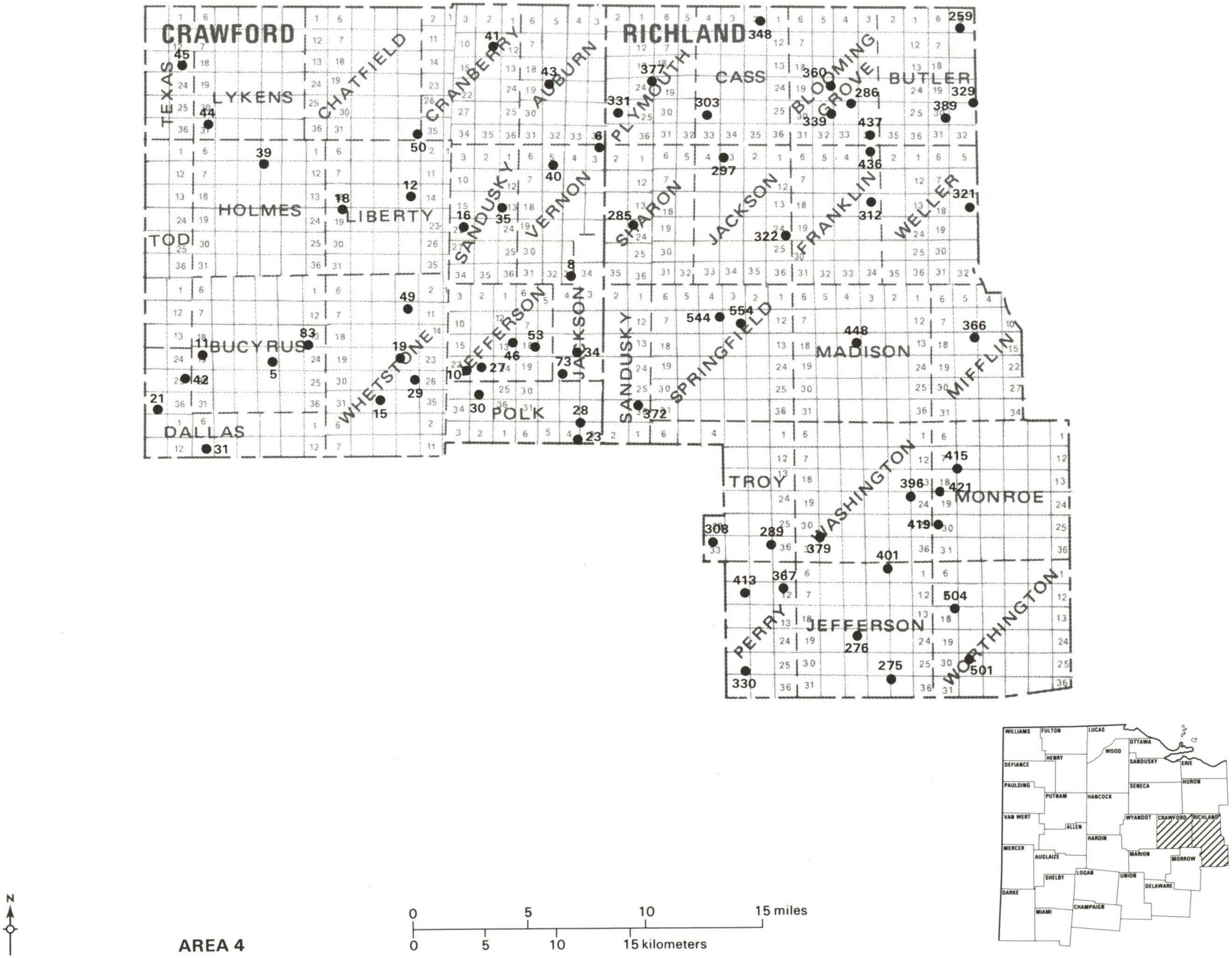
AREA 3

APPENDIX — AREA 3

Permit no.	County	Township	Land sub-division	Operator	Lease name	Elevation	Depth to top (ft)					
							Cincinnati group	Point Pleasant Fm	Trenton Ls	Black River Gp	Wells Creek Fm	Knox Dolomite
9	ERIE	BERLIN	L9,2ND¼	FLOTO-MAMMOTH	WILLIS	664	1668	2717	2863	2926	3458	3480
32	ERIE	BERLIN	L9,2ND¼	PENZOIL	NEIDING	780	1841	?	3024	3106	3641	3663
7	ERIE	FLORENCE	L48,4TH¼	OHIO FUEL GAS	SAYLER	819	1967	3011	3176	3255	3790	3817
11	ERIE	FLORENCE	L98,1ST¼	SUN OIL CO	WAKEFIELD UNIT	828	1968	3025	3201	3270	3816	3838
12	ERIE	FLORENCE	L97,1ST¼	SUN OIL CO	SCHLECHTER	826	1978	3025	3191	3265	3814	3837
14	ERIE	FLORENCE	L87,1ST¼	SUN OIL CO	KNIGHT UNIT	775	1910	2966	3133	3207	3756	3778
15	ERIE	FLORENCE	L98,1ST¼	SUN OIL CO	LATTEMAN	833	1936	3043	3211	3286	3833	3856
16	ERIE	FLORENCE	L87,1ST¼	SUN OIL CO	HUME UNIT	828	1962	3014	3180	3253	3800	3822
18	ERIE	FLORENCE	L77,1ST¼	TROLZ & ASSOC INC	ORTNER ET AL	825	2030	3101	3267	3342	3886	3909
19	ERIE	FLORENCE	L97,1ST¼	SUN OIL CO	HERMAN ET AL	829	1970	3037	3203	3276	3827	3850
20	ERIE	FLORENCE	L86,1ST¼	SUN OIL CO	HUME	817	1960	3032	3194	3268	3818	3840
24	ERIE	FLORENCE	L68,1ST¼	MURPHY	HANKO	738	1922	2978	3145	3221	3762	3785
25	ERIE	FLORENCE	L54,2ND¼	TRA-KAY PETROLEUM	GRIFFITH	831	2000	3054	3214	3290	3831	3853
26	ERIE	FLORENCE	L18,4TH¼	NEUBERGER	ALAIMO	830	1925	2962	3110	3189	3733	3755
27	ERIE	FLORENCE	L74,2ND¼	SUN OIL CO	HUNTER ET AL	809	1941	?	3171	3249	3787	3814
29	ERIE	FLORENCE	L62,2ND¼	SUN OIL CO	NIEMUTH ET AL	795	1936	2996	3152	3226	3769	3791
30	ERIE	FLORENCE	L98,1ST¼	SUN OIL CO	BEMIS ET AL	812	1954	3016	3185	3258	3808	3830
31	ERIE	FLORENCE	L74,2ND¼	KUBAT	HUNTER	800	NL	2993	3153	3230	3772	3794
63	ERIE	FLORENCE	L97,1ST¼	SUN OIL CO	SCHLECHTER	835	1980	3039	3207	3281	3830	3853
77	ERIE	FLORENCE	L22,3RD¼	POMINEX INC	NUHN	786	1927	2969	3123	3198	3730	3752
79	ERIE	FLORENCE	L86,1ST¼	SUN OIL CO	ERIE UNIT TRACT	809	1932	2993	3160	3233	3782	3804
10	ERIE	OXFORD		JACK LONG	F & A WENSINK	710	1328	?	2419	2480	3005	3025
21	ERIE	VERMILION	L9,TR1	MURPHY	HUMES	764	1933	2994	3156	3229	3783	3805
28	ERIE	VERMILION	L6,TR3	E & W OIL	PECK	630	1758	2820	2962	3041	3570	3593
34	ERIE	VERMILION	L11,TR2	E & W OIL	HAUFF-MILLER-NOVY	720	1845	2900	3061	3128	3663	3685
58	HURON	BRONSON	L32,4TH¼	KIN-ARK OIL CO	LAWRENCE-HESTER- HETTLE	833	1588	2582	2731	2791	3327	3349
62	HURON	BRONSON	L9,3RD¼	MCMAHON & BULLINGTON	MAXWELL	805	1588	2596	2737	2800	3340	3361
81	HURON	BRONSON	L9,4TH¼	LAKE SHORE PIPELINE CO	KNUPKE UNIT	919	1777	2771	2922	2981	3519	3540
69	HURON	CLARKSFIELD	L23,4TH¼	LAKE SHORE PIPELINE CO	SPOERR	943	2076	3142	3302	3376	3932	3955
72	HURON	CLARKSFIELD	L3,2ND¼	RELIANCE OIL CORP	LEITNER	914	2150	3240	3402	3490	4036	4060
32	HURON	FITCHVILLE	L6,1ST¼	ROBERTS	VARGO	980	2010	3056	3232	3300	3857	3891
42	HURON	FITCHVILLE	L42,3RD¼	KIN-ARK OIL CO	GRAY	1021	1974	2992	3155	3217	3766	3804
43	HURON	FITCHVILLE	L31,3RD¼	KIN-ARK OIL CO	CLAYTON-CRECELIUS	1003	1957	2978	3140	3205	3740	3778
74	HURON	FITCHVILLE	L46,4TH¼	ASHLAND OIL	REDDICK UNIT	998	1996	3021	3184	3252	3802	3842
91	HURON	FITCHVILLE	L28,3RD¼	TRIO-PETRO	LORTCHER	988	1937	2964	3127	3195	3741	3771
25	HURON	GREENFIELD	L40,3RD¼	PURE OIL CO	WHEELER	891	1517	2475	2641	2704	3239	3261
33	HURON	GREENFIELD	L9,4TH¼	BRADLEY	SMITH	880	1517	2484	2644	2702	3242	3262
60	HURON	HARTLAND	L6,4TH¼	STOCKER & SITLER	ERNSBERGER-GERSTENBERGER	955	1950	2984	3148	3229	3780	3813
67	HURON	HARTLAND	L1,2ND¼	HOLTOM	METZ-KETTEL	934	1960	3000	3162	3240	3791	3825
75	HURON	HARTLAND	L5,3RD¼	STOCKER & SITLER	STACKER ET AL UNIT	953	1923	2944	3104	3185	3742	3779
84	HURON	HARTLAND	L33,2ND¼	STOCKER & SITLER	JOHANNSEN ET AL	949	1913	2937	3101	3178	3732	3757
41	HURON	LYME	L27,3RD¼	SOUTH UNION PROD CO	YINGLING	794	1223	2127	2292	2354	2892	2908
28	HURON	NEW HAVEN	L107,1ST¼	RELIANCE OIL CORP	NEWMYER	787	1774	2764	2925	2981	3528	3560
39	HURON	NEW HAVEN	L105,1ST¼	STOCKER & SITLER	JOPLAND-CHAPMAN UNIT	966	1740	2708	2867	2925	3468	3490
38	HURON	NEW LONDON	L14,4TH¼	HADSON OHIO OIL CO	JOHNSON	989	2190	?	3427	3508	4056	4090
40	HURON	NEW LONDON	L20,3RD¼	COLORADO OIL & GAS	RUMBAUGH	949	2124	3186	3350	3424	3978	4011
35	HURON	NORWICH	L14,4TH¼	HORN	HILLIS	914	1360	?	2458	2512	3048	3071
119	HURON	PERU	L11,2ND¼	CABOT OIL & GAS CORP	STANG	762	1412	?	2527	2595	3125	3157
30	HURON	RICHMOND	L5,3RD¼	RELIANCE OIL CORP	NIEDERMEIER	957	1423	2354	2523	2581	3104	3122
36	HURON	RIPLEY	L33,1ST¼	HADSON OHIO OIL CO	WILLET	1044	1935	2992	3162	3220	3772	3811

APPENDIX — AREA 3 (continued)

Permit no.	County	Township	Land sub-division	Operator	Lease name	Elevation	Depth to top (ft) Cincinnati group	Point Pleasant Fm	Trenton Ls	Black River Gp	Wells Creek Fm	Knox Dolomite
46	HURON	TOWNSEND	L57,2ND¼	HEFNER PROD CO	BECK	883	1925	2970	3113	3183	3724	3739
50	HURON	TOWNSEND	L58,2ND¼	HEFNER PROD CO	HYDE	884	1927	2991	3118	3190	3731	3748
54	HURON	TOWNSEND	L37,2ND¼	TROLZ & ASSOC INC	CONRY ET AL	877	1959	3004	3154	3226	3778	3800
57	HURON	TOWNSEND	L77,3RD¼	KUBAT	KOSA	890	1900	2924	3075	3148	3674	3704
59	HURON	TOWNSEND	L56,2ND¼	HEFNER PROD CO	MEYERS	903	1934	2989	3113	3184	3724	3743
61	HURON	TOWNSEND	L32,2ND¼	HEFNER PROD CO	PLUE	882	1917	2958	3112	3186	3743	3762
63	HURON	TOWNSEND	L66,2ND¼	KIN-ARK OIL CO	FINLEY	885	1916	2924	3085	3156	3704	3727
73	HURON	TOWNSEND	L9,2ND¼	MANSFIELD DRLG CO	O'BRIEN & LYKINS	864	1910	?	3102	3173	3714	3736
76	HURON	TOWNSEND	L128,1ST¼	ASHLAND OIL	BOMGUT & HAHN UNIT	926	1947	2982	3140	3216	3768	3804
88	HURON	TOWNSEND	L100,4TH¼	JADOIL INC	LILES	892	1894	2934	3076	3140	3683	3706
94	HURON	TOWNSEND	L35,2ND¼	POMINEX INC	TUCKER	880	1933	2984	3118	3193	3736	3758
95	HURON	WAKEMAN	L12,3RD¼	OSBORN HEIRS CO	CENFIELD-PEABODY UNIT	859	1980	3030	3180	3250	3798	3822
103	HURON	WAKEMAN	L92,2ND¼	APPLACHIAN EXPLORATION	WOLF UNIT	856	2041	3110	3276	3350	3900	3922
105	HURON	WAKEMAN	L27,4TH¼	OSBORN HEIRS CO	BRUCKER	891	2028	3086	3250	3320	3868	3889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SENECA
HURON
VAN WERT
ALLEN
WYANDOT
CRAWFORD
RICHLAND
MERCER
AUGLAIZE
HARDIN
MARION
MORROW
SHELBY
LOGAN
UNION
DELAWARE
DARKE
MIAMI
CHAMPAIGN

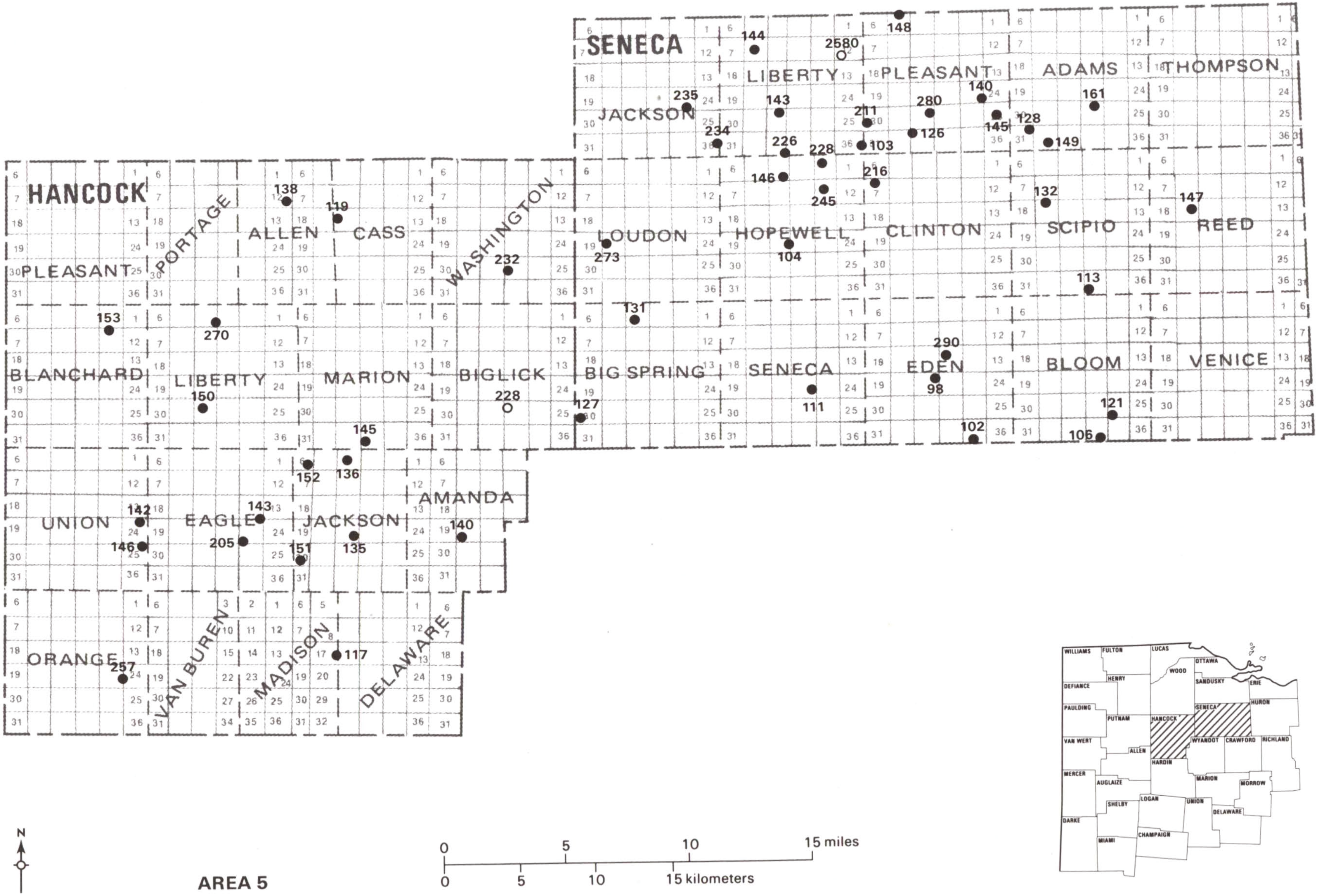
AREA 4

APPENDIX — AREA 4

Permit no.	County	Township	Land subdivision	Operator	Lease name	Elevation	Depth to top (ft)						
							Cincinnati group	Point Pleasant Fm	Trenton Ls	Black River Gp	Wells Creek Fm	Knox Dolomite
43	CRAWFORD	AUBURN	S20	KENTUCKY NTL OIL CO	STUMP	1018	NL	NL	2658	2715	3251	3283
5	CRAWFORD	BUCYRUS	S22	PLAINS EXPLORATION	BLICKE	1004	1026	1955	2109	2163	2695	2719
11	CRAWFORD	BUCYRUS	S19	BERMAN SHAFER	MILLER	973	854	1782	1934	1987	2503	2529
83	CRAWFORD	BUCYRUS	S13	BEREA OIL & GAS CORP	GREENICK	1013	1110	2033	2185	2241	2771	2794
50	CRAWFORD	CHATFIELD	S34	HAWKINS & HAWKINS	LEONHARDT	1008	1278	2217	2371	2442	2964	2980
77	CRAWFORD	CHATFIELD	S34	LULING OIL & GAS CO	REIDEL-FANKHAUSER	1013	1284	2231	2385	2454	2984	3008
41	CRAWFORD	CRANBERRY	S11	MUTUAL OIL & GAS CO	HEYDINGER	974	NL	2343	2481	2540	3078	3102
21	CRAWFORD	DALLAS	S35	SCHOONMAKER CO	RUFFENER-UNDERWOOD	954	785	1701	1853	1914	2435	2459
31	CRAWFORD	DALLAS	S7	SCHARER & LUDWICK	LUDWICK	962	NL	?	1940	2001	2522	2539
42	CRAWFORD	DALLAS	S25	HAMMERSTONE OIL CO	HARMON	966	830	1748	1900	1954	2482	2512
39	CRAWFORD	HOLMES	S10	P FULK SR	HAYCOCK	975	NL	?	2039	2105	2620	2640
34	CRAWFORD	JACKSON	S16	KECKLER	GARRETT	1162	NL	?	2898	2966	3500	3528
73	CRAWFORD	JACKSON	S21	KECKLER; CRAWFORD DRLG	ZEGER & JONES	1179	NL	2646	2817	2884	3418	3446
10	CRAWFORD	JEFFERSON	S22	BALDWIN	SHERER	1076	NL	2383	2548	2609	3149	3165
27	CRAWFORD	JEFFERSON	S23	V T DRLG & CHESWELL OIL	EICHHORN	1085	1458	2437	2593	2660	3188	3215
32	CRAWFORD	JEFFERSON	S18	HARDING BROS OIL & GAS	CRAWFORD NURSERIES	1142	1535	2490	2656	2728	3240	3256
46	CRAWFORD	JEFFERSON	S13	SUN OIL CO	APP	1126	1505	2450	2619	2685	?	3148?
53	CRAWFORD	JEFFERSON	S18	S A GARFIELD	PHILP	1162	NL	?	2718	2786	3318	3348
54	CRAWFORD	JEFFERSON	S17	S A GARFIELD	DEGRAY	1153	NL	?	2745	2808?	NDE	NDE
12	CRAWFORD	LIBERTY	S15	VANDEVEER	BRAUSE	1030	1268	2218	2372	2428	2966	3009
18	CRAWFORD	LIBERTY	S19	VANDEVEER	CRALL	1005	1140	2066	2218	2284	2801	2823
44	CRAWFORD	LYKENS	S31	PIGGOTT JR	SPITLER-BROWN	977	920	1800	1953	2022	2543	2564
23	CRAWFORD	POLK	S4	COWEN	STEVENS	1202	1760	2736	2911	2968	3512	3532
28	CRAWFORD	POLK	S4	BAUER BROS	BAUER	1185	1738	2718	2890	2953	3486	3517
30	CRAWFORD	POLK	S26	SUN OIL CO	RICKER	1102	1470	2418	2587	2650	ABS	3168
16	CRAWFORD	SANDUSKY	S22	VANDEVEER	RUTH	1062	1370	2326	2489	2555	3094	3137
35	CRAWFORD	SANDUSKY	S13	DEE OIL CO	ECKSTEIN	1053	1472	2434	2591	2659	3189	3223
45	CRAWFORD	TEXAS	S13	KIN-ARK OIL CO	FLICKINGER-ZIMMER	953	874	1780	1911	1967	2490	2513
82	CRAWFORD	TEXAS	S11	PIONEER OIL CO INC	DENINGER	912	NL	?	1850	1916	2450	2475
6	CRAWFORD	VERNON	S3	HAYNES OIL & GAS	CRUM	1087	1715	2688	2853	2916	3445	3470
8	CRAWFORD	VERNON	S33	SUN OIL CO	KIRCHBAUM	1130	1692	2662	2834	2902	3434	3460
40	CRAWFORD	VERNON	S5	MT CARMEL DRLG CO	STROHM-SNYDER	1093	1614	2580	2743	2808	3337	3372
15	CRAWFORD	WHETSTONE	S33	VANDEVEER	KUEHNLE	1029	1248	2191	2359	2413	2949	2975
19	CRAWFORD	WHETSTONE	S22	VANDEVEER	CRALL	1013	1294	2240	2401	2468	2989	3008
29	CRAWFORD	WHETSTONE	S27	RIDER	PERRY	1061	NL	?	2437	2493	3020	3029
49	CRAWFORD	WHETSTONE	S10N	KATEX OIL CO	WAGNER	1048	1296	2237	2395	2444	2983	3009
86	CRAWFORD	WHETSTONE	S13	BEREA OIL & GAS CORP	PHILLIPS	1077	1389	2331	2495	2543	3075	3113
286	RICHLAND	BLOOMING GROVE	S28	SOUTHERN TRIANGLE OIL	BARNO	1136	2178	3203	3383	3440	3998	4037
339	RICHLAND	BLOOMING GROVE	S29	STOCKER & SITLER	DYER	1033	2086	?	3262	3330	3880	3922
360	RICHLAND	BLOOMING GROVE	S20	SHAW	CUPPY	1132	2128	3158	3334	3402	3950	3987
437	RICHLAND	BLOOMING GROVE	S34	SOUTHERN TRIANGLE OIL	WINTERS UNIT	1155	2276	3300	3483	3546	4099	4122
259	RICHLAND	BUTLER	S5	RINGLER	TROXEL	1110	2368	?	3604	3671?	4233	4272
329	RICHLAND	BUTLER	S29	HURON EXPLORATION CO	EVEL	1198	2496	3542	3746	3798	4359	4388
351	RICHLAND	BUTLER	S11	R FARRAR & J YOUNG OIL CO	WOLFORD	1190	2304	3298	3520	3590	4146	4173
389	RICHLAND	BUTLER	S30	ASHLAND OIL	MAST-JOHNSON UNIT	1142	2398	3425	3612	3673	4236	4262
303	RICHLAND	CASS	S28	HAMBLIN/T & D INVEST	DAVIES	1070	1891	2880	3046	3105	3643	3668
325	RICHLAND	CASS	S26	MUTUAL OIL & GAS CO	MCGREGOR	1060	1980	2930	3160	3224	3767	3820
348	RICHLAND	CASS	S2	BAINES DRLG CO	GILGER	1083	1992	2992	3162	3221	3768	3791
312	RICHLAND	FRANKLIN	S15	GALLAGHER	OSWALT	1105	2245	3300	3500	3555	4124	4148
436	RICHLAND	FRANKLIN	S3	S TRIANGLE ET AL	STACKER & LEHMAN	1092	2208	?	3420	3480	4032	4056

APPENDIX — AREA 4 (continued)

Permit no.	County	Township	Land sub-division	Operator	Lease name	Elevation	Depth to top (ft) Cincinnati group	Point Pleasant Fm	Trenton Ls	Black River Gp	Wells Creek Fm	Knox Dolomite
297	RICHLAND	JACKSON	S3	SUN OIL CO	HOHLER	1105	1938	2934	3108	3168	3686	3700
322	RICHLAND	JACKSON	S24	SUN OIL CO	STAUFFER	1222	2192	3200	3379	3432	3988	4007
337	RICHLAND	JACKSON	S10	SUN OIL CO	WHITE ET AL	1117	1992	2978	3156	3218	3730	3773
275	RICHLAND	JEFFERSON	S34	MAMMOTH PROD C0	GRIMWOOD	1200	NL	NL	3735	3805	4359	4391
276	RICHLAND	JEFFERSON	S21	MAMMOTH PROD CO	MCCONKLE	1179	2390	3414	3595	3664	4216	4259
401	RICHLAND	JEFFERSON	S3	TRI-STATE PROD CO	GATTON	1365	NL	3620	3816	3896	4439	4472
448	RICHLAND	MADISON	S16	D.W.P.C. CORP	E.R.S. DIV.	1176	2322	3340	3530	3603	4147	4174
366	RICHLAND	MIFFLIN	S17	OLYMPIC PET CO	REED	1143	2472	3514	3712	3766	4325	4349
415	RICHLAND	MONROE	S18	OLYMPIC PET CO	SAUDER	1253	2573	3600	3800	3856	4408	4410
419	RICHLAND	MONROE	S30	TRI-STATE PROD CO	RUSSELL	1401	2706	3738	3940	3992	4554	4586
421	RICHLAND	MONROE	S19	TRI-STATE PROD CO	MABEE	1230	2523	3550	3749	3800	4349	4351
330	RICHLAND	PERRY	S27	T & W OIL CO	BURGETT	1224	2169	3182	3358	3413	3957	3988
367	RICHLAND	PERRY	S12	HALLWELL GAS & OIL	PFEIFER	1183	2194	NL	3389	3451	ABS	3983
413	RICHLAND	PERRY	S10	HALLWELL GAS & OIL	MILLER	1239	NL	NL	3397	3452	4000	4031
423	RICHLAND	PERRY	S35	STOCKER & SITLER	UPDIKE UNIT	1316	2306	NL	3481	3546	4026	4060
331	RICHLAND	PLYMOUTH	S26	MCCLURE OIL CO	BAKER	1084	1736	2717	2867	2929	3463	3487
377	RICHLAND	PLYMOUTH	S24	GRAHAM	STROUP	1099	1818	2795	2964	3020	3549	3558
372	RICHLAND	SANDUSKY	S36	GOSS	TAYLOR	1249	1950	?	3106	3161	3704	3729
285	RICHLAND	SHARON	S24	RELIANCE OIL CORP	GWIRTZ	1121	1774	2767	2938	3000	3524	3556
343	RICHLAND	SHARON	S14	ADAMS	REBER	1136	NL	NL	2920	2974	3516	3587
544	RICHLAND	SPRINGFIELD	S9	MANSFIELD DRLG CO	GOTTFRIED	1348	2186	NL	3380	3428	3974	3991
554	RICHLAND	SPRINGFIELD	S10	CYCLOPS CORP	MCKENZIE	1378	2282	?	3454	3513	4051	4053
287	RICHLAND	TROY	S26	GERNHARDT	VANDERBILT	1356	NL	NL	3500	3560	4110	4140
289	RICHLAND	TROY	S35	PAN AMERICAN PET CORP	PALMER	1416	2404	3404	3590	3647	4191	4191
308	RICHLAND	TROY	S33	PAN AMERICAN PET CORP	GORTNER	1352	2224	3220	3401	3457	ABS	3994
342	RICHLAND	WASHINGTON	S13	BLAIR & MORSE	STULLER	1306	2459	3616	3816	3874	ABS	4422
379	RICHLAND	WASHINGTON	S31	GREAT BASIN PET CO	KOCHEISER	1157	2252	?	3453	3510	4054	4072
390	RICHLAND	WASHINGTON	S15	TRI-STATE PROD CO	BAUER	1386	2496	3637	3828	3886	4430	4443
396	RICHLAND	WASHINGTON	S23	TRI-STATE PROD CO	HOOKS	1344	2624	3640	3844	3895	ABS	4434
321	RICHLAND	WELLER	S17	SANDS OIL CORP	KELLEY	1079	2368	3420	3615	3672	4242	4270
382	RICHLAND	WELLER	S2	SOUTHERN TRIANGLE OIL	OBRYNABA-HATTERY	1158	2310	3340	3526	3582	4140	4164
501	RICHLAND	WORTHINGTON	S29	MANSFIELD DRLG CO	SPOHN	1333	2761	3810	3996	4062	4626	4672
504	RICHLAND	WORTHINGTON	S18	MANSFIELD DRLG CO	WILSON	1128	2500	3533	3727	3789	4358	4388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AREA 5

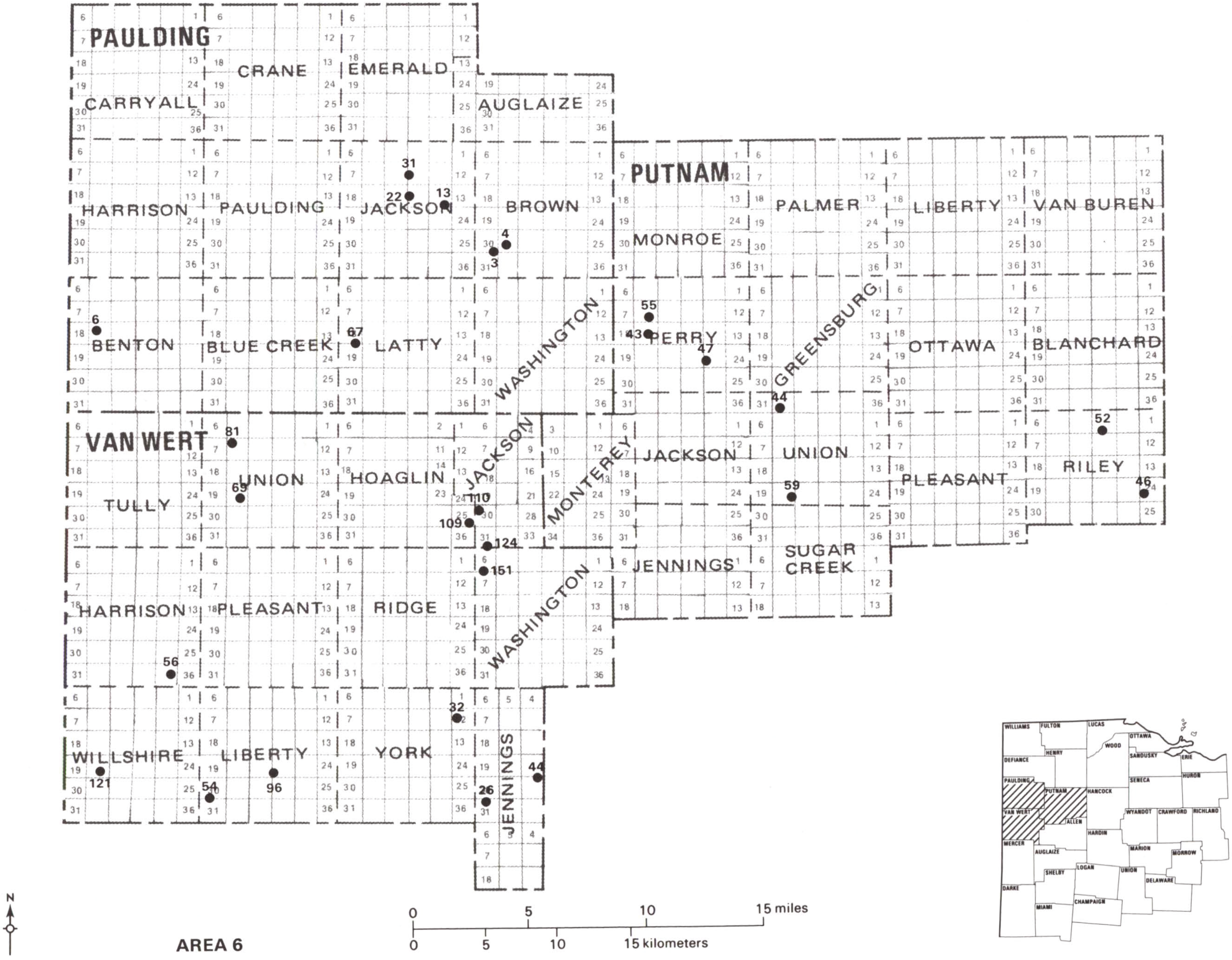
APPENDIX — AREA 5

Permit no.	County	Township	Land subdivision	Operator	Lease name	Elevation	Depth to top (ft)					
							Cincinnati group	Point Pleasant Fm	Trenton Ls	Black River Gp	Wells Creek Fm	Knox Dolomite
138	HANCOCK	ALLEN	S12	PLUNKETT & SHIELDS	HOADLEY	777	280	ABS	1100	1335	NDE	NDE
140	HANCOCK	AMANDA	S20	COWEN	HARRIS	833	309	1162	1273	1352	1844	1872
228	HANCOCK	BIG LICK	S27	J & J OPERATING INC	FRY	797	NL	1198	1268	1378	NDE	NDE
153	HANCOCK	BLANCHARD	S11	TRANSAMERICAN PET CORP	LENHART	806	601	?	1423	1654	NDE	NDE
119	HANCOCK	CASS	S16	CONTINENTAL OIL CO	BAKER	786	311	ABS	1120	1358	NDE	NDE
143	HANCOCK	EAGLE	S14	O'NEIL	STAHL	840	384	1236	1260	1423	1800	1828
205	HANCOCK	EAGLE	S23	BRETT	MAPSTONE	838	NL	1242	1274	NDE	NDE	NDE
118	HANCOCK	JACKSON	S21	CONTINENTAL OIL CO	BUTLER	840	369	?	1289	1421	1904	1908
135	HANCOCK	JACKSON	S21	PLUNKETT & SHIELDS	DOTY	829	NL	?	1190	1304	1773	1778
136	HANCOCK	JACKSON	S4	PLUNKETT & SHIELDS	ELSEA	805	NL	?	1146	1311	1788	1798
151	HANCOCK	JACKSON	S30	ASHLAND OIL	COTNER	848	362	1222	1276	1405	1878	1902
152	HANCOCK	JACKSON	S6	KIN-ARK OIL CO	BRUMMELSMITH	809	334	1178	1211	1390	1876	1892
150	HANCOCK	LIBERTY	S28	ASHLAND OIL	CRAMER	793	430	ABS	1252	1456	1912	1918
270	HANCOCK	LIBERTY	S4	HAMBLIN	NEWCOMER	811	NL	?	1331	NDE	NDE	NDE
117	HANCOCK	MADISON	S17	CONTINENTAL OIL CO	ESSEX	891	374	1230	1336	1432	1870	1886
145	HANCOCK	MARION	S34	DEVER-PILGRIM OIL	ALTMAN	798	265	1120	1146	1308	1796	1818
257	HANCOCK	ORANGE	S23	CAMEO PETROLEUM	SALTZMAN	889	454	1336	1359	1524	NDE	NDE
139	HANCOCK	UNION	S24	DEVER-SHANNON OIL	FRAZIER	824	452	ABS	1310	1494	1922	1926
142	HANCOCK	UNION	S24	DEVER-SHANNON OIL	WALTERS	811	460	ABS	1321	1508	NDE	NDE
146	HANCOCK	UNION	S25	DEVER	SCHWIN	829	450	ABS	1304	1488	1924	1956
232	HANCOCK	WASHINGTON	S27	BELDEN & BLAKE CORP	HOLMAN	823	394	ABS	1242	1424	1919	1924
233	HANCOCK	WASHINGTON	S36	BELDEN & BLAKE CORP	RADER	835	435	1286	1305	1456	1954	1960
128	SENECA	ADAMS	S31	ASHLAND OIL	STEGMIRE-STONEBRAKER	796	810	1660	1810	1868	2400	2428
149	SENECA	ADAMS	S32	ASHLAND OIL	RUKE	799	838	?	1847	1911	2444	2463
161	SENECA	ADAMS	S27	ASHLAND OIL	HOPFINGER	804	897	1750	1903	1965	2497	2522
127	SENECA	BIG SPRING	S30	COMANCHE OIL INC	NEWCOMER LANDS INC	823	NL	?	1341	1413	1909	1912
131	SENECA	BIG SPRING	S4	BRINKERHOFF DRLG CO	SMITH	834	480	1306	1407	1511	2022	2043
106	SENECA	BLOOM	S34	L B JACKSON CO	STUCKEY	965	1007	?	2069	2130	2652	2677
121	SENECA	BLOOM	S26	MT CARMEL DRLG CO	SHOOK	947	1016	1907	2067	2128	2654	2680
216	SENECA	CLINTON	S7	A-S ENERGY INC	WATSON	759	490	1336	1470	1535	2054	2068
272	SENECA	CLINTON	S6	A-S ENERGY INC	EVERETT-WATSON COMM	740	500	1366	1487	1547	2075	2091
98	SENECA	EDEN	S21	SUN OIL CO	DOWNS	838	722	1580	1738	1800	2336	2361
102	SENECA	EDEN	S35	PLUNKETT & SHIELDS	HUSHOUR	885	782	?	1802	1873	2405	2428
290	SENECA	EDEN	S15	CHARLEBOIS ENERGY	KUHN	824	696	1554	1705	1771	2282	2300
104	SENECA	HOPEWELL	S21	FLOTO-BRASEL	KUMMERER-STEINMETZ	775	NL	?	1587	1651	2182	2198
123	SENECA	HOPEWELL	S12	STOCKER & SITLER	CRUMM ET AL	742	513	1359	1487	1555	2074	2094
146	SENECA	HOPEWELL	S4	KIN-ARK OIL CO	VOGEL	765	510	1338	1427	1543	2062	2076
227	SENECA	HOPEWELL	S1	A-S ENERGY INC	CLOUSE	746	518	1356	1483	1550	2068	2092
228	SENECA	HOPEWELL	S2	A-S ENERGY INC	KLOPP	741	496	1335	1443	1543	2069	2083
245	SENECA	HOPEWELL	S11	A-S ENERGY INC	KNEPPER	752	514	1340	1465	1553	2078	2093
255	SENECA	HOPEWELL	S3	A-S ENERGY INC	SHEELEY	762	527	1370	1472	1578	NDE	NDE
234	SENECA	JACKSON	S36	INLAND DRLG CO INC	HAMMER	760	NL	1338	1385	1551	2089	2111
235	SENECA	JACKSON	S23	INLAND DRLG CO INC	ASH	742	464	?	1306	1504	2022	2041
103	SENECA	LIBERTY	S36	MCMAHON & BULLINGTON	EWALD	738	506	?	1458	1538	2066	2080
143	SENECA	LIBERTY	S28	GALIANO	DEVANNA	739	473	1300	1373	1516	2046	2065
144	SENECA	LIBERTY	S8	HADSON OHIO OIL CO	WALDROGEL	724	484	1304	1332	1521	2049	2077
150	SENECA	LIBERTY	S13	MCMAHON & BULLINGTON	MCDONALD	702	522	1310	1413	1546	2065	2093
218	SENECA	LIBERTY	S34	A-S ENERGY INC	BRICKNER	768	495	1320	1402	1525	2047	2066
226	SENECA	LIBERTY	S33	A-S ENERGY INC	SCHERGER	767	476	1314	1390	1508	2034	2046
229	SENECA	LIBERTY	S28	A-S ENERGY INC	BEARD	760	470	1283	1358	1498	2015	2023

APPENDIX — AREA 5 (continued)

Permit no.	County	Township	Land sub-division	Operator	Lease name	Elevation	Depth to top (ft) Cincinnati group	Point Pleasant Fm	Trenton Ls	Black River Gp	Wells Creek Fm	Knox Dolomite
2580	SENECA	LIBERTY	S12	OHIO DIV. GEOL. SURVEY	M & B ASPHALT CO.	697	559	1320	1451	1580	2119	2129
273	SENECA	LOUDON	S20	BELDEN & BLAKE CORP	SHIFF	804	410?	1202?	1285	1443	1953	1982
117	SENECA	PLEASANT	S17	PILGRIM OIL CO	SMITH	700	NL	?	1531	1636	2167	2190
122	SENECA	PLEASANT	S27	ALGONQUIN PET CO	SANFORD	715	577	1408	1555	1628	2163	2194
126	SENECA	PLEASANT	S33	HOBSON OIL CO	SHAULL	670	NL	?	1436	1504	2031	2046
140	SENECA	PLEASANT	S23	SHURE OIL CORP	OAKLEAF	732	680	1520	1673	1738	2289	2302
145	SENECA	PLEASANT	S25	ASHLAND OIL	BRUNDAGE-GOTZ-ROBINSON	740	670	1524	1655	1714	2251	2278
148	SENECA	PLEASANT	S5	SHURE OIL CORP	WATSON	677	544	1358	1437	1581	2107	NDE
211	SENECA	PLEASANT	S30	AMERICAN STANDARD INC	SHULTS	721	502	1318	1442	1531	2063	2094
265	SENECA	PLEASANT	S31	A-S ENERGY INC	BONNIE	732	473	1310	1418	1504	2031	2046
280	SENECA	PLEASANT	S28	A-S ENERGY INC	WISE	718	572	1394	1540	1600	2140	2160
147	SENECA	REED	S17	MT CARMEL DRLG CO	SMITH	907	1095	1987	2154	2206	2742	2770
113	SENECA	SCIPIO	S34	R WRAY	GOODING	954	998	1884	2032	2088	2617	2636
132	SENECA	SCIPIO	S17	DUNCAN	OAKLEAF	838	844	1724	1850	1906	2446	2465
111	SENECA	SENECA	S22	PLUNKETT & SHIELDS	CANAVAUGH	840	634	1436	1604	1662	2188	2196

APPENDIX CONTINUES ON PAGE 64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WYANDOT
CRAWFORD
RICHLAND
HARDIN
MERCER
AUGLAIZE
MARION
MORROW
SHELBY
LOGAN
UNION
DELAWARE
DARKE
MIAMI
CHAMPAIGN

AREA 6

APPENDIX — AREA 6

Permit no.	County	Township	Sub-division	Operator	Lease name	Elevation	Depth to top (ft)					
							Cincinnati group	Point Pleasant Fm	Trenton Ls	Black River Gp	Wells Creek Fm	Knox Dolomite
6	PAULDING	BENTON	S17	NORTHERN INDIANA PROD	LINCOLN NATIONAL BANK	758	NL	ABS	1362	1560	ABS?	1878
3	PAULDING	BROWN	S30	MYERS	DOBBELAERE	720	598	ABS	1400	NDE	NDE	NDE
4	PAULDING	BROWN	S29	MYERS	SHERRY	715	616	ABS	1429	1648	1995	2028
13	PAULDING	JACKSON	S14	MT PLEASANT MINES	AREND	725	631	ABS	1442	1666	2016	2033
22	PAULDING	JACKSON	S15	PAULDING CORP	FRESHWATER	726	654	ABS	1459	NDE	NDE	NDE
31	PAULDING	JACKSON	S10	PAULDING CORP	MANZ	721	670	ABS	1473	1690	2034	2046
67	PAULDING	LATTY	S18	BELDEN & BLAKE CORP	EISENMANN	741	640	ABS	1415	1614	1950	1952
43	PUTNAM	PERRY	S17	WHITE	SHAFER	722	651	ABS	1364	NDE	NDE	NDE
47	PUTNAM	PERRY	S23	HAMBLIN	KAHLE	727	?	ABS	1352	NDE	NDE	NDE
55	PUTNAM	PERRY	S8	WALLACE	ETTER TIRE CO	717	NL	ABS	1376	NDE	NDE	NDE
46	PUTNAM	RILEY	S24	DEVER-SHANNON OIL CO	HAVENSTEIN	803	496	ABS	1300	1508	1932	1938
52	PUTNAM	RILEY	S3	TRANSAMERICAN DRILLING	BAUMANN	761	500	ABS	1302	NDE	NDE	NDE
53	PUTNAM	RILEY	S3	TRANSAMERICAN DRILLING	BAUMANN	763	500	ABS	1304	NDE	NDE	NDE
54	PUTNAM	RILEY	S10	UNIVERSAL MAJORS	SUTTER	765	488	ABS	1292	NDE	NDE	NDE
44	PUTNAM	UNION	S32	HAMBLIN	RIENDEL	732	NL	ABS	1333	1557	1942	1954
59	PUTNAM	UNION	S20	J & J OPERATING INC	GERDEMAN	736	NL	ABS	1308	1515	1908	1946
56	VAN WERT	HARRISON	S35	PIONEER DRLG	GERMANN	822	512	ABS	1220	NDE	NDE	NDE
109	VAN WERT	HOAGLIN	S25	J & J OPERATING INC	KNIPPEN FARMS INC	751	NL	ABS	1247	NDE	NDE	NDE
105	VAN WERT	JACKSON	S30	J & J OPERATING INC	LOUTZERHEISER	745	508	ABS	1241	NDE	NDE	NDE
110	VAN WERT	JACKSON	S30	J & J OPERATING INC	TRIBOLET	752	520	ABS	1250	NDE	NDE	NDE
124	VAN WERT	JACKSON	S31	J & J OPERATING INC	HIRE	758	532	ABS	1246	NDE	NDE	NDE
26	VAN WERT	JENNINGS	S31	BARNWELL PROD CO	BASSETT	815	NL	ABS	1210	NDE	NDE	NDE
44	VAN WERT	JENNINGS	S28	WEST OHIO GAS CO	MILLER	820	408	ABS	1183	1378	1752	1768
42	VAN WERT	LIBERTY	S30	FOX OIL CO	THOMAS	840	NL	ABS	1175	NDE	NDE	NDE
54	VAN WERT	LIBERTY	S30	FOX OIL CO	MT ZION BIBLE CHURCH	842	450	ABS	1166	1367?	NDE	NDE
96	VAN WERT	LIBERTY	S22	RESERVE EXPLOR CO	GALLOWAY	830	454	ABS	1179	1373	1728?	1750?
60	VAN WERT	UNION	S20	BELDEN & BLAKE CORP	MACE	768	542	ABS	1241	NDE	NDE	NDE
69	VAN WERT	UNION	S20	BELDEN & BLAKE CORP	POLING	768	NL	ABS	1242	1456	1777	1808
81	VAN WERT	UNION	S8	BELDEN & BLAKE CORP	IMLER	756	586	ABS	1285	NDE	NDE	NDE
123	VAN WERT	WASHINGTON	S7	J & J OPERATING INC	ENGEL	766	NL	ABS	1230	NDE	NDE	NDE
150	VAN WERT	WASHINGTON	S7	J & J OPERATING INC	TRIBOLET	765	530	ABS	1242	NDE	NDE	NDE
151	VAN WERT	WASHINGTON	S6	J & J OPERATING INC	WEIGEL	760	?	ABS	1227	NDE	NDE	NDE
87	VAN WERT	WILLSHIRE	S20	RESERVE EXPLORATION CO	HAMERICK	802	486	ABS	1170	NDE	NDE	NDE
121	VAN WERT	WILLSHIRE	S20	RESERVE EXPLORATION CO	EHMAN	806	476?	ABS	1168	1367	1700?	1710
25	VAN WERT	YORK	S1	HOLT ENTERPRISES	MORRIS	794	NL	ABS	1198	NDE	NDE	NDE
27	VAN WERT	YORK	S1	HOLT ENTERPRISES	MORRIS	794	425	ABS	1195	NDE	NDE	NDE
30	VAN WERT	YORK	S1	HOLT ENTERPRISES	LEHMAN	796	442	ABS	1196	NDE	NDE	NDE
31	VAN WERT	YORK	S1	HOLT ENTERPRISES	REESE	796	436	ABS	1206	NDE	NDE	NDE
32	VAN WERT	YORK	S12	HOLT ENTERPRISES	EVANS	795	443	ABS	1212	NDE	NDE	NDE
34	VAN WERT	YORK	S11	HOLT ENTERPRISES	OWENS	779	NL	ABS	1206	NDE	NDE	NDE


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GIBSON
GRANVILLE
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SPENCER
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LOGAN
UNION
DELAWARE
DARKE
MIAMI
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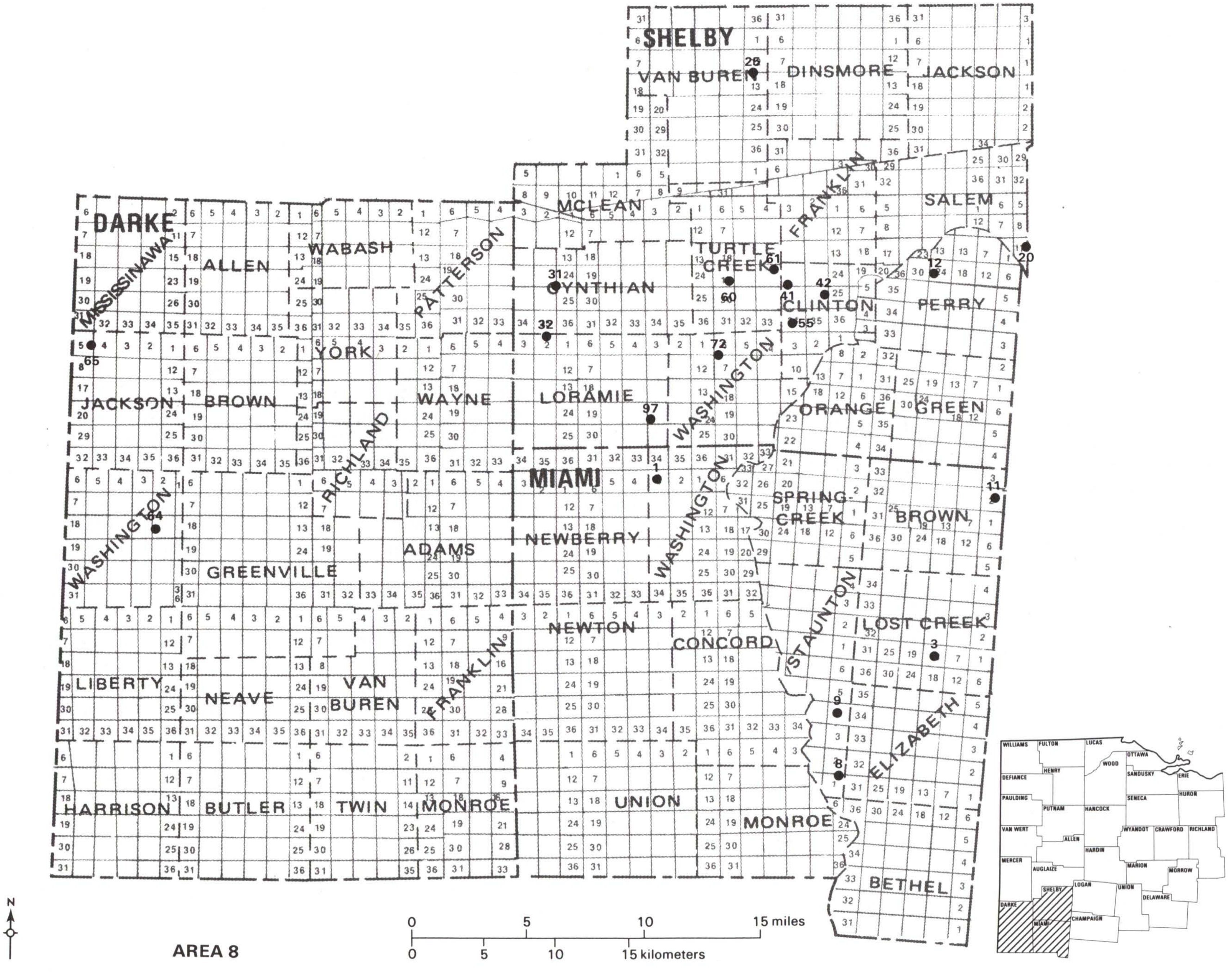
AREA 7

APPENDIX — AREA 7

Permit no.	County	Township	Land sub-division	Operator	Lease name	Elevation	Depth to top (ft)					
							Cincinnati group	Point Pleasant Fm	Trenton Ls	Black River Gp	Wells Creek Fm	Knox Dolomite
113	ALLEN	AMANDA	S2	BATES	BOYER	836	394	ABS	1230	NDE	NDE	NDE
57	ALLEN	AUGLAIZE	S29	DEVER-SHANNON OIL CO	MACBURDEN	1037	496	1400	1438	1526	1950	1959
59	ALLEN	RICHLAND	S25	DEVER-SHANNON OIL CO	CRIBLEZ	881	515	ABS	1331	1502	1949	1970
67	ALLEN	SHAWNEE	S2	VISTRON CORP	STANDARD OIL CO	872	408	ABS	1254	1418	1804	1818
71	ALLEN	SHAWNEE	S11	VISTRON CORP	STANDARD OIL CO	854	390	ABS	1245	1408	1820	1842
84	ALLEN	SHAWNEE	S2	VISTRON CORP	STANDARD OIL CO	856	400	ABS	1250	1415	1806	1811
60	ALLEN	SPENCER	S22	H & H OIL CO	POHLMAN	808	NL	NL	1217	1416	1791	1806
62	ALLEN	SPENCER	S23	ALCO OIL CO	ETZKORN	810	434	ABS	1192	1388	ABS	1771
63	ALLEN	SPENCER	S25	ALCO OIL CO	LOUTH	816	NL	ABS	1213	1408	1786	1800
64	ALLEN	SPENCER	S22	ALCO OIL CO	POHLMAN, FRUEND, ETZKORN	811	NL	ABS	1196	1394	1770	1785
55	AUGLAIZE	DUCHOUQUET	S4	PYRAMID OIL CO	SMITH	883	NL	ABS	1217	1366	1764	1778
41	AUGLAIZE	GOSHEN	V12276	PRYER	MYERS	1030	NL	NL	1392	1452	1880	1908
42	AUGLAIZE	GOSHEN	S11	DONALD D RUNYON CO	BARNES	1027	378	1287	1390	1452	1874	1898
44	AUGLAIZE	GOSHEN	V12276	TEETER BROS	GOLLIDAY	1025	NL	NL	1382	1444	1856	1858
51	AUGLAIZE	GOSHEN	V10659	SOHIO PET CO	NICKELL	1039	NL	?	1410	1472	NDE	NDE
83	AUGLAIZE	NOBLE	S20	JOHNSU CORP	CISCO	862	346	1108	1156	NDE	NDE	NDE
85	AUGLAIZE	NOBLE	S34	JOHNSU CORP	BACH	878	363	1089	1168	NDE	NDE	NDE
56	AUGLAIZE	PUSHETA	S7	HOLLY OIL	MCCORMACK	912	NL	1122	1178	NDE	NDE	NDE
71	AUGLAIZE	ST. MARYS	S22	WEST OHIO GAS CO	HOELSCHER	896	288	?	1094	1228	1618	1650
164	MERCER	BLACK CREEK	S30	TURNER PET CORP	KRALL	834	NL	1054	1092	1274	1640	1664
149	MERCER	BUTLER	S10	WEST OHIO GAS CO	HARTKE	930	340	1065	1122	NDE	NDE	NDE
150	MERCER	BUTLER	S1	WEST OHIO GAS CO	SELHORST	921	350	1077	1126	NDE	NDE	NDE
151	MERCER	BUTLER	S33	AVCO CORP	AVCO NEW IDEA	918	348	1064	1115	NDE	NDE	NDE
141	MERCER	CENTER	S4	HARNER UNION OIL CO	YEWEY	838	326	1078	1115	1286	1658	1690
142	MERCER	DUBLIN	S19	DAL-KEN CORP	DAUGHERTY	818	387	1108	1120	1308	1663	1684
128	MERCER	FRANKLIN	S35	SKILES CENTRAL OHIO EXP	HEIN	900	NL	NL	1130	1264	1648	1658
148	MERCER	GRANVILLE	S13	WEST OHIO GAS CO	KUNKLER	932	322	1073	1128	NDE	NDE	NDE
129	MERCER	JEFFERSON	S1	BOASE	ZUMBERGE	862	NL	?	1102	1268	1638	1672
103	MERCER	UNION	S1	MILAM	VAN HORN	825	444	1173	1194	NDE	NDE	NDE
132	MERCER	UNION	S34	HOPKINS	THOMAS	823	340	1086	1122	1290	1659	1676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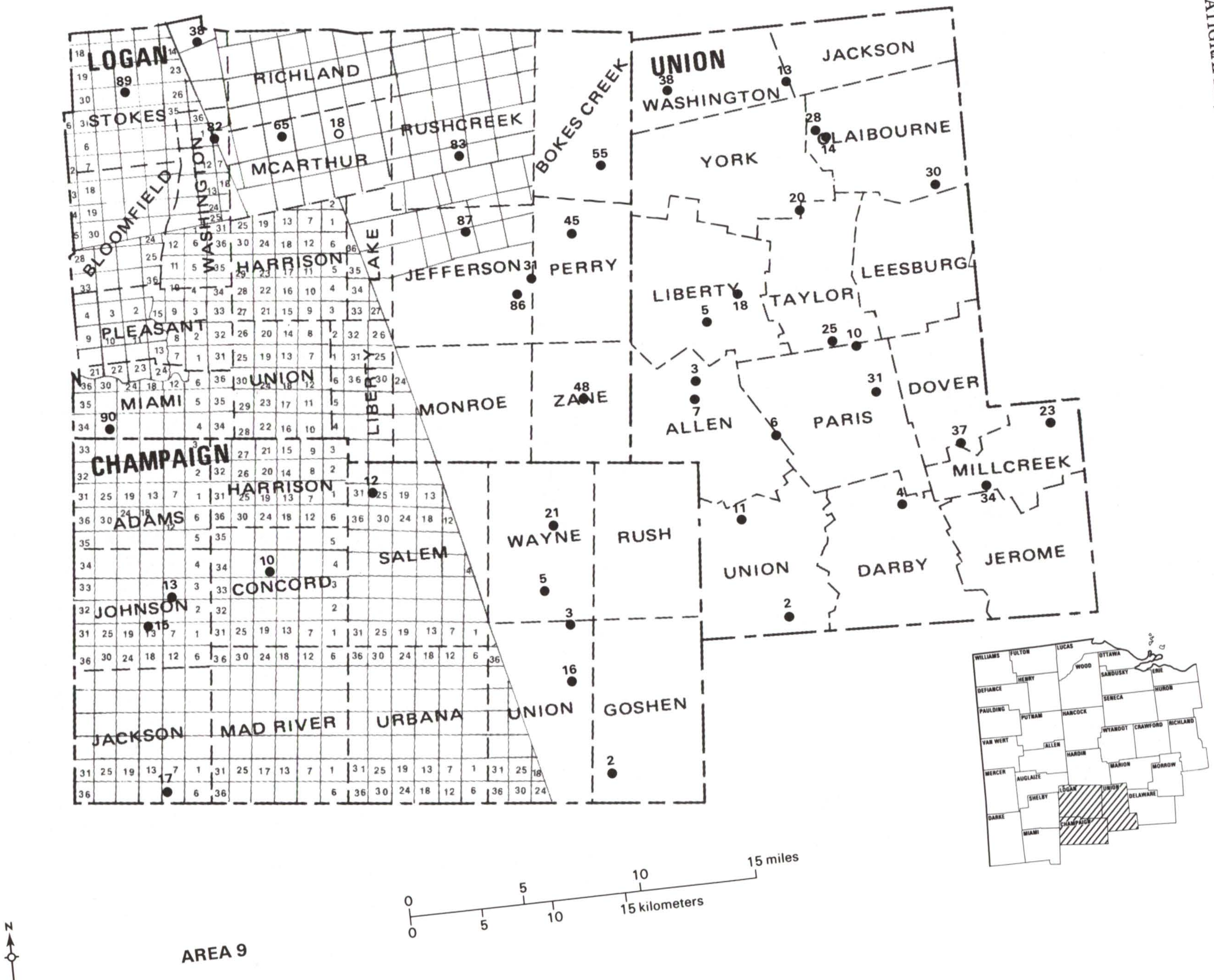
APPENDIX — AREA 8

Permit no.	County	Township	Land subdivision	Operator	Lease name	Elevation	Depth to top (ft)					
							Cincinnati group	Point Pleasant Fm	Trenton Ls	Black River Gp	Wells Creek Fm	Knox Dolomite
65	DARKE	JACKSON	S5	PREMIER OIL	BREYMIER	1038	250?	1032	1140	1256	1632	1668
64	DARKE	WASHINGTON	S14	AN-CAR OIL CO	MARTIN	1077	280?	1009	1168	1235	1600	1634
11	MIAMI	BROWN	S2	MCHALE	ROEMISCH	1138	350?	1230	1396	1430	1864	1892
3	MIAMI	LOST CREEK	S13	NAT ASSOC PET CO	WALKER	1035	205?	1044	1227	1260	1696	1725
8	MIAMI	STAUNTON	S1S	PETTIT	TROJAN FARMS	801	NL	828	1002	1032	1475	1492
9	MIAMI	STAUNTON	S4S	PETTIT	KNOOP	867	NL	?	1074	1100	1530	1562
1	MIAMI	WASHINGTON	S3	SUN OIL CO	LEVERING	995	186?	1040	1168	1214	1600	1626
41	SHELBY	CLINTON	S22	L H WRIGHT INC	DUNSON	993	270	1146	1253	1310	1694	1710
42	SHELBY	CLINTON	S26	L H WRIGHT INC	RUSSELL	1049	326	1200	1329	NDE	NDE	NDE
55	SHELBY	CLINTON	S34	L H WRIGHT INC	STOLLE CORP	1027	308	1162	1294	NDE	NDE	NDE
31	SHELBY	CYNTHIAN	S23W	WELSH & CAMPBELL DRLG	ZIRCHER	1010	287	NL	1242	1314	NDE	NDE
32	SHELBY	LORAMIE	S2	WELSH & CAMPBELL DRLG	SCHIELTZ	1003	284	NL	1240	1307	NDE	NDE
97	SHELBY	LORAMIE	S22E	LAUBER	PATTERSON	1000	242	1112	1227	1260	1669	1697
12	SHELBY	PERRY	S24	SUN OIL CO	NELSON	1050	NL	1215	1318	1370	1786	1806
20	SHELBY	SALEM	S17E	FAIRWAY PET CORP	MOTTER	1058	NL	1280	1397	1448	1863	1888
46	SHELBY	TURTLE CREEK	S33	L H WRIGHT INC	JELLEY	1002	227	?	1261	NDE	NDE	NDE
48	SHELBY	TURTLE CREEK	S33	L H WRIGHT INC	FRANTZ	982	250	?	1247	NDE	NDE	NDE
57	SHELBY	TURTLE CREEK	S21	L H WRIGHT INC	WENRICK	1002	285	1150?	1266	NDE	NDE	NDE
60	SHELBY	TURTLE CREEK	S19	LAUBER	JESS	985	240	?	1212	1252	1648	1678
61	SHELBY	TURTLE CREEK	S21	L H WRIGHT INC	EIDEMILLER	997	NL	?	1262	1318	1709	1728
63	SHELBY	TURTLE CREEK	S21	KIMBREL & WRIGHT	MEYER	990	268	?	1302	1332	NDE	NDE
25	SHELBY	VAN BUREN	S12	DEE OIL CO	BRANDT	986	416	1198	1302	1364	1768	1788
72	SHELBY	WASHINGTON	S6	SOLATRON INC	BURREY	987	NL	NL	NL	NL	1691	1712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MIAMI
MONROE
ZANE
JACKSON
CLAIBOURNE
YORK
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TAYLOR
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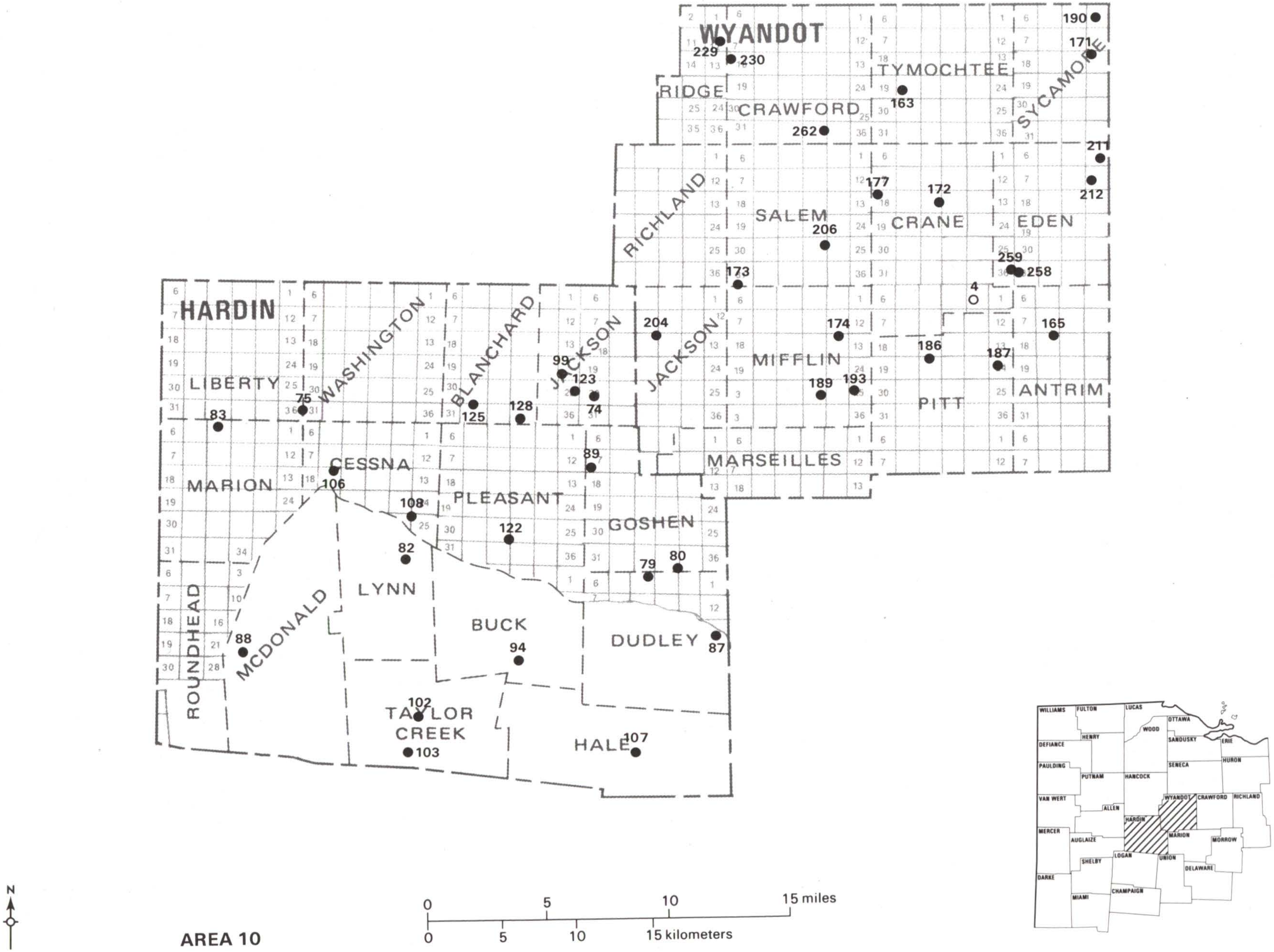
AREA 9

APPENDIX — AREA 9

Permit no.	County	Township	Land subdivision	Operator	Lease name	Elevation	Depth to top (ft) Cincinnati group	Point Pleasant Fm	Trenton Ls	Black River Gp	Wells Creek Fm	Knox Dolomite
10	CHAMPAIGN	CONCORD	S22	SOUTHERN INDEPENDENT	SCHULTZ	1133	350	1220	1391	1432	1876	1906
2	CHAMPAIGN	GOSHEN	V6349	HODGES INDUSTRIES, INC	ROPP	1267	NL	1454	1610	1652	2094	2112
17	CHAMPAIGN	JACKSON	S12	TEETER BROS	CYRUS CIRCLE	1162	?	1162	1331	1368	1808	1828
13	CHAMPAIGN	JOHNSON	S9	TEETER BROS	VAUGHN	1126	345	1226	1396	1436	1872	1900
15	CHAMPAIGN	JOHNSON	S13	TEETER BROS	WELLER	1196	?	1282	1469	1500	1940	1990
11	CHAMPAIGN	SALEM	S25N	SOUTHERN INDEPENDENT	MCCANDLESS	1072	312	1200	1349	1389	1826	1841
12	CHAMPAIGN	SALEM	S25N	SOUTHERN INDEPENDENT	DETWEILER	1069	312	1193	1342	1382	1833	1857
14	CHAMPAIGN	SALEM	S31	TARTAN OIL CO	MCCANDLESS	1076	315	1196	1345	1385	1835	1844
3	CHAMPAIGN	UNION	V5596	LELLY OIL CO	YOCUM	1227	528	1434	1584	1624	2095	2123
16	CHAMPAIGN	UNION	V6195	TEETER BROS	PERRY	1239	528	1434	1585	1626	2094	2154
5	CHAMPAIGN	WAYNE	V4516	BRANDEBERRY	BLACK	1325	NL	1490	1660	1702	2146	2164
21	CHAMPAIGN	WAYNE	V3695	MARSH OIL & GAS CO	CROWDER	1364	650	1442	1690	1730	2191	2214
55	LOGAN	BOKES CREEK	V7995	HADSON OHIO OIL CO	WALTON ASSOC INC	1091	NL	1342	1472	1516	1992	2032
31	LOGAN	JEFFERSON	V5088	HUMBLE OIL & REFINING	HEMINGER	1385	NL	?	1738	1785	2256	2298
86	LOGAN	JEFFERSON		WORTHINGTON OIL CO	COMER	1439	754	1642	1774	1822	ABS	2320
87	LOGAN	JEFFERSON	L3438	DAYTON POWER & LIGHT	HEMLEBEN	1364	724	1600	1764	1810	2275	2306
18	LOGAN	MCARTHUR	V9930	OHIO OIL CO	JOHNS ET AL	1190	NL	?	1510	1550	2020	2068
65	LOGAN	MCARTHUR	V9903, 9928	FIELDS	WHITAKER	1058	NL	?	1413	1446	1890	1914
90	LOGAN	MIAMI	S28	OXFORD OIL	EVANS	1090	391	1252	1410	1440	1874	1894
45	LOGAN	PERRY	V4210	B-H INVESTMENT CORP	ROBSON	1100	NL	NL	1460	1505	1979	2006
91	LOGAN	PERRY	V4210	ALLERTON RESOURCES INC	ROBSON ET AL	1101	NL	1280	1452	1498	1970	1996
83	LOGAN	RUSHCREEK	V9887	NATIONAL PET CORP	ROBERTS	1292	618	1506	1646	1688	2152	2179
38	LOGAN	STOKES	V12276	VIVIRSKI	COUNTRYMAN	1022	NL	?	1376	1438	1854	1881
89	LOGAN	STOKES	S28	JERRY MOORE INC	CLEMENS	1000	386	1308	1405	1460	1878	1906
82	LOGAN	WASHINGTON	S6	MIDWEST OIL & GAS	HORN-GOEBEL	992	340	1197	1323	1363	1791	1817
48	LOGAN	ZANE	V3680	PRUITT TOOL & SUPPLY CO	DEVAULT	1168	502	?	1538	1578	2064	2086
3	UNION	ALLEN	V3151	ADAMS	BROWN	1093	478	1355?	1504	1549	2032	2059
6	UNION	ALLEN	V3742	ADAMS	HOLYCROSS	1043	490	1369	1525	1570	2060	2102
7	UNION	ALLEN	V3749	LAUCK DRLG CO	GLIES	1077	NL	NL	1494	1538	2032	2059
8	UNION	ALLEN	V2979	LAUCK DRLG CO	MERKLE	1015	400	?	1445	1490	1978	2005
14	UNION	CLAIBOURNE	V7869	PAN AMERICAN PET CORP	HOUCK	991	394	1290	1441	1486	1995	2019
28	UNION	CLAIBOURNE	V7869	HADSON OHIO OIL CO	LEWIS	996	388	1286	1432	1480	1985	2028
30	UNION	CLAIBOURNE	V7008	HADSON OHIO OIL CO	RANDALL	945	450	1346	1505	1553	2064	2090
4	UNION	DARBY	V15310	ADAMS	SNYDER	1040	570	1456	1625	1664	2165	2200
37	UNION	DOVER	V3956	NOBLE	FREY	962	NL	?	1544	1589	2080	2118
67	UNION	DOVER	V4065	FUNK EXPLORATION INC	GRAVER	966	NL	1426	1592	1640	2142	2172
5	UNION	LIBERTY	V12400?	ADAMS	CARREKER	1078	460	1338	1475	1525	1988	2011
18	UNION	LIBERTY	V5777	BARNWELL PROD CO	HALL	1052	420	1304	1468	1516	2000	2022
15	UNION	MILL CREEK	V2989	TEXAS COASTAL OIL CORP	PARROTT-HABBERSETT	930	NL	1610	1770	1818	2290	2322
22	UNION	MILL CREEK	V3006	D J KRIST CO	HEIDORN	968	NL	?	1842	1888	2304	2306
23	UNION	MILL CREEK	V2998	TEXAS COASTAL OIL CORP	BOVIC	935	691	1576	1748	1800	2297	2332
34	UNION	MILL CREEK	V1394	HAMPTON LTD	PUTNAM	977	600	1490	1658	1709	2214	2251
10	UNION	PARIS	V5503	LAUCK DRLG CO	BROOKER	1029	506	1395	1556	1606	2107	2136
31	UNION	PARIS	V3353	MOTT DRLG CO	KLEIBER	996	NL	1388	1550	1600	2099	2152
25	UNION	TAYLOR	V4264	BRANOCO INC	BEESON	1025	485	1372	1530	1575	2068	2094
2	UNION	UNION	V7474	H H & R OPER ACCT	ZENITH HOLDING & TRADING	1001	NL	?	1488	1532	2026	2084
11	UNION	UNION	V7770	LAUCK OIL CO	HOWARD	998	410	1298	1465	1500	1990	2018
13	UNION	WASHINGTON	V10938	T & W OIL CO	LANE	996	354	1254	1397	1442	1932	1941
38	UNION	WASHINGTON	V10971	EPHRAIM PETROLEUM	BROWN HAT LANDS INC	1052	415	1309	1434	1482	1965	1984
20	UNION	YORK	V3470	MILLER-PITERONI ASSOC	POTTS	1011	397	1300	1451	1498	ABS	1974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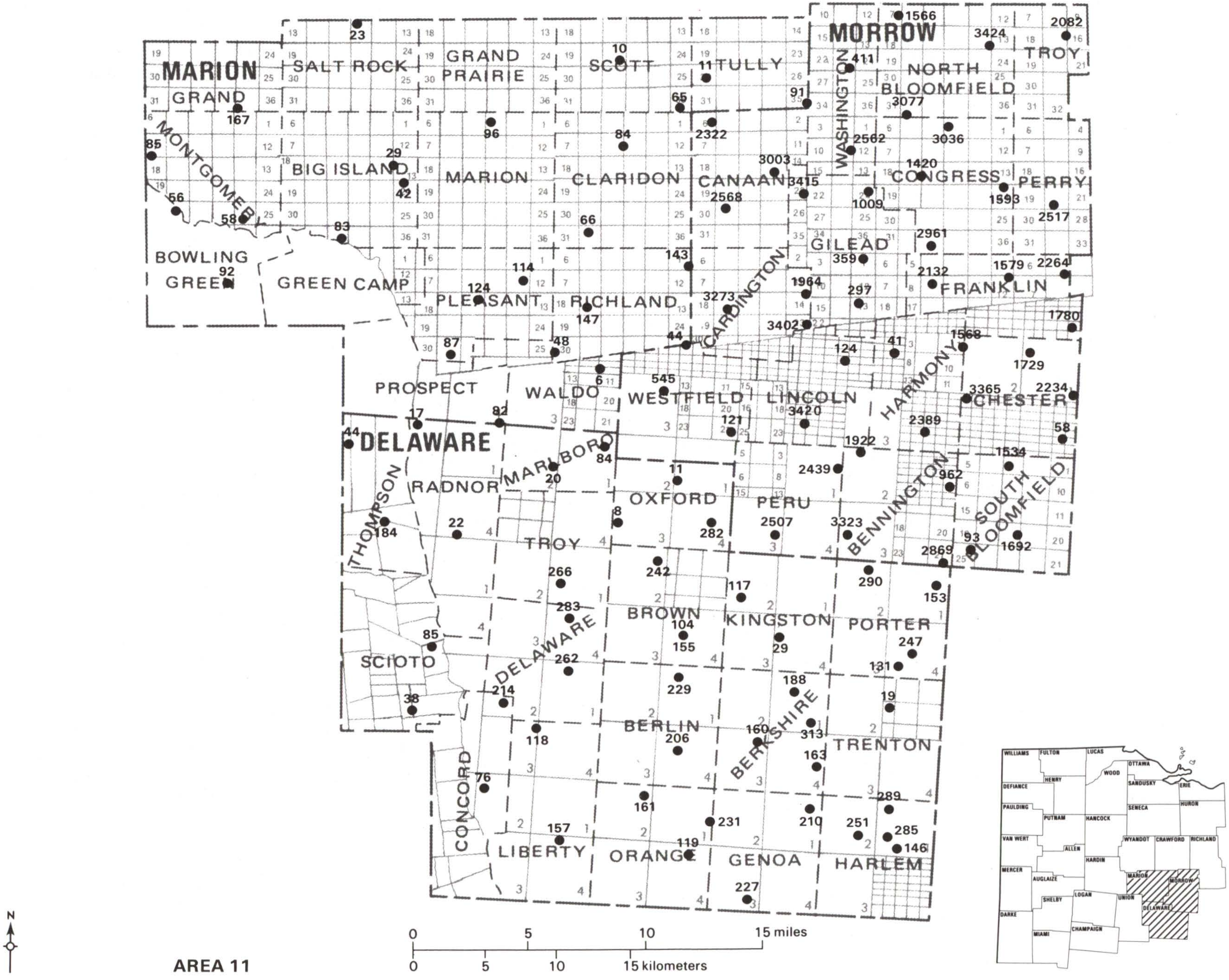
HURON
VAN WERT
ALLEN
WYANDOT
CRAWFORD
RICHLAND
HARDIN
MERCER
AUGLAIZE
MARION
MORROW
SHELBY
LOGAN
UNION
DELAWARE
DARKE
MIAMI
CHAMPAIGN

APPENDIX — AREA 10

Permit no.	County	Township	Land subdivision	Operator	Lease name	Elevation	Depth to top (ft)					
							Cincinnati group	Point Pleasant Fm	Trenton Ls	Black River Gp	Wells Creek Fm	Knox Dolomite
86	HARDIN	BLANCHARD	S34	TURNER PET CORP	LOTZ	911	282	1162	1286	1340	1814	1836
125	HARDIN	BLANCHARD	S32	WM TIPKA	KURT UNIT	920	NL	NL?	1326	1379	1851	1879
128	HARDIN	BLANCHARD	S34	WM TIPKA	LOTZ	912	301	?	1292	1343	1814	1824
94	HARDIN	BUCK	V10048	SUNSET INTERNATIONAL PET	SALYER	1040	386	1271	1395	1439	1914	1934
106	HARDIN	CESSNA	S17	FERGUSON OIL CO	BEAMAN	997	394	1293	1383	1438	1890	1910
108	HARDIN	CESSNA	S26	TEETER BROS	STEPHENS	982	376	1221	1365	1414	1876	1883
79	HARDIN	DUDLEY	S4	MCMAHON & BULLINGTON	WOLF	971	306	1198	1336	1385	1880	1907
87	HARDIN	DUDLEY	V15523	WILLIAMS	ELSASSER	931	275	1178	1290	1336	1820	1829
80	HARDIN	GOSHEN	S34	RELIANCE OIL CORP	LAUBIS	960	320	1192	1331	1380	1878	1918
89	HARDIN	GOSHEN	S7	TURNER PET CORP	WINEBRENNER	924	308	1203	1317	1376	1858	1882
107	HARDIN	HALE	V10900	MCMAHON & BULLINGTON	KENNEDY	1035	384	1280	1395	1442	1937	1962
74	HARDIN	JACKSON	S30	EDMUND	JONES	941	NL	1116	1253	1304	1795	1801
99	HARDIN	JACKSON	S24	TURNER PET CORP	KELLOGG	926	256	1108	1235	1290	1757	1770
123	HARDIN	JACKSON	S25	GABLE ALAN DEV CO	KELLOGG	946	262	1108	1253	1306	1798	1820
75	HARDIN	LIBERTY	S36	HUMBLE OIL & REFINING	MARLING	946	378	1245	1355	1422	1890	1912
82	HARDIN	LYNN	V12096	COWEN	DULIN	1002	390	1294	1400	1444	1907	1928
83	HARDIN	MARION	S4	HALCAR DRILLING	HUBBELL	1010	NL	NL	1415	1490	1941	1963
85	HARDIN	MCDONALD	V10221	ZIMMER & PRYER	LENHART	1034	NL	NL	1426	1480	1924	1950
88	HARDIN	MCDONALD	V10221	ZIMMER & PRYER	ZEIGLER	1032	435	1290	1411	1454	1910	1935
122	HARDIN	PLEASANT	S28	GABLE ALAN DEV CO	DULIN	974	NL	1252	1376	1424	1889	1906
102	HARDIN	TAYLOR CREEK	V10296	RELIANCE OIL CORP	BIDWELL	1067	435	1306	1440	1486	1953	1978
103	HARDIN	TAYLOR CREEK	V12051	RELIANCE OIL CORP	KROCH	1070	422	1306	1440	1480	1945	1962
165	WYANDOT	ANTRIM	S17	FLOTO-BRASEL	ABNETT	901	658	1542	1708	1767	2299	2325
2	WYANDOT	CRANE	S2	MARATHON RESOURCES	SMALLEY	880	470	?	1512	1569	NDE	NDE
4	WYANDOT	CRANE	S2	MARATHON RESOURCES	SMALLEY	870	448	?	1451	1498	NDE	NDE
172	WYANDOT	CRANE	S16	FULK & ASSOC	WALTON	811	393	1301	1439	1493	2021	2045
177	WYANDOT	CRANE	S18	TEXAS COASTAL OIL CORP	BINAU	826	NL	?	1314	1358	NDE	NDE
179	WYANDOT	CRAWFORD	S33	BARNWELL PROD CO	O'BRIAN	823	NL	?	1299	1362	1864	1900
230	WYANDOT	CRAWFORD	S18	WORTHINGTON OIL CO	PUTNAM	858	342	1192	1328	NDE	NDE	NDE
262	WYANDOT	CRAWFORD	S34	HAMBLIN	DAHL	821	400	1206	1347	1460	NDE	NDE
211	WYANDOT	EDEN	S3	MINNESOTA-OHIO OIL CO	EYESTONE	942	744	1624	1784	1850	2375	2396
212	WYANDOT	EDEN	S10	DUNCAN & GEORGE	FAILOR	932	725	1590	1760	1814	2345	2368
258	WYANDOT	EDEN	S31	BEREA OIL & GAS CORP	BROCKLESBY	887	690	1605	1739	1781	2299	2350
259	WYANDOT	EDEN	S36	BEREA OIL & GAS CORP	KUENZLI	892	626	1468	1610	1664	2164	2187
204	WYANDOT	JACKSON	S16	BRINKERHOFF DRLG CO	FOX	942	NL	?	1391	1440	1943	1975
174	WYANDOT	MIFFLIN	S14	TEXACO INC	BOWEN	846	300	1156	1314	1363	0?	1850
189	WYANDOT	MIFFLIN	S27	CLINTON OIL CO	NEEDS	889	324	1200	1343	1391	1900	1919
193	WYANDOT	MIFFLIN	S25	CLINTON OIL CO	CRABARKALEE FARMS	890	342	1226	1370	1420	1933	1954
186	WYANDOT	PITT	S21	TURNER PET CORP	HULL	892	406	?	1428	1480	2006	2018
187	WYANDOT	PITT	S24	KISSINGER & CO	LAWRENCE	870	NL	NL	1552	1607	2140	2162
229	WYANDOT	RIDGE	S12	WORTHINGTON OIL CO	NEYERS & LORTZ	890	506	1252	1391	NDE	NDE	NDE
232	WYANDOT	RIDGE	S12	WORTHINGTON OIL CO	COPPLER	892	400	?	1371	NDE	NDE	NDE
173	WYANDOT	SALEM	S31	COMANCHE OIL INC	FREY	868	308	1201	1321	1368	1868	1902
206	WYANDOT	SALEM	S27	TURNER PET CORP	HULL	846	310	1190	1326	1374	1886	1905
171	WYANDOT	SYCAMORE	S15	TRI-STATE PROD CO	HARPER ET AL	854	710	1586	1734	1800	2330	2348
190	WYANDOT	SYCAMORE	S3	VANCE	KOEHL	880	740	?	1758	1818	2356	2390
163	WYANDOT	TYMOCHTEE	S20	CONTINENTAL OIL CO	ECKERT	813	370	1194	1362	1413	1939	1962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BIG ISLAND
MARION
CLARIDON
CANAAN
CONGRESS
PERRY
BOWLING GREEN
GREEN CAMP
PLEASANT
RICHLAND
CARDINGTON
GILEAD
FRANKLIN
PROSPECT
WALDO
WESTFIELD
LINCOLN
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CHESTER
THOMPSON
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SOUTH BLOOMFIELD
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MERCER
AUGLAIZE
MARION
MORROW
SHELBY
LOGAN
UNION
DELAWARE
DARKE
MIAMI
CHAMPAIGN

APPENDIX — AREA 11

Permit no.	County	Township	Land subdivision	Operator	Lease name	Elevation	Depth to top (ft)					
							Cincinnati group	Point Pleasant Fm	Trenton Ls	Black River Gp	Wells Creek Fm	Knox Dolomite
160	DELAWARE	BERKSHIRE	L3,3RD¼	SKILES CENTRAL OHIO EXPL	ALEXANDER	934	1270	2198	2388	2450	2953	2967
163	DELAWARE	BERKSHIRE	L19,4TH¼	EASTERN PETROLEUM CO	MACBLANE	945	1360	2294	2493	2554	3077	3115
188	DELAWARE	BERKSHIRE	L3,1ST¼	KIN-ARK OIL CO	SHULTZ	966	1346	2285	2475	2540	3055	3092
313	DELAWARE	BERKSHIRE	L7,1ST¼	JADOIL INC	MILLER	952	1468	2308	2482	2546	3054	3060
206	DELAWARE	BERLIN	L6,4TH¼	ALGONQUIN PET CO	SLEMMONS-MARSHALL	863	1048	1965	2148	2200	2716	2766
229	DELAWARE	BERLIN	L17,1ST¼	KIN-ARK OIL CO	SHADE	940	NL	2025	2206	2262	2756	2769
104	DELAWARE	BROWN	L10,4TH¼	ALCONQUIN PET CO	INNIS	945	1122	2056	2237	2297	2809	2848
155	DELAWARE	BROWN	L10,4TH¼	ALGONQUIN PET CO	INNIS	926	1115	NL	NL	NL	NL	NL
242	DELAWARE	BROWN	L7,2ND¼	MCCLURE OIL CO	SMITH	992	1105	2038	2212	2266	2786	2817
76	DELAWARE	CONCORD	L17,2ND¼	SLATZER OIL & GAS CO	MOORE	914	NL	NL	1859	1910	2420	2460
214	DELAWARE	CONCORD	L37,2ND¼	HAMPSTON LTD	DILGER-WATTS	946	764	1660	1837	1890	2394	2440
262	DELAWARE	DELAWARE	LN,1ST¼	JOHNSON OIL CO	SCHNIPKE	875	NL	?	1952	2004	2520	2554
283	DELAWARE	DELAWARE	L7N,4TH¼	LULING OIL & GAS CO	WARD	937	921	1832	2005	2060	2566	2587
210	DELAWARE	GENOA	L6,1ST¼	LEWIS	EVARTS	960	1364	?	2480	2542	3048	3055
227	DELAWARE	GENOA	L11,3RD¼	HADSON OHIO OIL CO	MARTIN	922	1234	2150	2350	2397	2908	2934
146	DELAWARE	HARLEM	L4,1ST¼	FEDERAL OIL & GAS CO	FRONK	1083	1680	2654	ABS	2912	3346	3351
251	DELAWARE	HARLEM	L8,2ND¼	KIN-ARK OIL CO	BOYD-YOUNG	1046	1546	?	2668	2732	3217	3249
285	DELAWARE	HARLEM	L3,1ST¼	BRASEL & BRASEL	PIPER	1071	1650	2563	2756	2816	3332	3361
289	DELAWARE	HARLEM	L15,1ST¼	FEDERAL OIL & GAS CO	PIPER-FEASEL	1062	1640	2591	2796	2848	3375	3411
29	DELAWARE	KINGSTON	L4,4TH¼	FERRALL	DAILY	992	1326	2280	2470	2517	3040	3075
117	DELAWARE	KINGSTON	L26,2ND¼	SUN OIL & F TURNER	WALTON	984	1240	2172	2356	2412	2882	2917
118	DELAWARE	LIBERTY	L1,3RD¼	WESTBURY PETROLEUM CO	COY	943	860	1765	1945	1996	2506	2538
157	DELAWARE	LIBERTY	L41,4TH¼	FEDERAL OIL & GAS CO	HALLEY	895	880	1780	1962	2014	2497	2504
20	DELAWARE	MARLBORO	L6, W½	LAW	WILSON	957	NL	?	1968	2031	2554	2594
84	DELAWARE	MARLBORO	LE	TRI-STATE PROD CO	BENEDICT	956	955	1883	2055	2108	2622	2646
119	DELAWARE	ORANGE	L5,4TH¼	KIDD	MCCAMMON	830	1070	1997	2182	2241	2755	2790
161	DELAWARE	ORANGE	L15,2ND¼	KIN-ARK OIL CO	ENGLISH	944	1085	2003	2188	2239	2746	2770
231	DELAWARE	ORANGE	L1,1ST¼	KIN-ARK OIL; SANTA FE	JAYCOX	910	1158	2080	2268	2320	ABS	2820
8	DELAWARE	OXFORD	L36,3RD¼	STEAMTOWN OIL CO	SMITH	957	995	1930	2100	2158	2685	2718
11	DELAWARE	OXFORD	L24,1ST¼	DENTON & SWINDLER	URBAN	977	1102	2045	2218	2274	2781	2807
282	DELAWARE	OXFORD	L7E,4TH¼	LULING OIL & GAS CO	BELL-CONDIT-SHAW	983	1175	2120	2294	2352	2859	2861
131	DELAWARE	PORTER	L31,4TH¼	THURLOW WEED	OVERTURE	1087	1656	2612	2803	2859	3386	3412
153	DELAWARE	PORTER	L14,1ST¼	PIPER SUPPLY CO	CHANDLER	1202	1826	2800	2985	3040	3570	3592
247	DELAWARE	PORTER	L23,4TH¼	PATRICK PETROLEUM CO	BALE	1130	NL	NL	2860	2916	3455	3490
290	DELAWARE	PORTER	L3,2ND¼	WORTHINGTON OIL CO	KIRBY	1127	NL	NL	2738	2800	3317	3344
17	DELAWARE	RADNOR	L21,2ND¼	J ADAMS	FRYMAN	917	570	1485	1644	1698	2212	2250
22	DELAWARE	RADNOR	L1,4TH¼	SOUTHERN TRIANGLE OIL	JONES	945	646	1550	1718	1768	2286	2334
38	DELAWARE	SCIOTO	L8,MASON S	MID-OHIO OIL & GAS	BROWN	935	646	1546	1718	1767	2261	2276
85	DELAWARE	SCIOTO	V835	DIAMOND & FORD	MCMILLIN	942	NL	?	1730	1783	2302	2351
44	DELAWARE	THOMPSON	V6293	SHEHORN	POTTS	907	464	1378	1538	1584	2104	2136
184	DELAWARE	THOMPSON	L27	KIN-ARK OIL CO	YOUNG	915	508	1414	1576	1624	2138	2168
19	DELAWARE	TRENTON	S8	PAN AMERICAN PET CORP	REPPART	1081	1646	2598	2790	2840	3371	3402
266	DELAWARE	TROY	L36,1ST¼	THORNHILL	CASE	892	840	1765	1938	1990	2511	2556
29	MARION	BIG ISLAND	S14	FRANK COX	WOOLEY	932	522	?	1572	1622	2147	2169
42	MARION	BIG ISLAND	S24	CONWAY	CRAWFORD	925	532	1437	1592	1642	2175	2199
59	MARION	BIG ISLAND	S11	FRANK COX	THACKER	941	NL	NL	1575	1634	2163	2188
83	MARION	BIG ISLAND	S33	BAGSDALE & CRAIN	BASEL	914	420	1328	1474	1522	2042	2068
100	MARION	BIG ISLAND	S14	BIG ISLAND EXPLORATION	WOOLEY	925	513	?	1558	1608	2144	2168
168	MARION	BIG ISLAND	S21	ANSCHUTZ CORP	GRACELY FARMS INC	924	NL	1315	1458	1508	2024	2050
174	MARION	BIG ISLAND	S22	TEXAS GAS EXPLORATION	GRACELY FARMS INC	916	451	1353	1495	1547	2030	2038

APPENDIX — AREA 11 (continued)

Permit no.	County	Township	Land sub-division	Operator	Lease name	Elevation	Depth to top (ft)					
							Cincinnati group	Point Pleasant Fm	Trenton Ls	Black River Gp	Wells Creek Fm	Knox Dolomite
176	MARION	BIG ISLAND	S21	TEXAS GAS EXPLORATION	GRACELY FARMS INC	924	490	1310	1449	1500	2024	2050
56	MARION	BOWLING GREEN	V9980	MERRILL DRLG CO	MATTIX	928	NL	1202	1326	1370	NDE	NDE
78	MARION	BOWLING GREEN	V9980	ALPHA-LARUE CO	MATTIX	925	270	1196	1322	NDE	NDE	NDE
92	MARION	BOWLING GREEN	V10299	GIBRALTAR OIL	GUTHERY	922	332	1240	1375	1422	1924	1951
7	MARION	CLARIDON	S36	W E SHRIDER ET AL	AULT	997	1160	2090	2270	2315	2835	2856
8	MARION	CLARIDON	S27	UNITED PROD CO INC	MITCHELL	1001	1035	1950	2120	2175	ABS	2647
14	MARION	CLARIDON	S3	ADAMS	KEY	999	1047	1974	2137	2190	2721	2747
17	MARION	CLARIDON	S10	ADAMS	SECKEL	999	1036	1962	2132	2184	2711	2745
18	MARION	CLARIDON	S25	ADAMS	GATEWOOD	996	1137	2067	2238	2291	2815	2847
22	MARION	CLARIDON	S36	SCHOONMAKER ET AL	AULT	997	1151	2094	2266	2318	2842	2871
49	MARION	CLARIDON	S32	MIDLAND DRLG CO	GRUBER	981	900	1824	1993	2047	2572	2600
66	MARION	CLARIDON	S32	MIDLAND DRLG CO	GRUBER	977	905	1833	1995	2053	2572	2600
74	MARION	CLARIDON	S34	ADAMS	SMITH	990	1055	1980	2153	2201	2716	2737
75	MARION	CLARIDON	S29	COMANCHE OIL INC	SCHWADERER	984	958	1882	2053	2106	2631	2663
77	MARION	CLARIDON	S13	LICHLYTER	BAYLES	1004	NL	?	2248	2303	2820	2841
81	MARION	CLARIDON	S26	TEXACO INC	RETTERER	995	1110	2040	2212	2266	2779	2805
84	MARION	CLARIDON	S9	ADKINS	SHOWERS ET AL	994	1020	1940	2100	2153	2679	2707
94	MARION	CLARIDON	S25	GREAT LAKES GAS CORP	GATEWOOD	985	NL	?	2223	2276	2800	2832
95	MARION	CLARIDON	S14	GREAT LAKES GAS CORP	SHOWERS	990	1057	1991	2160	2213	2737	2760
99	MARION	CLARIDON	S14	MERSHON	FIELDS	990	1063	1988	2157	2210	2735	2762
102	MARION	CLARIDON	S36	STAR EXPLORATION	MAYER	994	NL	?	2258	2312	ABS?	2821
108	MARION	CLARIDON	S25	O'NEILL	TAYLOR-HUSTON-WUESCHER	990	NL	?	2250	2305	2833	2863
167	MARION	GRAND	S35	DELRAY OIL INC	HERR	905	298	1185	1321	1384	1890	1933
96	MARION	MARION	S3	T. L. M., INC	LINN	959	724	?	1796	1846	ABS	2378
58	MARION	MONTGOMERY	S26	HARDING BROS OIL & GAS	CAROZZA & CANCRO	915	357	1267	1400	1454	1956	1986
76	MARION	MONTGOMERY	S27	STADLER & MATTIX	EVANS	917	NL	?	1350	1401	1887	1910
85	MARION	MONTGOMERY	S7	STADLER & MATTIX	PARISH	980	329	?	1368	1413	1914	1945
173	MARION	MONTGOMERY	S21	TEXAS GAS EXPLORATION	OEHLER	974	441	?	1406	1434	1918	1936
86	MARION	PLEASANT	S21	MORROW PET & A J WALKER	ECKLEY	983	780	1690	1858	1911	2434	2466
87	MARION	PLEASANT	S29	HADSON OHIO OIL CO	CUSICK	953	620	1540	1702	1751	2283	2313
93	MARION	PLEASANT	S13	LOHMANN-JOHNSON DRLG CO	ACKERMAN	982	812	1724	1893	1948	2467	2492
114	MARION	PLEASANT	S11	ENERGY RESEARCH & EXP	MILLER	977	800	1710	1880	1932	2460	2492
117	MARION	PLEASANT	S16	RIALTO RESOURCES INC	RIALTO FARMS	974	756	?	1820	NDE	NDE	NDE
119	MARION	PLEASANT	S9	OXFORD OIL CO	FYFFE	974	740	?	1790	1841	NDE	NDE
124	MARION	PLEASANT	S16	OXFORD OIL CO	SEITER	979	767	?	1830	1882	2406	2439
125	MARION	PLEASANT	S9	DESCO CORP	WILLIAMS	973	NL	?	1818	NDE	NDE	NDE
127	MARION	PLEASANT	S17	RIALTO RESOURCES INC	RIALTO FARMS/TALLY BROS	962	NL	1659	1830	NDE	NDE	NDE
130	MARION	PLEASANT	S16	GASEARCH INC	AKERS UNIT	987	776	1692	1858	NDE	NDE	NDE
133	MARION	PLEASANT	S17	VAUGHT OIL CO	MCCLASKEY	954	NL	1536	1700	1753	ABS	2212
138	MARION	PLEASANT	S21	OXFORD OIL CO	NASH	974	780	?	1865	1921	?	NDE?
82	MARION	PROSPECT	L18,4TH¼	PIGGOTT JR	HOLT	967	NL	1656	1828	1876	2390	2401
15	MARION	RICHLAND	S10	CLINTON OIL CO	STOSE	982	NL	?	2135	2190	2696	2702
21	MARION	RICHLAND	S24	WAGNER	BUSH	992	NL	2072	2244	2300	2816	2847
24	MARION	RICHLAND	S11	ADAMS	KRAMER	992	1108	2022	2193	2246	2754	2760
41	MARION	RICHLAND	S22	TATUM	YAKE	995	1025	1961	2133	2187	2708	2741
44	MARION	RICHLAND	S25	JENKINS ENGINEERING CO	HEIMLICH	986	1111	2050	2224	2276	2783	2786
48	MARION	RICHLAND	S30	BAREFIELD OIL CO	KLINGEL	966	878	1790	1960	2017	2541	2581
67	MARION	RICHLAND	S3	ADAMS	JEVAS	987	1040	1957	2127	2178	2678	2683
89	MARION	RICHLAND	S22	CITIES SERVICE OIL CO	YAKE ET AL	985	918	1892	2063	2118	2621	2632
143	MARION	RICHLAND	S1	D & H OIL CO	VAN VOORHIS-SHEPARD	1000	NL	?	2276	2331	2856	2889

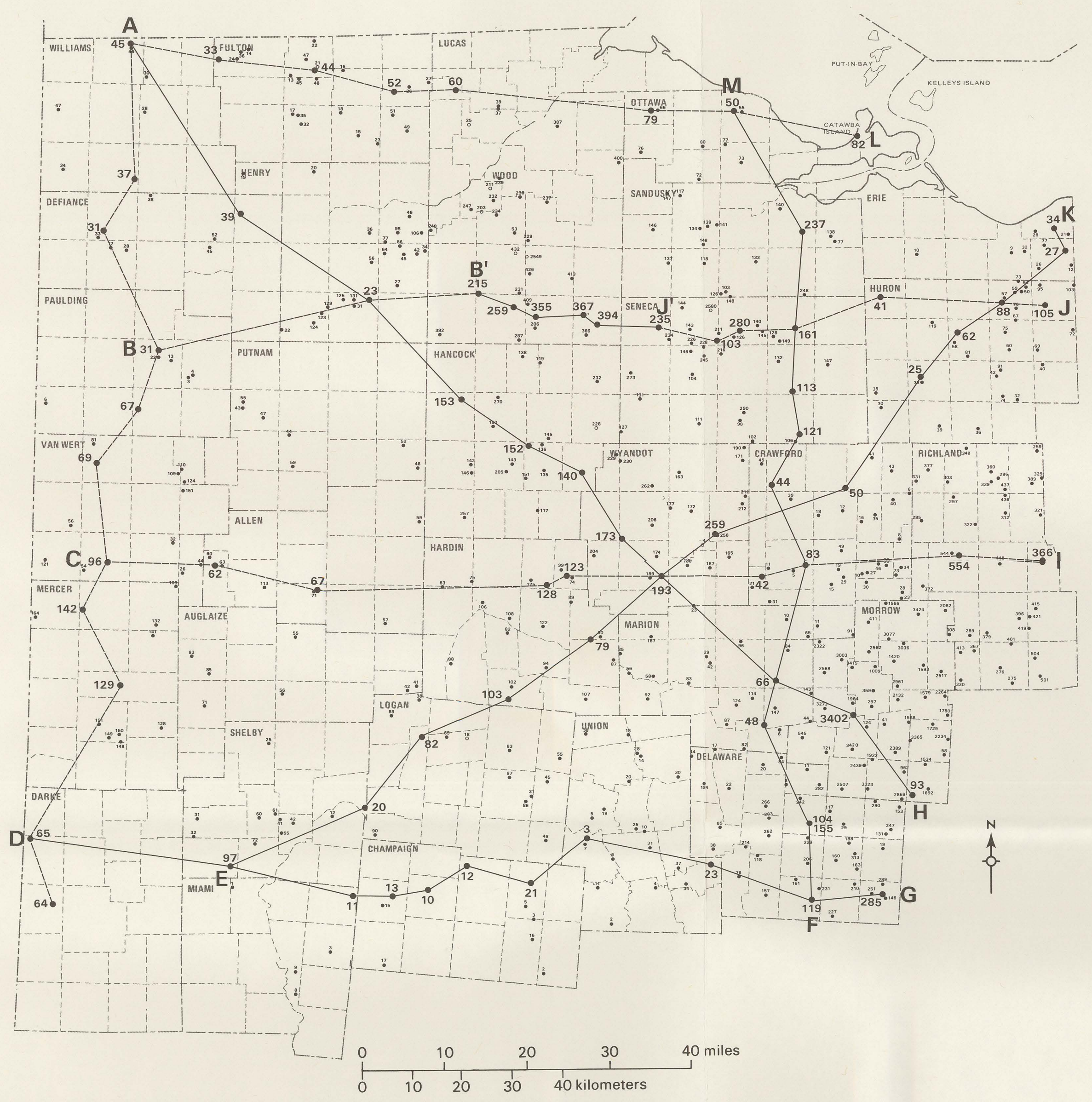
147	MARION	RICHLAND	S17	X-ALPHA INT'L LTD	MCNAMARA	977	NL	?	1972	2025	2522	2524
148	MARION	RICHLAND	S17	X-ALPHA INT'L LTD	MCNAMARA	982	NL	?	1984	2040	2547	2568
23	MARION	SALT ROCK	S15	MEESE BROS	LANE	892	440	1296	1446	1499	2006	2063
10	MARION	SCOTT	S21	UNITED PROD CO INC	PUGH	1016	996	1930	2090	2143	2670	2690
65	MARION	SCOTT	S36	IDEAL DRLG CO	LONGACRE	1005	NL	2048	2204	2257	2781	2807
9	MARION	TULLY	S30	LAKE SHORE PIPELINE CO	LANDIS	1011	1183	2114	2278	2333	2856	2875
11	MARION	TULLY	S30	LAKE SHORE PIPELINE CO	CRAWBAUGH	1006	1163	2093	2256	2310	2836	2860
16	MARION	TULLY	S31	HOGAN & LEONARD OIL CO	KELLOGG-HONAKER UNIT	1005	NL	?	2282	2340	2868	2895
20	MARION	TULLY	S35	SHAW	COX	1049	1390	?	2530	2575	3107	3137
91	MARION	TULLY	S35	CALVERT EASTERN DRLG CO	COX	1070	NL	?	2553	2607	3143	3173
103	MARION	TULLY	S27	LAKE SHORE PIPELINE CO	HEDDING	1035	1317	2260	2433	2490	3026	3054
6	MARION	WALDO	L4,1ST1/4	ATLAS EXPLORATION	DENZER	972	956	1881	2054	2107	2625	2658
962	MORROW	BENNINGTON	L3,1ST1/4	BRASEL & BRASEL	RAMEY	1267	1916	2888	3067	3121	3659	3690
1922	MORROW	BENNINGTON	L9,2ND1/4	CLINTON OIL CO	MASON	1113	1576	2537	2715	2769	3298	3330
2869	MORROW	BENNINGTON	S21	MINNESOTA-OHIO OIL CO	MOODY	1196	1843	2818	3008	3066	3604	3640
3323	MORROW	BENNINGTON	L3,3RD1/4	HORTIN & HUFFMAN INC	HEINTZ	1068	NL	2488	2660	2716	3247	3284
2322	MORROW	CANAAN	S6	AFFELD-FALESE OIL CO	BAKER	1000	NL	?	2266	2325	2855	2881
2568	MORROW	CANAAN	S29	ASHLAND OIL	MURPHY	1020	NL	?	2332	2387	2907	2917
3003	MORROW	CANAAN	S15	MIDWEST OIL & GAS	HIGHLY	1032	1313	2250	2423	2478	ABS	2999
706	MORROW	CARDINGTON	S28	ROACH	BENDING-FORMAN	1005	1255	2196	2370	2425	2942	2952
1087	MORROW	CARDINGTON	S23	ASHLAND OIL	PATTERSON	1038	1350	2289	2465	2518	ABS	3010
1549	MORROW	CARDINGTON	S3	ASHLAND OIL	BUSH	1037	1335	2280	2456	2511	3030	3059
1958	MORROW	CARDINGTON	S17	PATRICK PETROLEUM CO	BURGRAFF	1011	1236	2190	2372	2430	2967	3013
1964	MORROW	CARDINGTON	S14	ASHLAND OIL	SHAFFER-CASTRO	1037	1368	2317	2493	2550	ABS	3062
3273	MORROW	CARDINGTON	S17	H FLOYD FAUST	CURL	983	NL	?	2326	2393	NDE	NDE
3402	MORROW	CARDINGTON	S23	ASHLAND EXPLORATION	MOSHER	1049	1374	2306	2486	2541	3051	3051
58	MORROW	CHESTER	L14,4TH1/4	OIL INVESTMENT INC	WOOD	1227	2098	3088	3272	3322	3850	3871
1729	MORROW	CHESTER	L6,1ST1/4	HOBSON OIL CO	HUNT	1175	2000	2990	3170	3229	3759	3793
2234	MORROW	CHESTER	L15,1ST1/4	CYSONY OIL CO	LEVERING	1094	2010	?	3193	3248	3784	3820
3365	MORROW	CHESTER	L40,3RD1/4	HORTIN & HUFFMAN INC	STONE UNIT	1231	NL	2900	3079	3134	3652	3684
1420	MORROW	CONGRESS	S17	COLLIER & HANSON	RODEBECK	1260	NL	2791	2966	3026	3564	3608
1593	MORROW	CONGRESS	S24	WILLIAMS	SMITH	1398	2140	3123	3301	3359	3907	3939
2961	MORROW	CONGRESS	S33	THOMAS	HIGGINS	1261	1882	2850	3030	3086	3621	3641
3036	MORROW	CONGRESS	S3	THOMAS	GREEN	1376	2004	2984	3164	3218	3762	3796
1579	MORROW	FRANKLIN	S12	WILLIAMS	SHERMAN	1349	2105	3096	3280	3334	3877	3920
1780	MORROW	FRANKLIN	L2,4TH1/4	COX	BURSEN	1299	2184	3187	3372	3430	3974	4012
2132	MORROW	FRANKLIN	S9	GRIFFITH PROD CO	GOODMAN	1226	1832	2815	2992	3049	3597	3642
2264	MORROW	FRANKLIN	S5E	HADSON OHIO OIL CO	BECK	1322	2193	?	3375	3441	3955	3960
297	MORROW	GILEAD	S13S	SOUTHERN TRIANGLE OIL	BROLLIER	1161	1618	2560	2730	2787	ABS	3264
359	MORROW	GILEAD	S1	DOCK OIL CO	GARVERICK	1101	1530	2479	2658	2716	ABS	3226
1009	MORROW	GILEAD	S24N	HURT DRLG CO	GHENT	1188	NL	?	2822	2896	3418	3447
2345	MORROW	GILEAD	S24N	ASHLAND OIL	CORBIN	1161	1616	2570	2751	2800	ABS	3320
3415	MORROW	GILEAD	S23W	FAUST	MURPHY	1058	NL	2314	2490	2542	3062	3074
41	MORROW	HARMONY	L12,2ND1/4	R K PET CORP	KINCAID	1176	1706	2675	2858	2910	3433	3474
1439	MORROW	HARMONY	S8	CAVALIER OIL	MCNAMEE	1195	1750	2710	2890	2942	3457	3477
1568	MORROW	HARMONY	S1	WILLIAMS	AULT	1180	1830	2806	2990	3045	3554	3562
2389	MORROW	HARMONY	L30,4TH1/4	ALLEN ASSOCIATES	CHILDERS	1218	1676	?	2946	2998	3536	3569
124	MORROW	LINCOLN	L4,1ST1/4	JERRY MOORE INC	BURR	1070	1488	2440	2618	2679	3152	3154
3420	MORROW	LINCOLN	L30,4TH1/4	GUARDIAN MGMT INC	FEGLEY	1053	NL	2374	2552	2606	3142	3177
1566	MORROW	NORTH BLOOMFIELD	S7	PETROLEUM PROMOTIONS	ROELLE	1168	NL	?	2788	2841	3382	3408
3077	MORROW	NORTH BLOOMFIELD	S32	ROMEI & PAYNE	RULE	1250	NL	?	2941	3008	3535	3562
3424	MORROW	NORTH BLOOMFIELD	S14	INDUSTRIAL NATURAL GAS	RINEHART	1340	2024	3008	3190	3243	3787	3817
2517	MORROW	PERRY	S20	SOHIO PET CO	LANKER	1410	2245	3240	3416	3480	4000	4035
2439	MORROW	PERU	L3,1ST1/4	KEENER OIL	BAILEY	1071	1490	2442	2624	2674	3190	3200
2507	MORROW	PERU	L14,3RD1/4	DAVIS DRLG CO INC	SILVEOUS	976	NL	?	2403	2456	2980	2996

APPENDIX — AREA 11 (continued)

Permit no.	County	Township	Land sub-division	Operator	Lease name	Elevation	Depth to top (ft)					
							Cincinnati group	Point Pleasant Fm	Trenton Ls	Black River Gp	Wells Creek Fm	Knox Dolomite
93	MORROW	SOUTH BLOOMFIELD	S25	FERGUSON OIL CO	HANKINS	1293	2016	2976	3176	3230	3760	3792
1534	MORROW	SOUTH BLOOMFIELD	S3	RINGLER	MEISER	1305	NL	?	3286	3332	3873	3914
1692	MORROW	SOUTH BLOOMFIELD	S18	COX	GROVE	1351	NL	?	3342	3400	3941	3978
2082	MORROW	TROY	S17	SHAW	SANDERLIN	1432	NL	?	3397	3435	3980	4019
411	MORROW	WASHINGTON	S23	KUYPCO OIL CORP	CLIFFSHIRE ESTATE INC	1100	NL	?	2716	2782	3300	3329
2562	MORROW	WASHINGTON	S11S	FARRAR & YOUNG OIL CO	MATTIX	1166	1580	2529	2700	2755	2770	3205
121	MORROW	WESTFIELD	S21	FERGUSON-BOSWORTH	MARTIN	994	1178	2103	2276	2326	2800?	2837?
545	MORROW	WESTFIELD	L9,3RD1/4	JENKINS ENGINEERING CO	MCGINNIS	980	1035	1966	2137	2188	2609	2635

STATE OF OHIO
George V. Voinovich, Governor
DEPARTMENT OF NATURAL RESOURCES
Frances S. Buchholzer, Director
DIVISION OF GEOLOGICAL SURVEY
Thomas M. Berg, Chief

DIVISION OF GEOLOGICAL SURVEY
REPORT OF INVESTIGATIONS NO. 143
PLATE 1



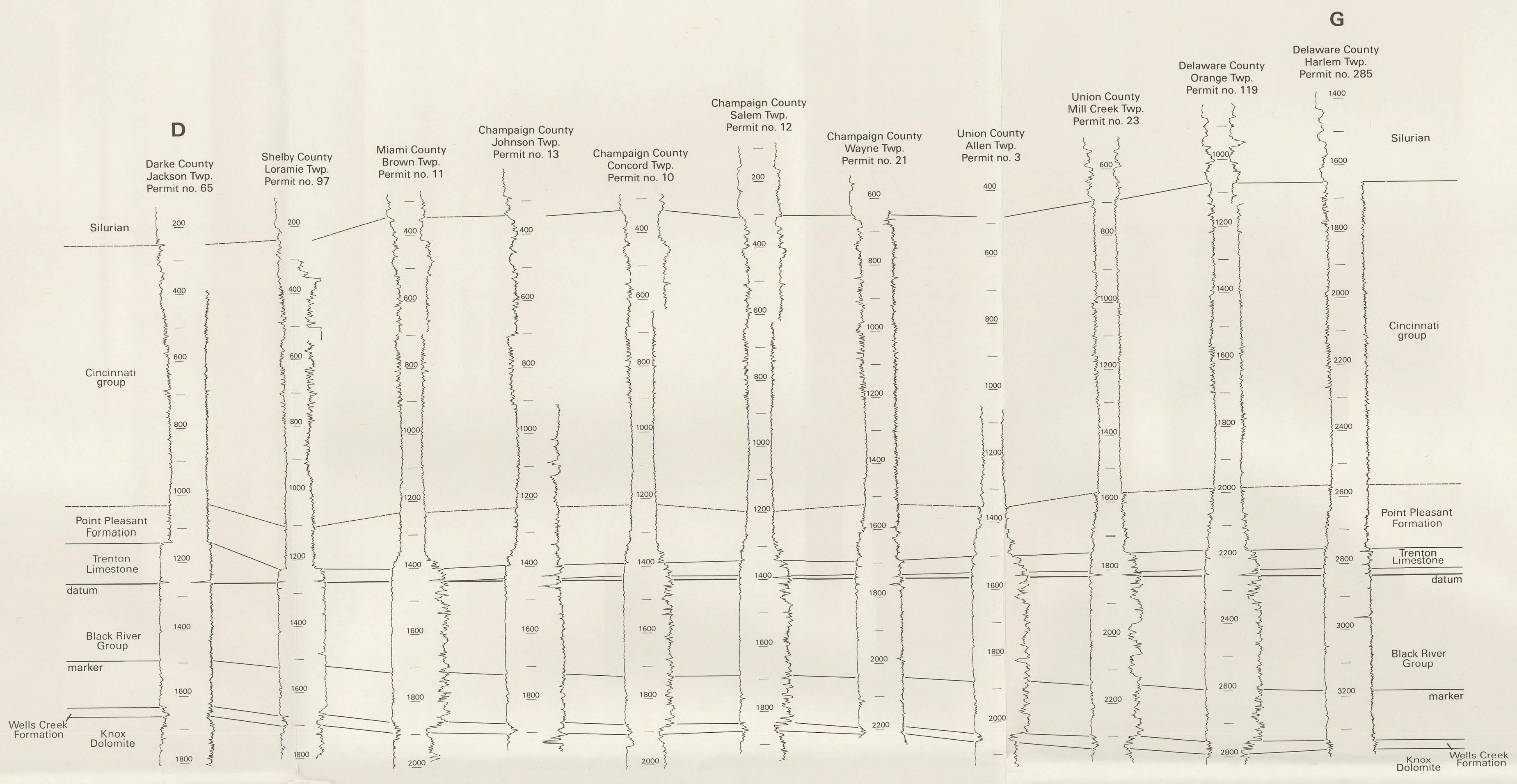
INDEX TO CROSS-SECTION NETWORK

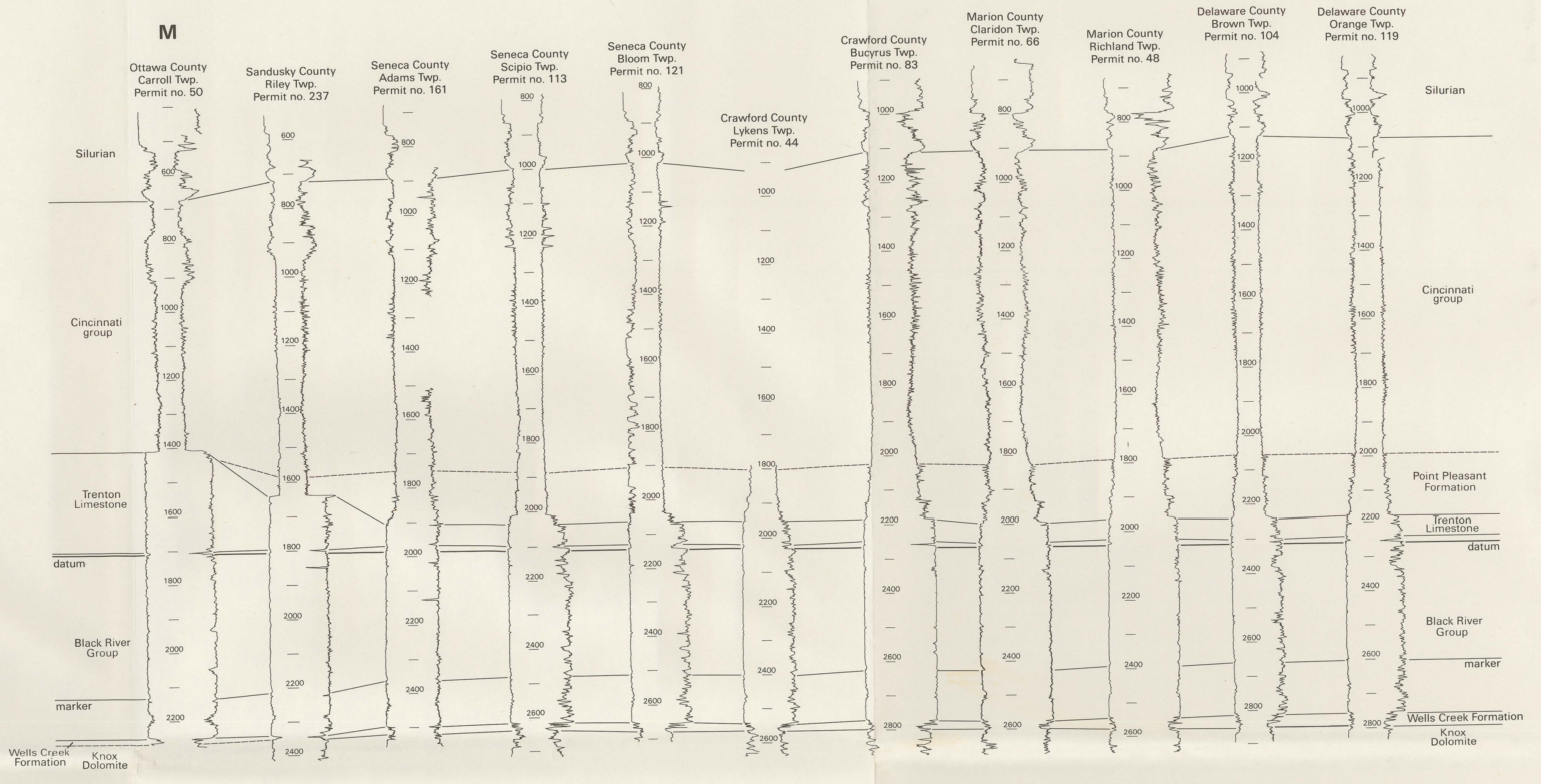
Solid lines represent stratigraphic and structural cross sections included in this report; dashed lines represent stratigraphic cross sections available on open file at the Division of Geological Survey. Refer to Appendix of report for information on individual wells.

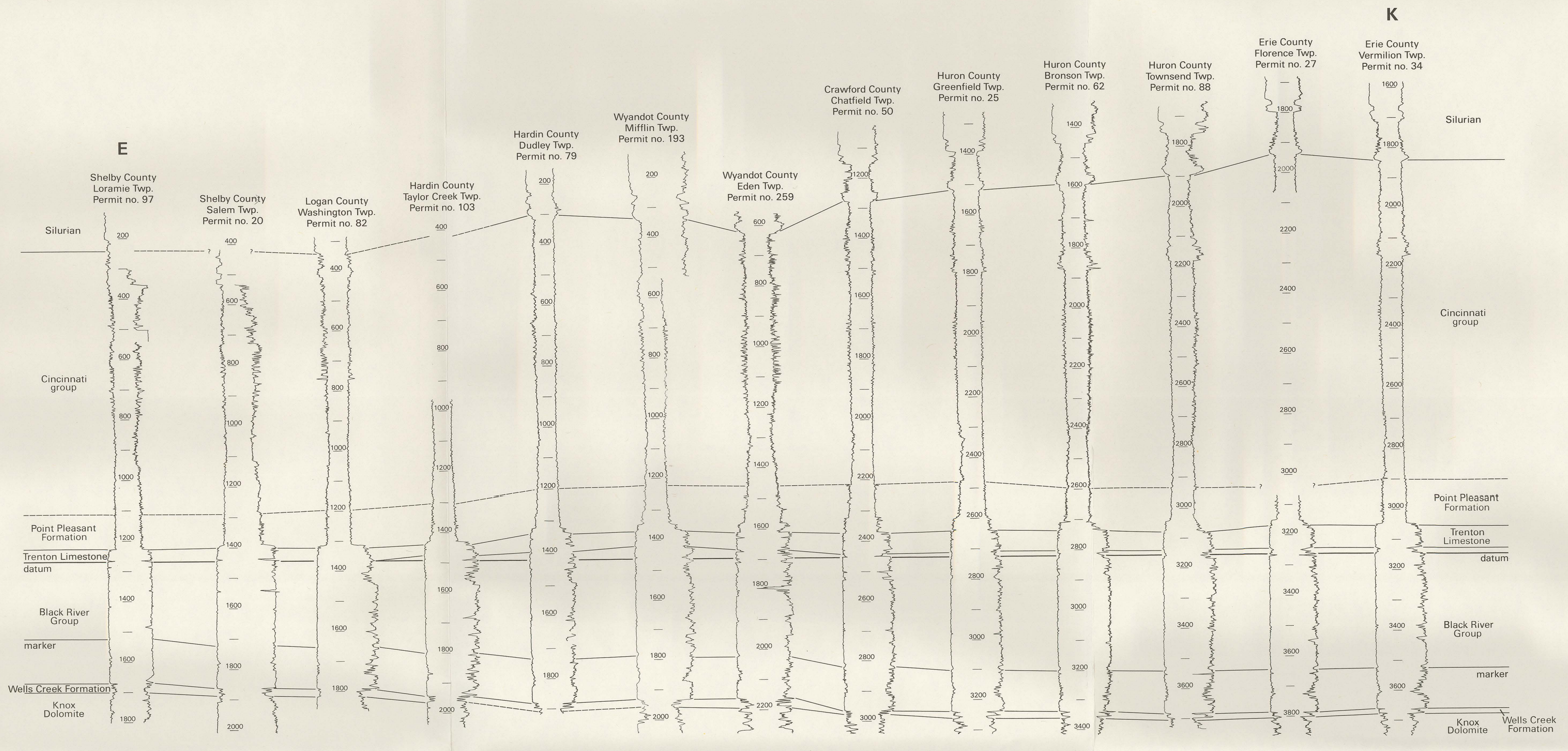
105 ● Well location and Division of Oil and Gas permit number

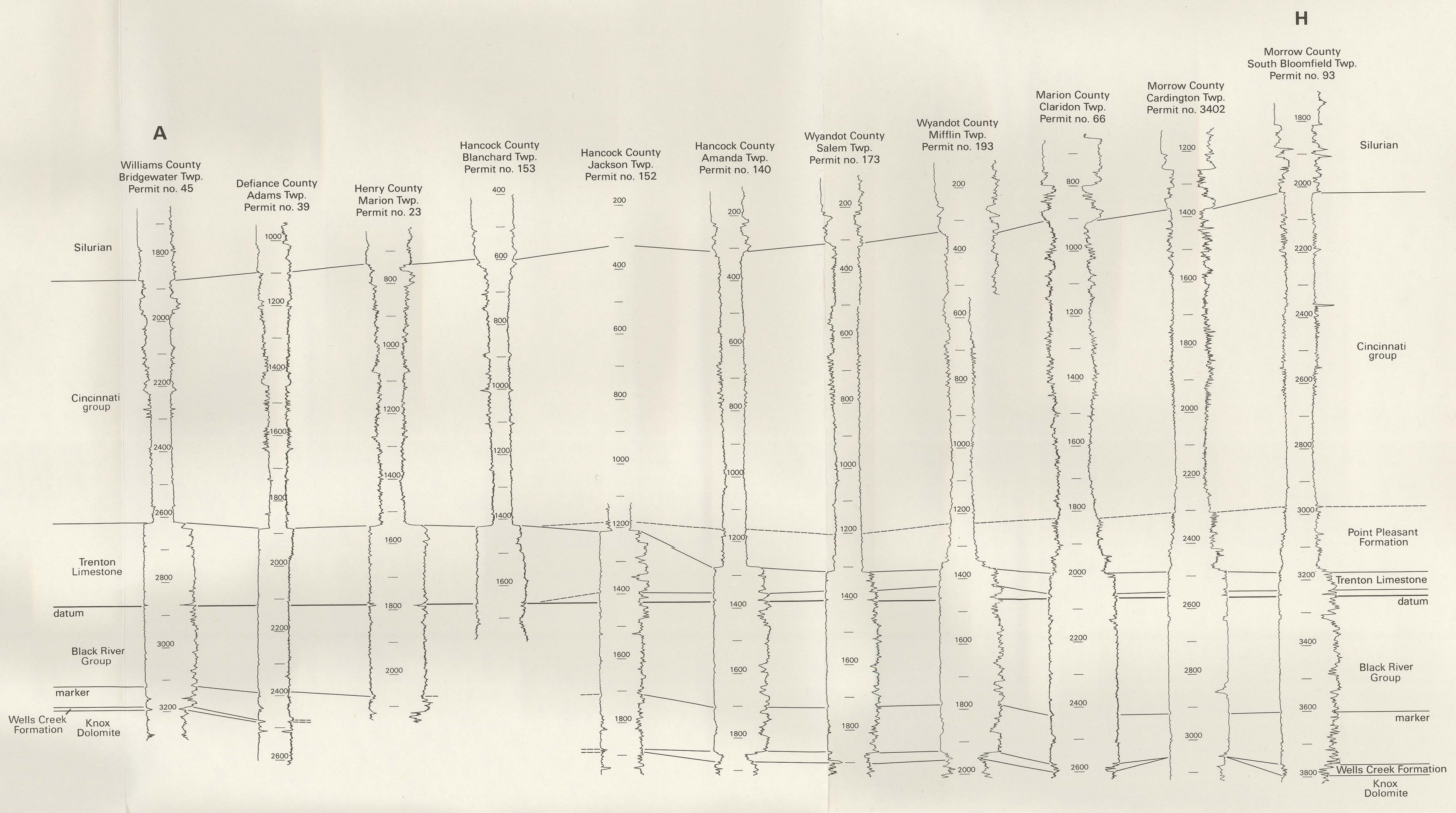
EXPLANATION

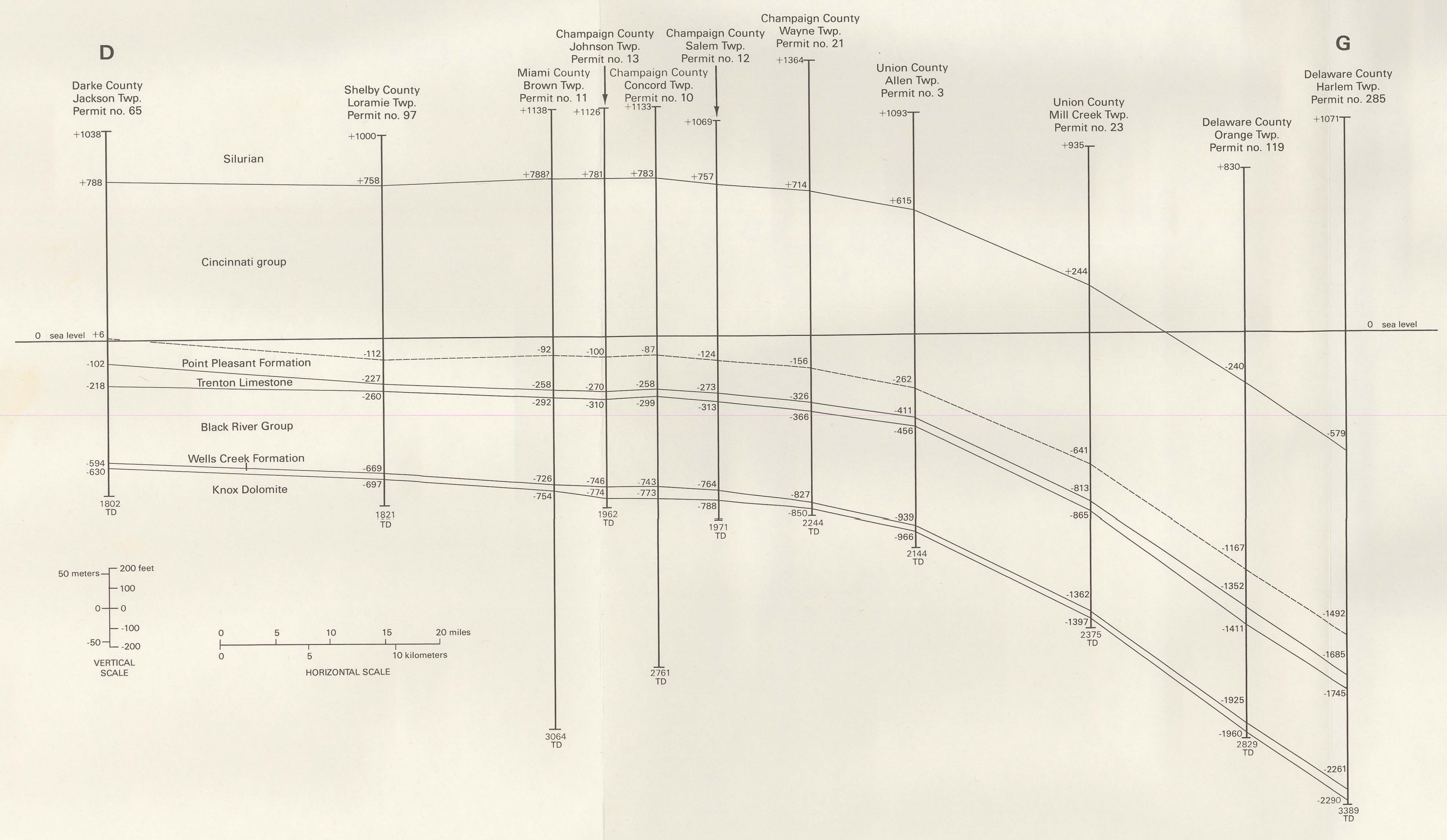
Datum for stratigraphic (geophysical-log) cross sections is uppermost bentonite bed in the Black River Group. marker = characteristic marker bed in the lower Black River Group. Depths in each well are along-hole depths, in feet. Datum for structural cross sections is present-day sea level. All elevations are in feet referred to sea level except total depth (TD).

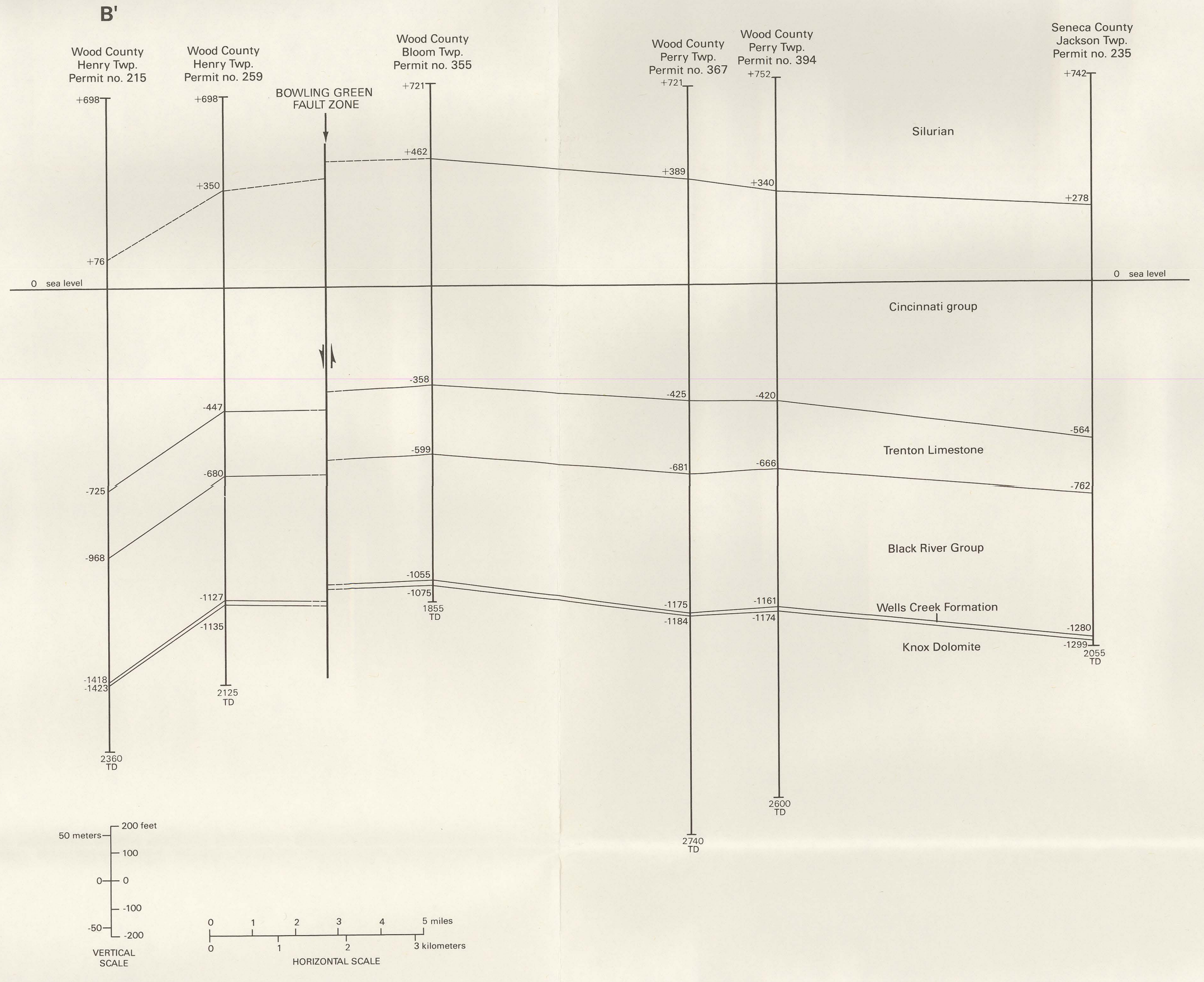












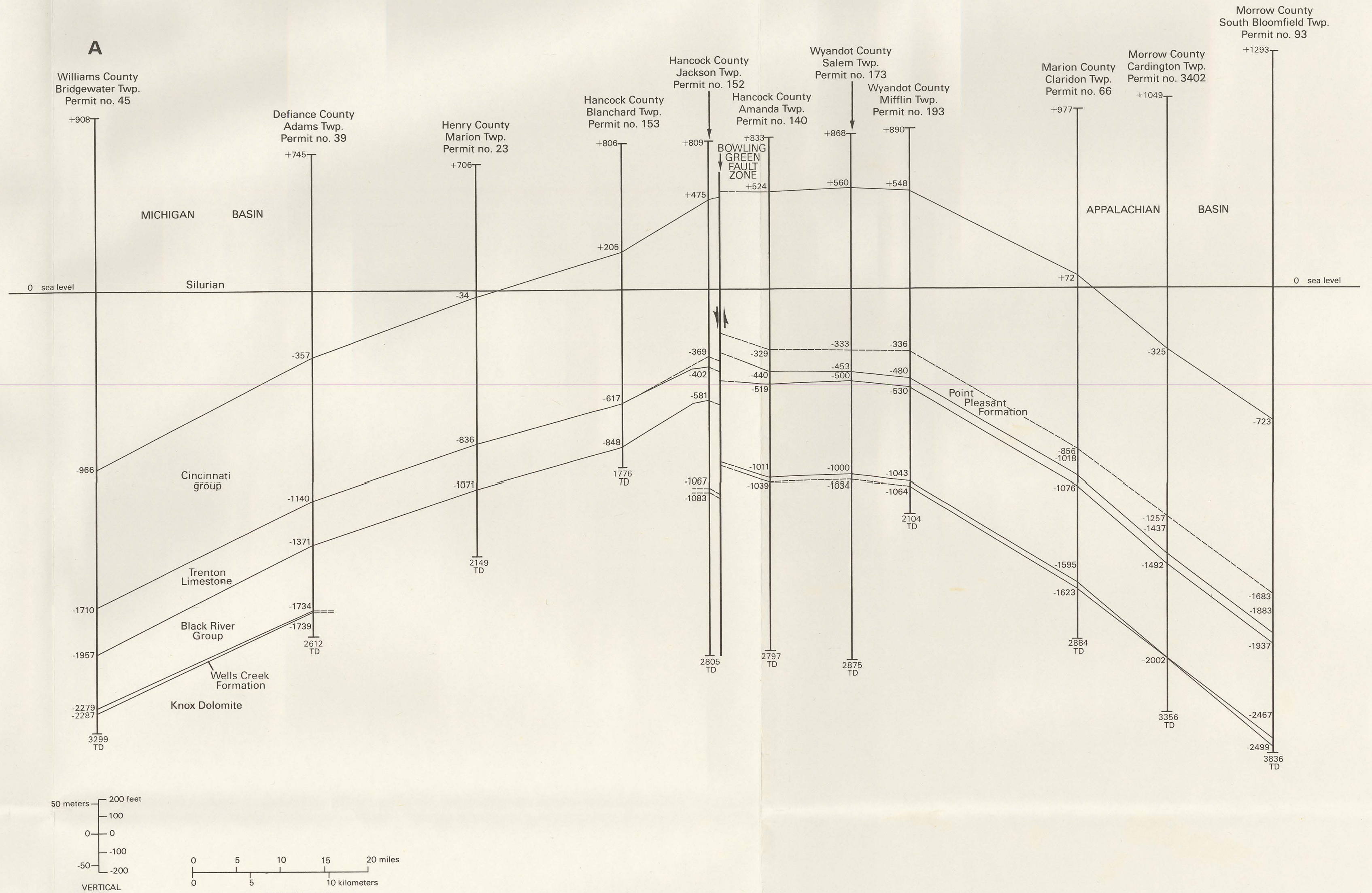


PLATE 1. STRATIGRAPHIC AND STRUCTURAL CROSS SECTIONS OF NORTHWESTERN OHIO

CARTOGRAPHIC DRAFTING BY EDWARD V. KUEHNLE

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OHIO Department of Natural Resources