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EVALUATION OF DEVONIAN-SHALE POTENTIAL IN OHIO

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EVALUATION OF THE DEVONIAN-SHALE POTENTIAL IN OHIO

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PREFACE

This report is a geologic screening effort to evaluate areas within Ohio that contain sufficient geologic and geochemical characteristics to warrant industry exploration activity. The results are an integration of contractor report data, maps, and logs generated in the Eastern Gas Shales Project. The areas outlined as favorable in this report are those in which the likelihood of encountering gas is greater than elsewhere. Within these areas, local geologic and geochemical factors must be considered as they can dictate success or failure. It is hoped that this information will guide industry activity to the areas of high shale gas potential.

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INTRODUCTION

Dark, organic-rich Devonian shales--distributed across more than 10 states from Illinois to Pennsylvania and Michigan to Mississippi, in the contiguous Appalachian, Illinois, and Michigan basins--represent an important natural gas resource. A recent authoritative estimate indicates in-place reserves of gas, entrapped in the matrix and fracture systems of the shale, at 277 to 900 trillion cubic feet (Tcf). Of this, about 20-50 Tcf of gas are expected to be recoverable using presently available methods in the Appalachian basin. Estimates of reserves in the Illinois and Michigan basins are not yet determined (Pulle and Seskus, 1980).

Although geologic and engineering evidence indicates that the volume of natural gas in the eastern Devonian shales is enormous, little of the gas can be recovered by conventional methods. Production to date has been limited to areas where fracturing is present and geochemical parameters are favorable. As a result, although production of gas from Devonian black shales begain in 1821 with the drilling of a well near Fredonia, New York, only about 2.5 Tcf of gas have been produced; most (2 Tcf) came from the Big Sandy gas field in eastern Kentucky (Hunter and Young, 1953). Additional production of gas from these eastern gas shales depends on identifying favorable areas for exploration and developing new stimulation techniques that will enhance the rate of gas recovery.

To evaluate the potential of the Devonian shale as a source of natural gas, the U.S. Department of Energy (DOE) has undertaken the Eastern Gas Shales Project (EGSP). The EGSP is designed not only to identify the resource, but also to test improved methods of inducing porosity and permeability to facilitate gas drainage, collection, and production. The ultimate goal of this project is to increase the production of gas from the eastern shales through advanced exploration and exploitation techniques.

The purpose of this report is to inform interested oil and gas operators about EGSP results as they pertain to the Devonian gas shales of the Appalachian basin in eastern Ohio. Geologic data and interpretations are summarized, and areas where the accumulation of gas may be large enough to justify commercial production are outlined. Because the data presented in this report are generalized and not suitable for evaluation of specific sites for exploration, the reader should consult the various reports cited for more detail and discussion of the data, concepts, and interpretations presented. A complete list of EGSP sponsored work pertinent to the Devonian shales in Ohio is contained as an appendix to this report.

SUMMARY AND CONCLUSIONS

Commercial quantities of gas are likely to occur within closely spaced natural fracture systems close to, or within, organic-rich source beds. Four principal source beds have been identified within the shales of eastern Ohio. Ranked in order of importance, based on their geographic distribution and thickness, they are the Huron, Rhinestreet, Cleveland, and Marcellus Shales. Within each of these zones, there is believed to be a north-south trending area of most favorable shale lying between immature shales to the west and shales too organically lean to the east.

Closely spaced localized fracturing of the Devonian shale sequence is likely to occur along two regional trends in eastern Ohio: the Cambridge arch and the Lake Erie shoreline. Operators drilling within these areas, or near any structurally disturbed area, should evaluate and test shale zones that exhibit indications of being naturally fractured.

Dual completion techniques offer a low-cost means of exploiting the Devonian shales in Ohio. The technology has been tested and, where ideal conditions exist, is well-suited for dual development of the shale and the Clinton sandstone.

GEOLOGIC SETTING

The Devonian shales of Ohio comprise the stratigraphic sequence overlying the Onondaga Limestone, or driller's "Big Lime" (Middle Devonian), and underlying the Berea Sandstone (Lower Mississippian). These shales are present in three areas of the state (fig. 1). The smallest area, the Bellefontaine outlier, is located in eastern Logan and Champaign Counties. A second area, in northwest Ohio, includes all or parts of Lucas, Henry, Defiance, Fulton, and Williams Counties. The Devonian shales in these two areas are not considered potential sources of commercial supplies of natural gas since they are relatively thin and lack adequate cover to allow the use of advanced stimulation techniques.

The largest and most favorable area for future gas supplies from the Devonian shales lies in eastern Ohio. In this area, the shales outcrop along a belt that extends from Adams County in southern Ohio to Erie County in the north. The belt continues in an eastward direction paralleling the southern shore of Lake Erie and extending into western Pennsylvania and New York.

For more than a century, this eastern area has been widely explored and developed by the petroleum industry. Tens of thousands of wells have been, and are being, drilled to targets underlying the shales (generally the lower Silurian Clinton-Medina sandstones). These wells have provided a great deal of information about the structural configuration and stratigraphy of the shales.

As shown in figure 2, the Devonian shale sequence thickens eastward from about 400 feet in the central part of the state to more than 4,000 feet in Belmont and Jefferson Counties. A southeasterly dip is reflected on the top of shales which descends from about 800 feet above sea level in Cuyahoga County to about 1,500 feet below sea level in eastern Meigs, Gallia, and Lawrence Counties (fig. 3). Since there is a pronounced thickening of the interval to the east, the base of the sequence reflects a steeper dip than the top. The base, at about 600 feet below sea level in Cuyahoga County, plunges to more than 4,300 feet below sea level in Belmont County (fig. 4).

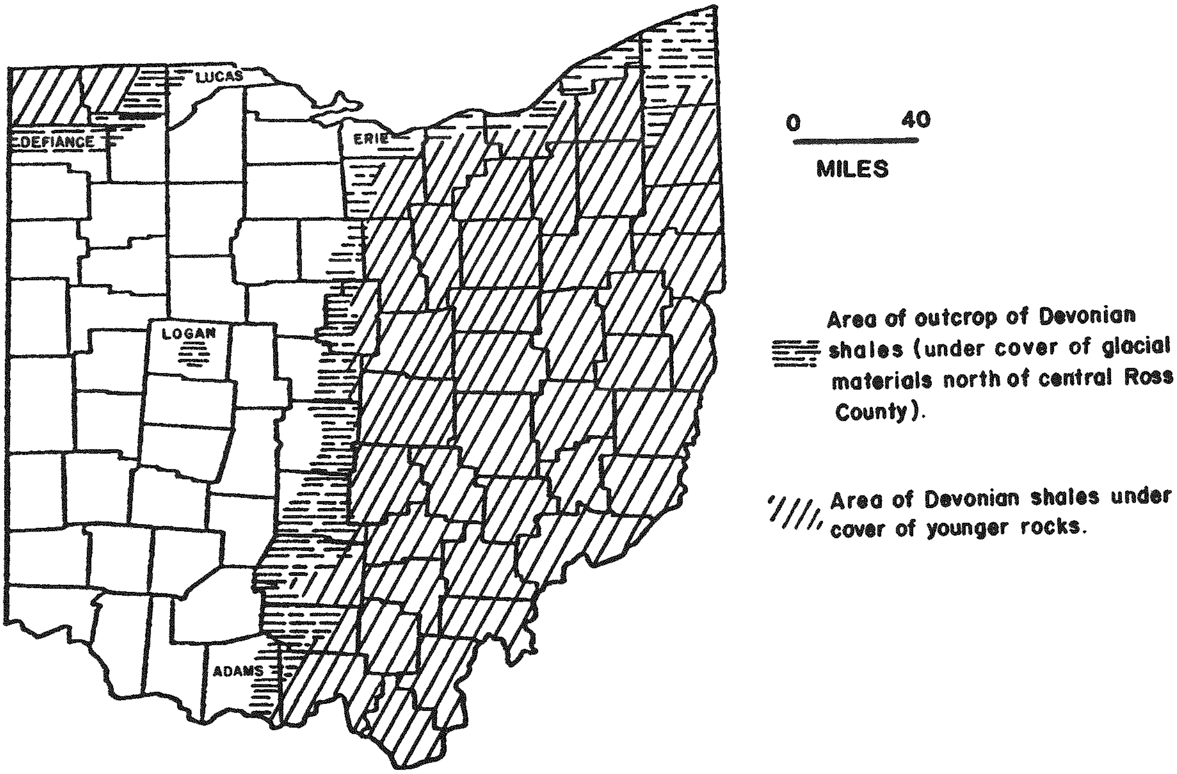


Figure 1. Generalized occurrence of the Devonian shales in Ohio. After Janssens and de Witt (1976).

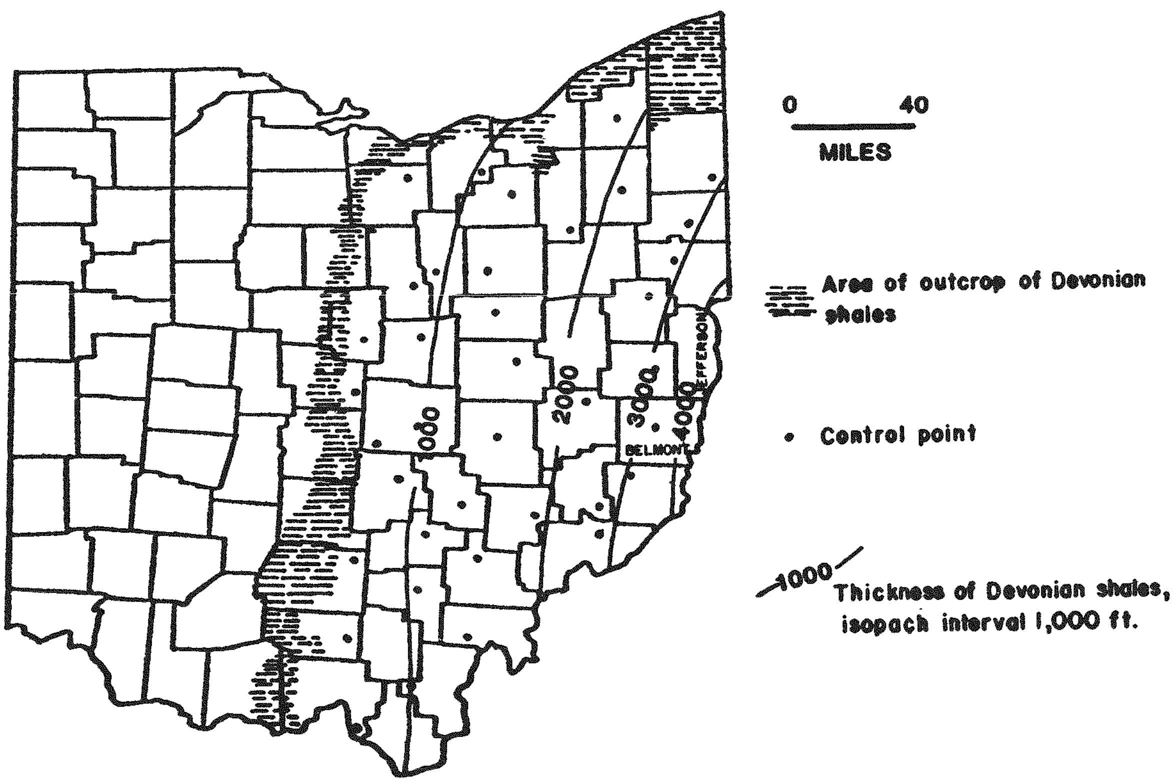


Figure 2. Thickness of the Devonian shales in eastern Ohio. After Janssens and de Witt (1976).

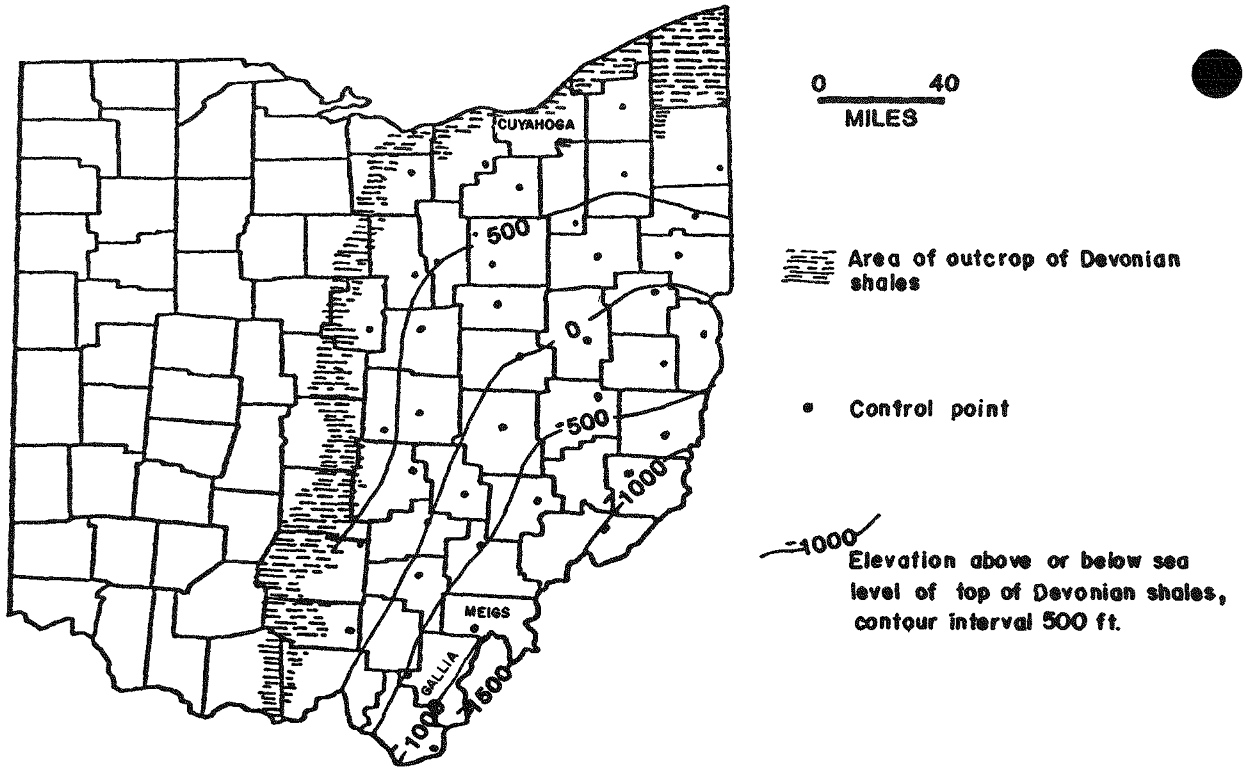


Figure 3. Elevation of the top of the Devonian shales in eastern Ohio. After Janssens and de Witt (1976).

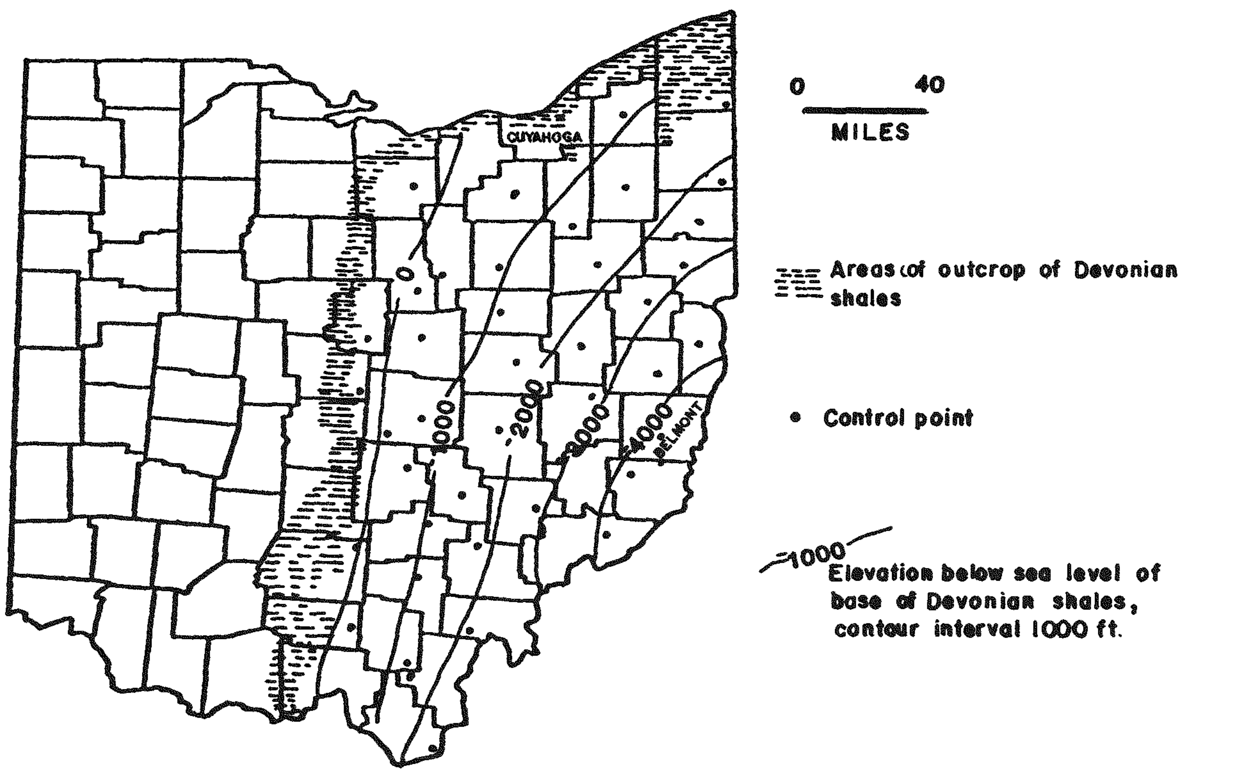


Figure 4. Elevation of the base of the Devonian shales in eastern Ohio. After Janssens and de Witt (1976).

STRATIGRAPHY[1]

The stratigraphy of the Devonian shales of eastern Ohio has been the subject of geologic investigations for more than a century. A comprehensive summary of previous research on the Upper Devonian and Lower Mississippian shales has been prepared by Hoover (1960). Recent investigations include a thorough surface and subsurface stratigraphic investigation of the Devonian shales throughout the central Appalachian basin area by Schwietering (1979) and a reconnaissance study by Janssens and de Witt (1976), focusing on the black shale facies and its relation to Devonian shales gas production. In addition, Potter, et al. (1980) prepared a special report on research, conducted at the University of Cincinnati, dealing with the geology, geochemistry, and petrology of the Devonian shales.

In eastern Ohio, the Devonian shales include, in ascending order, the Olentangy Shale; the Ohio Shale and its members--the Huron, Chagrin, and Cleveland Shales; and the Bedford Shale. Figure 5 is a schematic diagram showing the sequence and its relative configuration.

The different stratigraphic units are identified and correlated in the subsurface by their distinctive signatures as recorded on gamma ray logs. A log showing typical gamma ray responses within the Devonian shales for a well drilled in central Ohio is presented on figure 6.

The stratigraphic relationships of the sequence are illustrated on a fence diagram (plate 1), based on detailed cross sections constructed by Majchszak (1980). The east-west panels of the diagram reflect a general facies transition from predominantly black or dark-colored shales in central Ohio to lighter colored, grayish shales and siltstones in the east. This feature is attributed to an eastward transition of depositional environments, from basinal, deep water regions in the west to a submarine shelf upon which slope turbidites were deposited in the east (Potter, et al., 1980). The north-south cross sections presented on the diagram reflect a characteristic lateral continuity of the stratigraphic units.

Olentangy Shale

The Olentangy Shale, at its type section outcrop in Delaware County, Ohio, is greenish gray and about 30 feet thick. It darkens eastward, and thickens to about 1,200 feet in eastern Ohio. Based on paleontological studies at the outcrop, Tillman (1970) divided the Olentangy into an upper unit of Late Devonian age and a lower unit of Middle Devonian age. The two units are separated by an unconformity. As shown on plate 1, the lower Olentangy thins to the south and is absent in southern Ohio.

Based on gamma ray log correlations, Java, West Falls, Sonyea, and Genesee equivalents have been traced from New York into the upper Olentangy in eastern Ohio. The lower Olentangy is thought to be equivalent to part of the Hamilton Group. A correlation chart for the Ohio and New York terminology is shown on the fence diagram (plate 1).

[1]The nomenclature in this report is that accepted by the Ohio Division of Geological Survey and does not necessarily conform to U.S. Geological Survey Usage.

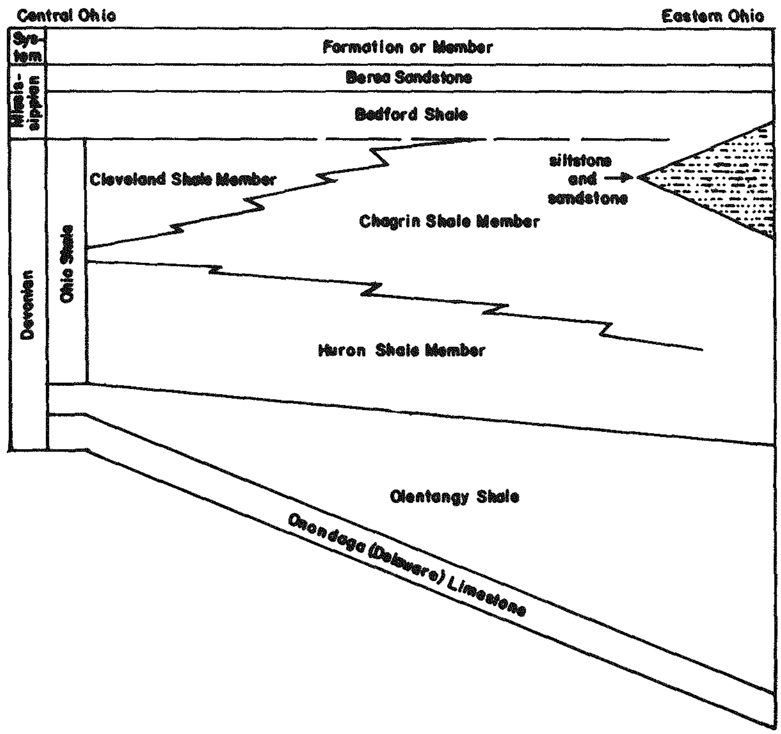


Figure 5. Stratigraphic column and schematic of the relative thickness changes of the Devonian shales in eastern Ohio. After Janssens and de Witt (1976).

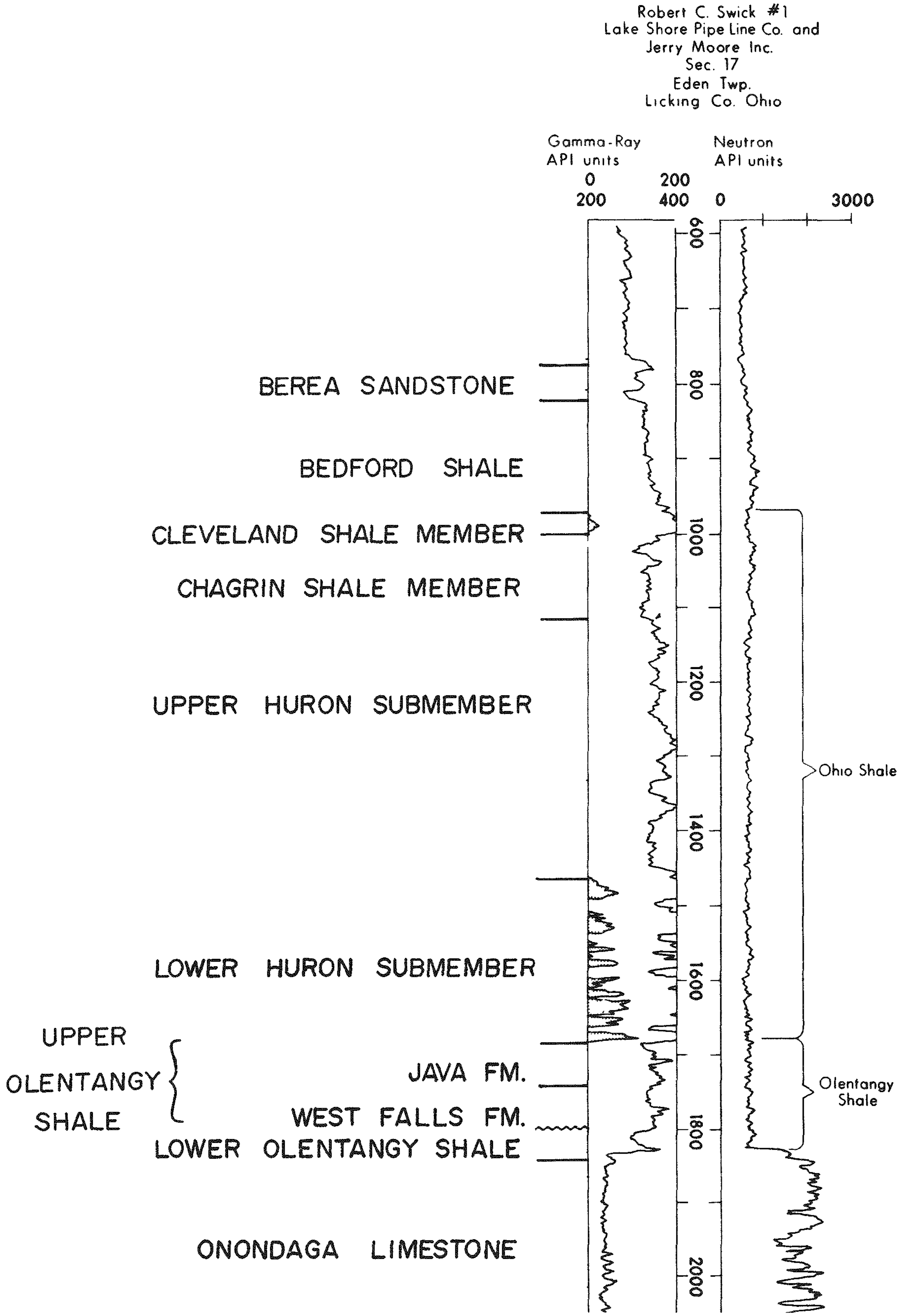


Figure 6. **Typical gamma ray-neutron log response of a well drilled through the Devonian shales in central Ohio. Modified after Schwietering (1979).**

In many areas of eastern Ohio, gamma ray logs run through the Olentangy will record two naturally radioactive shales. These units are, in ascending order, the Marcellus and Rhinestreet Shales. The Marcellus is located at the base of the lower Olentangy and has a limited presence in Ohio. The unit is thickest in Monroe County, and thins rapidly westward (Majchszak and Honeycutt, 1980a). The radioactive zone generally is absent in the central areas of the state. The upper radioactive zone is equivalent to the Rhinestreet Member of the West Falls Formation. This unit is more than 200 feet thick in eastern Ohio, thins westward, and is not present in the western areas of eastern Ohio (Honeycutt and Majchszak, 1980).

Ohio Shale

The Ohio Shale has been subdivided into the Huron, Chagrin, and Cleveland Shale Members. The Huron, exposed at its type area along the Huron River near Norwalk, Ohio, consists of about 350 feet of black shale. In the subsurface of eastern Ohio, based on gamma ray characteristics, the unit has been divided into an upper and lower submember.

As illustrated on the fence diagram, the contact between the upper Huron and the overlying Chagrin becomes undistinguishable in eastern Ohio, because of a change in natural gamma ray radiation from radioactive to nonradioactive facies in the upper submember. Consequently, the Huron-Chagrin contact is impossible to establish eastward of the upper Huron facies change.

The lower Huron Submember is distinguishable from the upper Huron by its anomalously high radioactive shale facies. The radioactive facies of the lower Huron continue much further eastward than the upper Huron, although it too undergoes a similar facies change (Majchszak, 1977).

The Huron Shale Member contains the thickest and most widely distributed radioactive shale beds in the state. In several areas of east-central Ohio, this unit is 350 feet thick (Majchszak and Honeycutt, 1980b).

The Chagrin Shale Member outcrops along the Chagrin River in Cuyahoga County and consists of greenish-gray or bluish-gray mudstone. The Chagrin is relatively thin in central Ohio, but, as illustrated on the fence diagram, thickens eastward. In the subsurface, the Chagrin is predominantly a gray to greenish-gray shale containing interbedded siltstones. These eastern Ohio siltstone beds represent the distal fringes of thicker prodelta marine clastics (slope turbidites) that are located in parts of New York, Pennsylvania, and West Virginia.

Within the upper part of the Chagrin, there is a stratigraphic marker, named the Three Lick Bed (Provo, et al., 1978), which has a distinctive lithologic sequence and characteristic gamma ray signature throughout much of the western half of eastern Ohio. Eastward into the state, the gamma ray signature becomes increasingly difficult to recognize until it is lost within the expanding Chagrin section.

The Cleveland Shale Member, in its type area along Doan Brook in Cleveland, consists of 20 to 50 feet of black shale. In the subsurface, the member parallels much of the outcrop belt across central and northeastern Ohio. Characteristically, the Cleveland is naturally radioactive. Its radioactive facies are thickest (more than 100 feet) in southern Lorain and northern Ashland Counties (Majchszak and Honeycutt, 1980c). As shown on the fence diagram, the Cleveland thins eastward and is absent in the eastern portions of the state.

Bedford Shale

The Bedford Shale is the youngest formation to be included within the Devonian shale sequence. Near Bedford, Cuyahoga County, Ohio, in its type area, the unit consists of 60 feet of red and gray shale. In eastern Ohio, the red shale facies grade laterally into gray shale and siltstone that is lithologically similar to the underlying Chagrin. Where the black shale beds of the Cleveland are not present, the contact between the Bedford and Chagrin cannot be differentiated. Close examination of Majchszak's cross sections (1980) suggests the possibility that, in some areas of eastern Ohio, the Bedford Shale is absent and the overlying Berea Sandstone may rest directly on the Chagrin. However, the Cussewago Sandstone, if present, separates the Bedford from the Chagrin.

In north-central Ohio, the basal few feet of the Bedford Shale contains the conodont Spathognathodos anteposicornis which is Latest Upper Devonian. The rest of the Bedford is Mississippian because it overlies the Mississippian age Cussewago Sandstone in Ashtabula and Trumbull Counties (de Witt, 1970). Because the Bedford is related genetically to the Berea Sandstone, Pepper and others (1954) assigned it to the lower Mississippian. Since the contact between the Bedford and Chagrin cannot be differentiated in eastern Ohio, the Bedford is included within the Devonian shales sequence.

STRUCTURE

The major structural features believed to have affected the deposition of the Devonian shales in Ohio and its bordering states are shown in figure 7. In western Ohio, the Cincinnati Arch is believed to bifurcate into the Findlay Arch, which trends north-northeast through the state, and the Kankakee Arch, which extends northwestward into Indiana and Illinois. These positive structural elements separate, in a general manner, the Appalachian, Michigan, and Illinois basins.

The shale sequence in Ohio represents part of the westward building Catskill delta deposited during middle and late Devonian time. The delta forms a clastic wedge within the Appalachian basin that extends from the Hudson River in eastern New York to eastern Ohio, and from central New York southward to northern Virginia. Although the exact location and nature of the eastern source area of the Catskill delta is not known, most geologists believe the sediments were derived from either the highlands associated with the Acadian orogeny or a stable continental land mass now separated by continental drift.

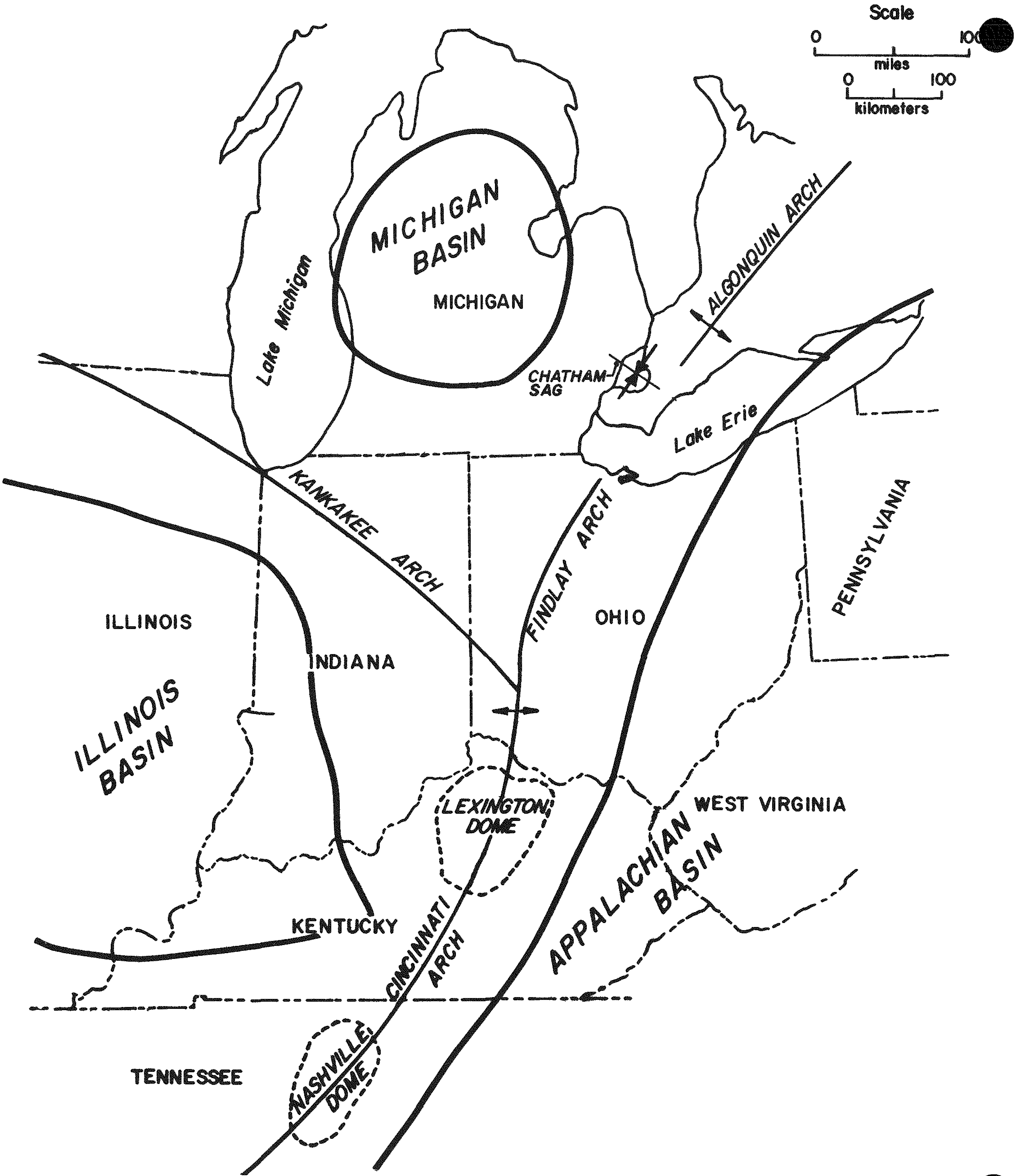


Figure 7. Major structural elements affecting the deposition of the Devonian shales.

GEOCHEMISTRY

The amount and type of organic matter and its thermal maturity are important geochemical factors affecting the gas potential of the shales. The organic content within specific stratigraphic units decreases eastward, and the thermal maturity increases in the same direction. Potter and others (1980) suggest that for each potential horizon there will be a north-south trending band of favorable shale lying between immature carbon in the west and too little carbon in the east.

Thermal Maturity

The generation of hydrocarbons from organic matter in sedimentary rocks depends largely on length and temperature of burial. The determination of vitrinite reflectance is one of the best methods of estimating the relative maturity of the Devonian shales.

Vitrinite occurs as silt-sized detrital particles within the matrix of the shales. The reflectance of light by vitrinite particles increases with increasing maturity. Particle reflectances are measured as a percentage of a known standard reflectance. A reflectance value of 0.5 is generally regarded the minimum state of maturity for a shale to be able to generate some hydrocarbons.

Vitrinite studies have been conducted on samples from several wells in eastern Ohio by Zielinski and others at the Mound Facility in Miamisburg, Ohio (table 1). As shown on figure 8, the mean thermal maturity for the entire shale interval increases in an eastward-southeastward direction within the state.

Organic Content

The amount of organic content within the shales also is an important factor affecting its potential to produce hydrocarbons. Shales with organic contents exceeding 1.4 weight percent have excellent potential as a hydrocarbon source (Ronov, 1958).

The strata-specific organic content of several shale wells has been measured at the Mound Facility and the University of Cincinnati. Although the organic content of the shales is variable, the black or darker colored shales generally contain significant quantities of organic carbon.

A map showing the organic content of the lower Huron submember of the Ohio Shale is presented on figure 9. The organic carbon decreases dramatically as the black shales grade into lighter colored equivalents in eastern Ohio.

The organic matter within the Devonian shales of the Appalachian basin is a mixture of terrestrial and marine carbon. Carbon isotope studies by Potter and others (1980) indicate that a terrestrial source of carbon predominated to the east and that marine organic matter steadily increases westward. This observation is significant since it suggests that the Cincinnati Arch was probably not emergent during much of the time when the shales were deposited.

Table 1. **Geochemistry data of Ohio wells**

Control number	Laboratory	Sample number	County	Mean R_o	Lower Huron organic carbon content (weight percent)
1	Mound	R109	Washington	0.58	2.57
2	Mound	OH 1	Carroll	0.71	-
3	Mound	OH 3	Knox	0.56	-
4	Mound	OH 4	Ashtabula	0.45	2.11
5	Cincinnati	OH-R11-4	Richland	-	6.28
6	Cincinnati	OH-DE-1	Delaware	-	-
7	Mound	OH 5	Lorain	0.37	7.94
8	Mound	OH 6-1	Gallia	0.51	2.44
9	Mound	OH 7	Trumbull	0.58	2.14

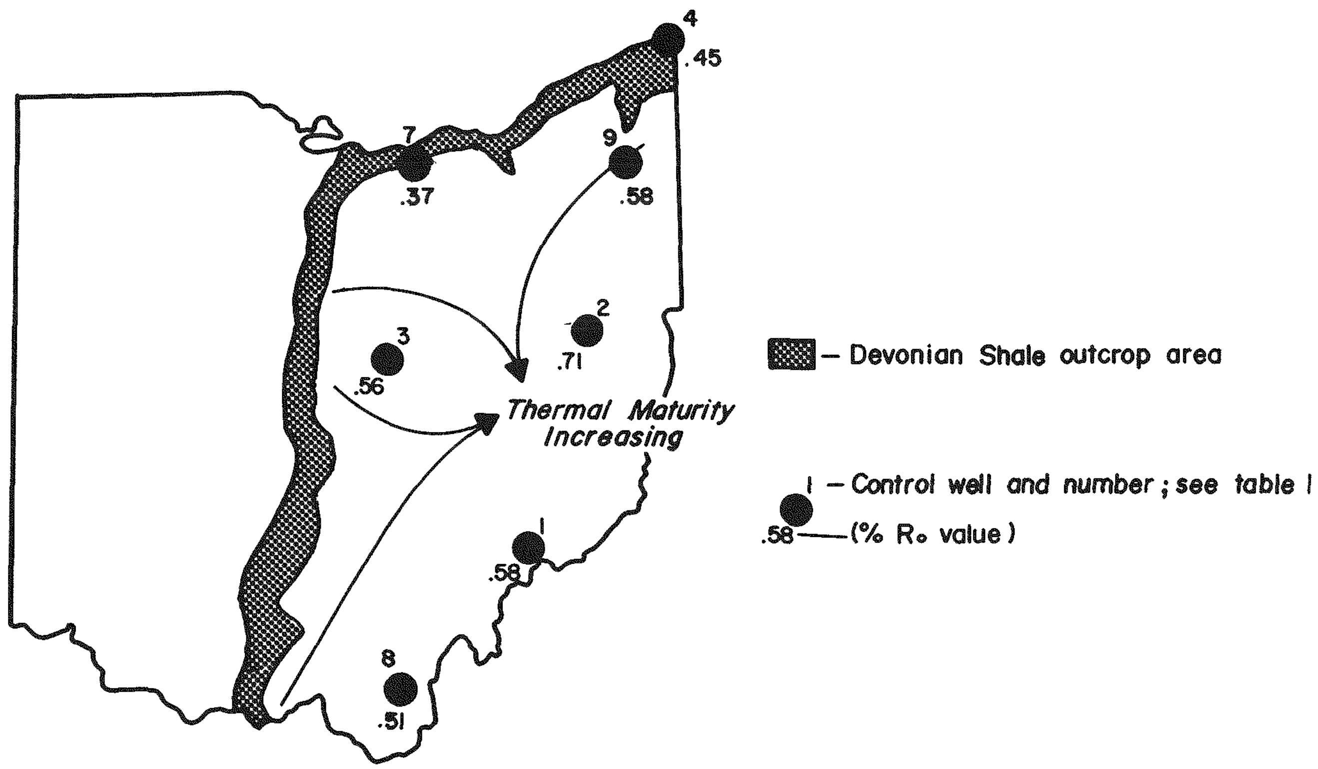


Figure 8. Thermal maturity of the Devonian shales as indicated by vitrinite reflectance.

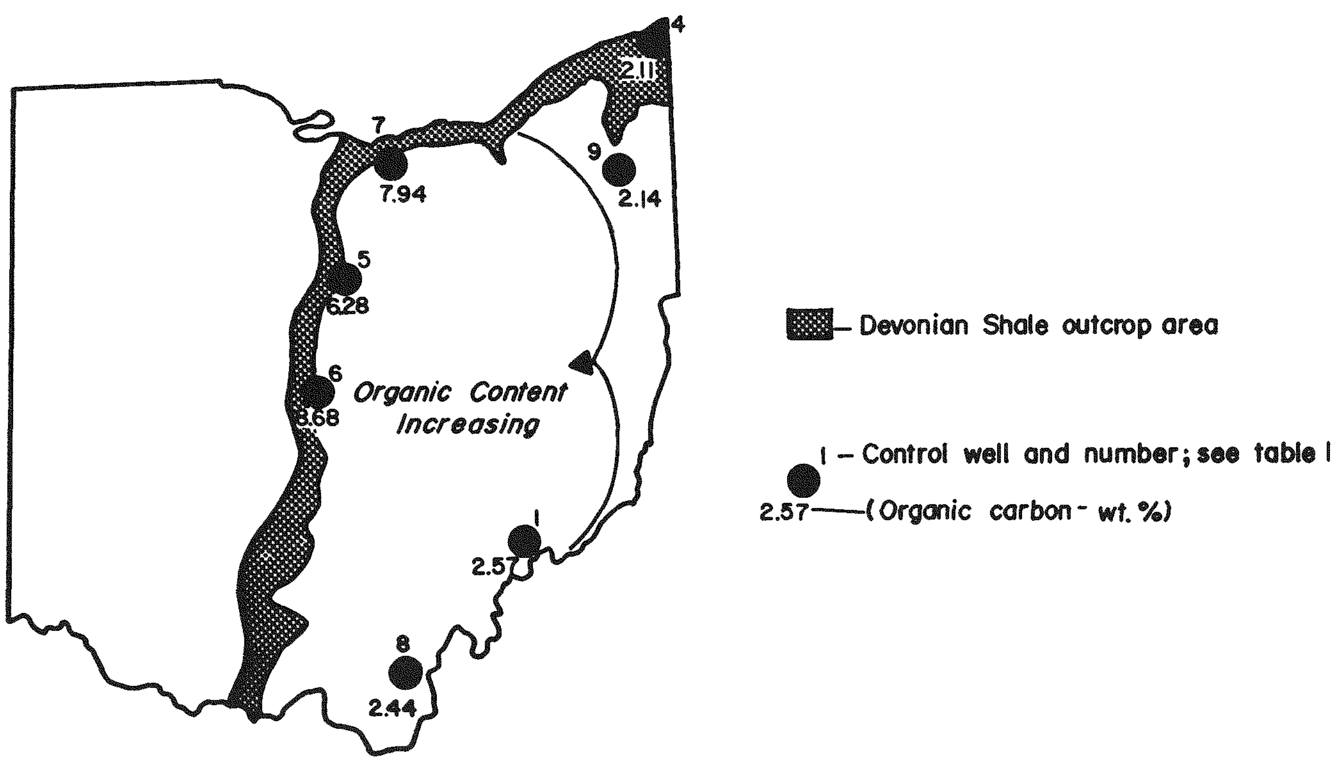


Figure 9. Distribution of organic carbon content (weight percent) in the lower Huron submember of the Ohio Shale.

Outgas Volume

The outgas volume, expressed in thousand cubic feet (Mcf) of gas per acre-foot (A-F) of shale, is a measurement of relative gas content of encapsulated samples. Although this is not a measurement of gas in place within the shale, the measurement will differentiate stratigraphic zones of high and low gas content.

Outgassing data have been compiled by the Mound Facility and are available for individual wells drilled in Knox (table 2) and Washington (table 3) Counties. In addition, data were obtained from a well drilled in Mason County, West Virginia (table 4), which borders Gallia and Meigs Counties, Ohio. As can be seen from table 3, the Washington County, Ohio data indicate an anomalously high content of gas; however, there is no reason to suspect the values since two independent analyses were performed on different sets of samples from the zones and the data were self-consistent. These data would indicate that further investigation of the Washington County area is warranted. (The R-109 well was never tested in the shale; it was cased and drilled to a deeper horizon.) (Zielinski, 1981).

FRACTURE AND PRODUCIBILITY INDICATORS

The major gas accumulations within the Devonian shales are thought to occur within closely spaced natural fracture systems and siltstone lithologies close to, or within, the organic-rich source beds. Widely scattered production, however, has been established in a variety of lithologies throughout the region. An examination of fields in several areas suggests that production is largely controlled by local factors, often related to unique geologic events that have fractured the shales.

Radioactive Shales

The dark, organic-rich, naturally radioactive beds within the Devonian shales are considered the principal source of hydrocarbons. An apparent empirical relationship exists between these shales and the occurrence of gas shows and some established production (fig. 10). The higher-than-normal gamma ray radiation observed in these dark beds is attributed to the preferential precipitation of uranium from sea water in the presence of organic matter (Swanson, 1961).

Evidence supporting this premise has been compiled by the staff of the Ohio Geological Survey through a project in which hot-wire gas detectors were installed on a number of wells in eastern Ohio. The early evaluation of this data indicates a high degree of correlation between anomalously high gamma ray log responses, shows of gas as detected by hot-wire gas detectors, and dark shales (Majchszak, 1978).

A series of maps showing the geographic distribution and net thickness of the four principal radioactive shale zones has been prepared by Majchszak and Honeycutt (1980a, b, and c, and Honeycutt and Majchszak, 1980). Ranked in order of importance, based on their distribution and thickness, these zones are the Huron, Rhinestreet, Cleveland, and Marcellus Shales.

Table 2. Outgas data—Knox County, Ohio, well control no. OH 3 (after Zielinski, 1981).

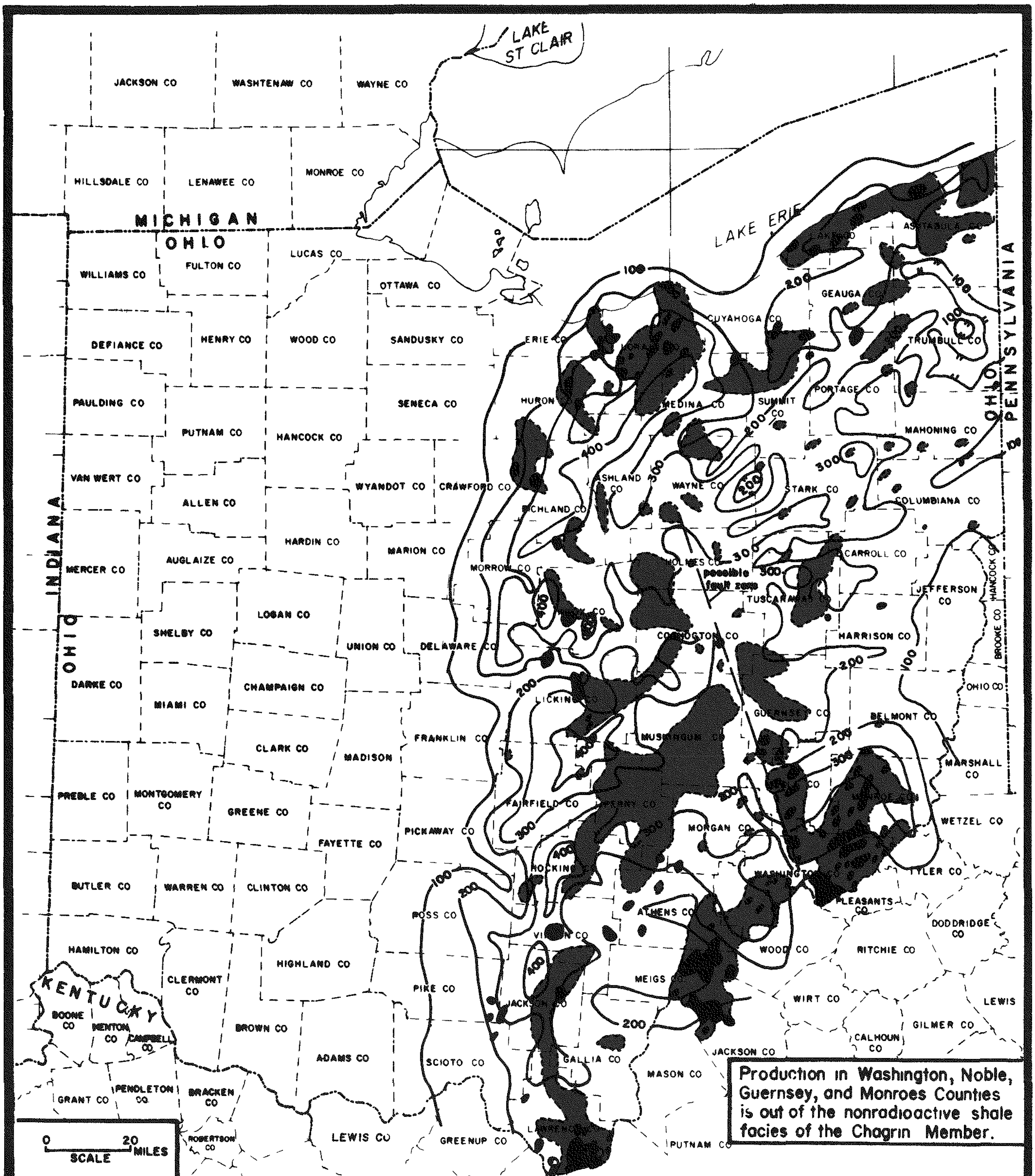
Stratigraphic unit	Interval	Thickness (feet)	Gas volume (Mcf of gas per A-F of shale)	Organic carbon (percent)
Cleveland	579-612	33	1.50	2.86
Three Lick	612-712	100	5.80	-
Huron	712-1154	443	7.80	2.73
Upper Olentangy	1154-1234	80	1.50	0.24
Lower Olentangy	1234-1251	17	3.30	0.42

Table 3. Outgas data—Washington County, Ohio, well control no. R-109 (after Zielinski, 1981).

Stratigraphic unit	Interval	Thickness (feet)	Gas volume (Mcf of gas per A-F of shale)	Organic carbon (percent)
Huron	3491-3580	89	156.99	1.09
Huron	3580-3610	30	353.71	2.86
Huron	3610-3700	90	707.41	1.02

Table 4. Outgas data—Mason County, West Virginia, well (after Zielinski, 1981).

Stratigraphic unit	Interval	Thickness (feet)	Gas volume (Mcf of gas per A-F of shale)	Organic carbon (percent)
Huron	2678-3050	372	11.05	2.43
Java	3050-3159	109	7.67	0.35
West Falls	3159-3407	248	11.26	2.50
Rhinestreet	3329-3407	78	20.38	1.27



Established production — Reported shows

Contour Interval 100ft

Figure 10. Areas of established production and shows superimposed on a map showing the combined net thickness of the radioactive facies of the Rhinestreet, Huron, and Cleveland Shales.

The manner in which hydrocarbons are contained within these organic-rich beds is reflected in the production characteristics of shale wells. Natural gas is absorbed within the organic matter and water, and adsorbed onto the mineral constituents that comprise the matrix of the rock. If natural fractures are present within the shale, the gas will desorb from the matrix and fill the fracture porosity. When a borehole cuts a fractured zone, the gas flows freely, accounting for the "flashy" show of gas that is typical of shale gas wells.

The flush of free gas generally declines rapidly, often within hours or days. The depletion of this gas causes a low-pressure sink within the fractured reservoir surrounding the borehole. The difference in pressure causes the matrix gas to desorb and slowly move toward the natural fractures and, in turn, into the well. This slow diffusion of matrix gas into the fractures accounts for the long-lived, yet low daily deliverability characteristic of shale wells. Annual production for this type of reservoir is about 10 million cubic feet (MMcf), with a modest decline throughout the life of the well.

The 14 active wells operated by the Columbia Gas Transmission Corporation in southern Lawrence County demonstrate these characteristics. Average longevity for these shale wells is approaching 40 years, and average ultimate production per well is estimated at 355 MMcf (Janssens and de Witt, 1976).

Siltstone Lithologies

In several areas in southeastern Ohio, significant quantities of gas are being produced from the siltstone beds (Gordon and Fifth Sand) within the Chagrin Shale Member. The production characteristics of these silty zones are similar to those of coarser grained clastic reservoir rocks. However, the quality of the primary reservoir characteristics (i.e., intergranular porosity and permeability) within these zones is rather poor. Production is believed to be greatly enhanced by many natural fractures within the siltstone and surrounding shale. Production data for estimating reserves in the type of reservoir are not available.

Prediction of Natural Fractures

The porosity within the matrix of the shales is generally less than 3 percent; permeability values generally are 0.005 millidarcy or less (Smith, 1978). Given these primary reservoir characteristics, the production of hydrocarbons from the Devonian shales is controlled largely by the density and openness of natural fractures within the rock. Consequently, the search for shale gas is a search for naturally fractured reservoirs.

Sophisticated geophysical methods of predicting fracture occurrence are available to oil and gas operators. Conventional aerial photography and satellite imagery are becoming reliable tools that can be used to predict jointed, fractured, and/or faulted areas. A LANDSAT lineament study of Ohio is being conducted by R. Struble and D. Hodges of the Ohio Division of Geological Survey. (The results should be available in late 1981.)

Fractured shales often are present in sequences of rocks that have been folded or faulted. For example, over basement faults, the strata flex and fracture due to tensional stress. Also, along salt pinch-outs where structural arches occur, the rocks may be fractured due to decollement-related thrust faulting. The extent of these fractured zones, however, often is localized and difficult to predict. Prediction methods include seismic analysis and detailed structural mapping on key stratigraphic horizons.

Geologists with the Ohio Division of Geological Survey have prepared detailed structural data base maps on the Packer Shell dolomite for several of the counties in northeastern Ohio. In addition, maps containing structural data for the Berea Sandstone, Onondaga Limestone, and Packer Shell dolomite are being prepared by J. Gray. These maps will be compiled on individual base maps (scale: 1:250,000) and should be published in late 1981. These structure maps, as well as the remote sensing study, will become valuable tools for future exploration in Ohio.

Fracture Gradient-Stress Ratio

Fracture gradients or stress ratios may be important indicators of natural fracture density. The stress ratio is defined as the ratio of minimum horizontal pressure caused by tectonic tension or compression to vertical pressure caused by overburden. The density of natural fractures is believed to be relatively high in areas where the stress-ratio factor is 0.3 to 0.5 (Komar et al., 1980). Figure 11 shows some areas where the stress ratio falls within this range (Komar and Bolyard, 1981).

Well Stimulation Technology

Thousands of wells have penetrated the organic-rich shale beds in eastern Ohio without encountering notable gas shows. In these areas, it is assumed the rocks have not been extensively fractured by natural forces. Much of the shale gas is thought to be in these areas, and unless an extensive fracture system can be induced artificially, much of the potential of the Devonian shales will not be realized.

"Shooting" the shale with conventional explosives has been the standard stimulation technique used in the past. Recent stimulation techniques include explosives (both solid and liquid) and hydraulic fracturing using liquefied gases and foams. Laboratory and field-oriented research has been undertaken to determine the factors affecting enhanced flows.

Hydraulically fractured wells generally are much more productive than wells shot by conventional methods. Tests suggest that foam fracturing is especially suited to the Devonian shales because of improved cleanup and reduced water damage to the formation (Komar, et al., 1980). Swelling from water-sensitive clays may be minimized effectively by using nonwetting foams.

Chemical explosive fracturing is a process in which liquid explosives are displaced into existing fractures surrounding the borehole. Detonation of the explosives extends and creates fractures (LaRocca and Spencer, 1977). Results obtained to date are encouraging, but its cost effectiveness has not been established.

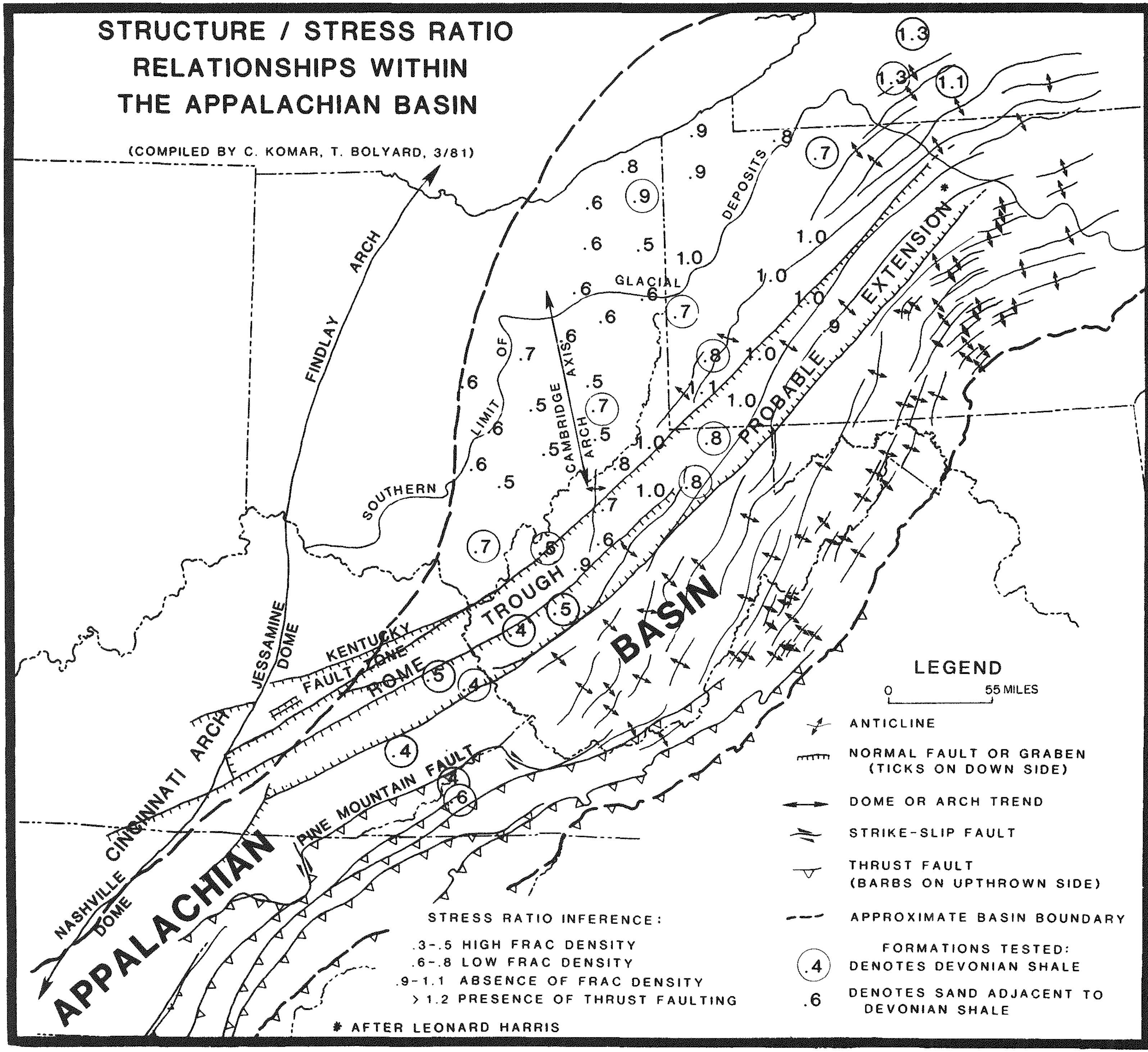


Figure 11. Structure/stress ratio relationships within the Appalachian basin. Compiled by Komar and Bolyard (1981).

GAS PRODUCTION

Based on a survey of well records filed with the Ohio Department of Natural Resources through January 1980, at least 1,249 wells have produced, or are producing, hydrocarbons from the Devonian shales in Ohio (fig. 12). This survey did not include an estimated 500 wells thought to have been completed before Ohio began keeping records, and several hundred wells completed in the Chagrin Member in southeastern Ohio in 1979. (The number of Devonian shale wells in Ohio may total 2,000.)

A map showing individual wells and fields producing from the shales was compiled by Janssens (1975). Complementing this map is a second map showing individual wells and clusters of wells with reported shows in Devonian shales (Gearheart and Grapes, 1977). Both of these maps are updated periodically and maintained in the open files of the Ohio Division of Geological Survey. A map showing areas of shale production and reported shows is presented in figure 13.

Historical

From about 1860 to 1930, hundreds of shallow wells were drilled along the shore of Lake Erie from Lorain County to the Pennsylvania line. These low-pressured wells seldom produced initial volumes exceeding 50 thousand cubic feet (Mcf) per day. However, these wells were long-lived, often supplying the domestic needs of their owners for more than 30 years.

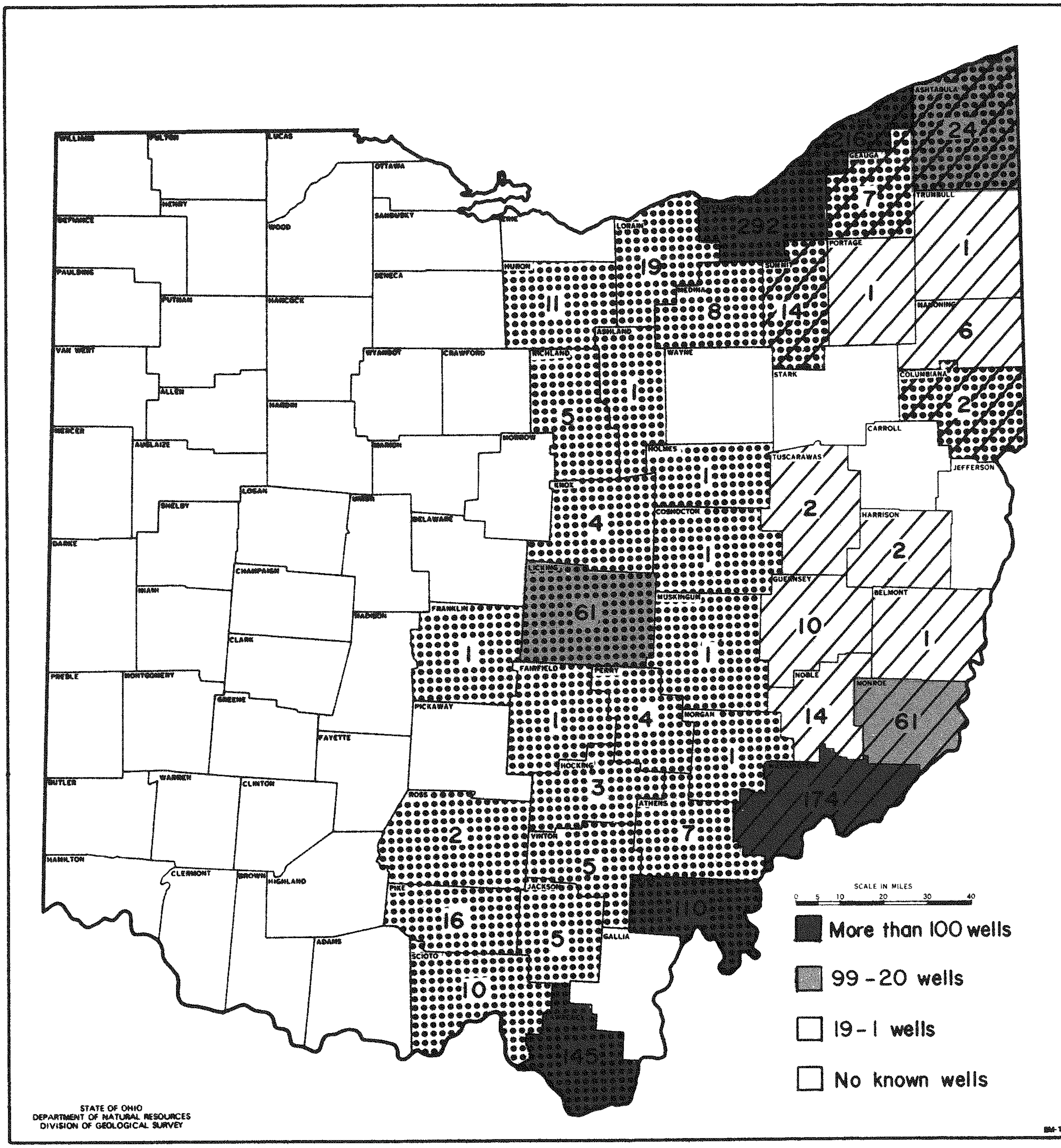
A second episode of drilling began in the 1930s, when a number of commercial shale gas wells were completed in central and southern Ohio. Significant gas fields were developed in Licking, Meigs, and Summit Counties. In southern Ohio, developmental drilling from eastern Kentucky was extended into southern Lawrence County, where more than 140 wells have been completed in the black shale beds.

In 1967, the Amerada #1 Ullman was drilled to a total depth of 11,442 feet in Elk Township, Noble County. Because the bottom zones of this well were dry, the hole was plugged back and completed in a silty zone within the Chagrin Member. After hydrofracturing, the well produced 30,000 barrels of oil and 50 MMcf of gas in 3 years. The discovery resulted in the drilling of more than 100 wells in Noble, Monroe, and Washington Counties. However, most of these wells were only moderately successful (Janssens and de Witt, 1976).

Current

Since early 1979, Washington County has been the subject of considerable drilling activity. As of October 1980, approximately 800 wells had been drilled. About 70 percent of these wells were drilled into the silty zones of the Chagrin Member. The number of successful completions, however, has not been compiled (Mychkovsky, 1980).

Most of the established production appears to be along the flank of an uplifted area northwest of the Burning Springs anticline in eastern Marietta and western Newport Townships (fig. 14). The possibility of faulting and the presence of fractures within the shale are believed to enhance productivity in this area. Production has been established in



Productive Zone

Black shales

Chagrin Shale Member

Black shales; Chagrin Shale Member

Figure 12. Map showing total Devonian Shale producing wells. Includes commercial and domestic producers. Based on State of Ohio well records through January 1980.

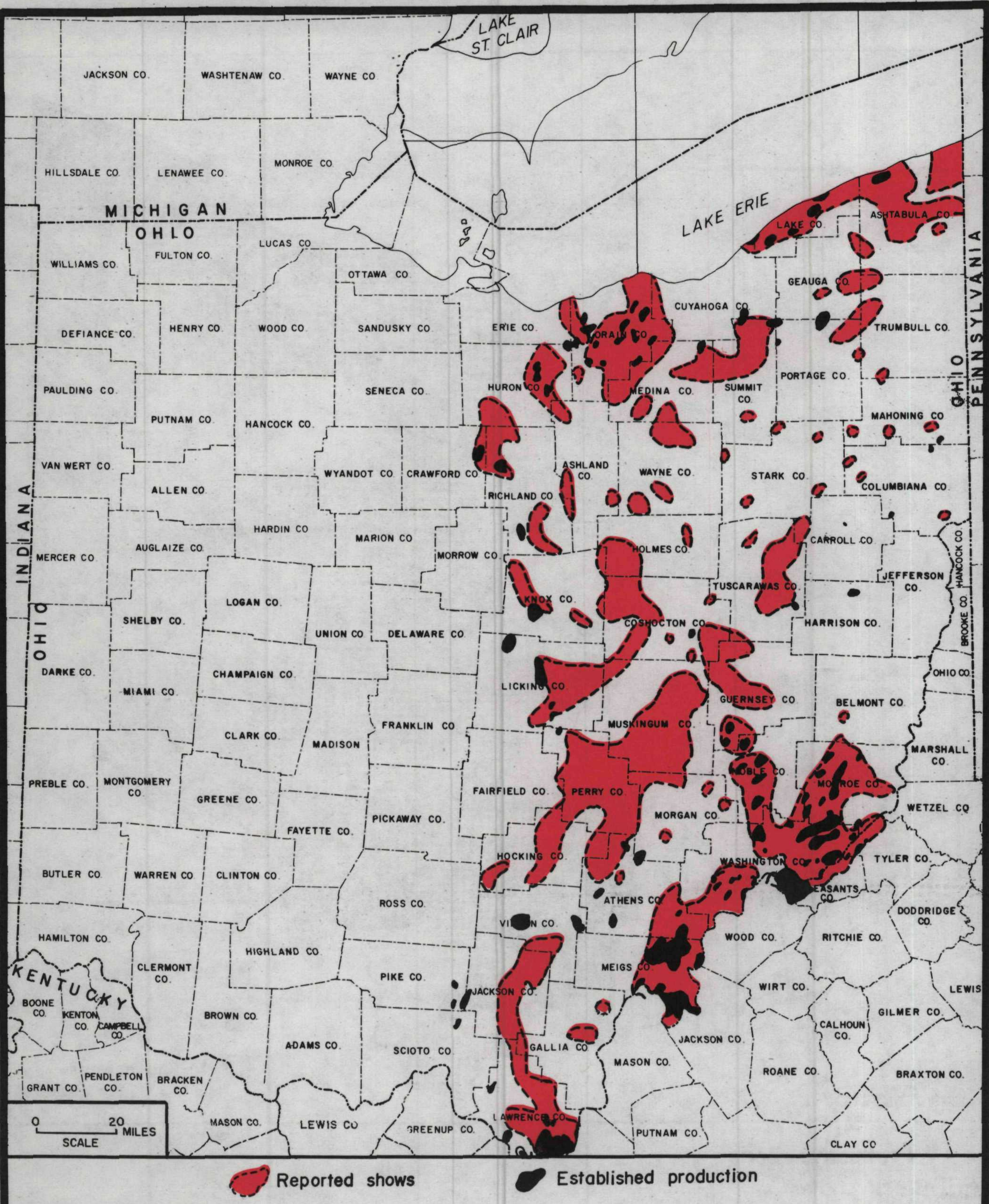


Figure 13. Areas of established production and reported shows in the Devonian shales. From Gearheart and Grapes (1977), and Janssens (1975).

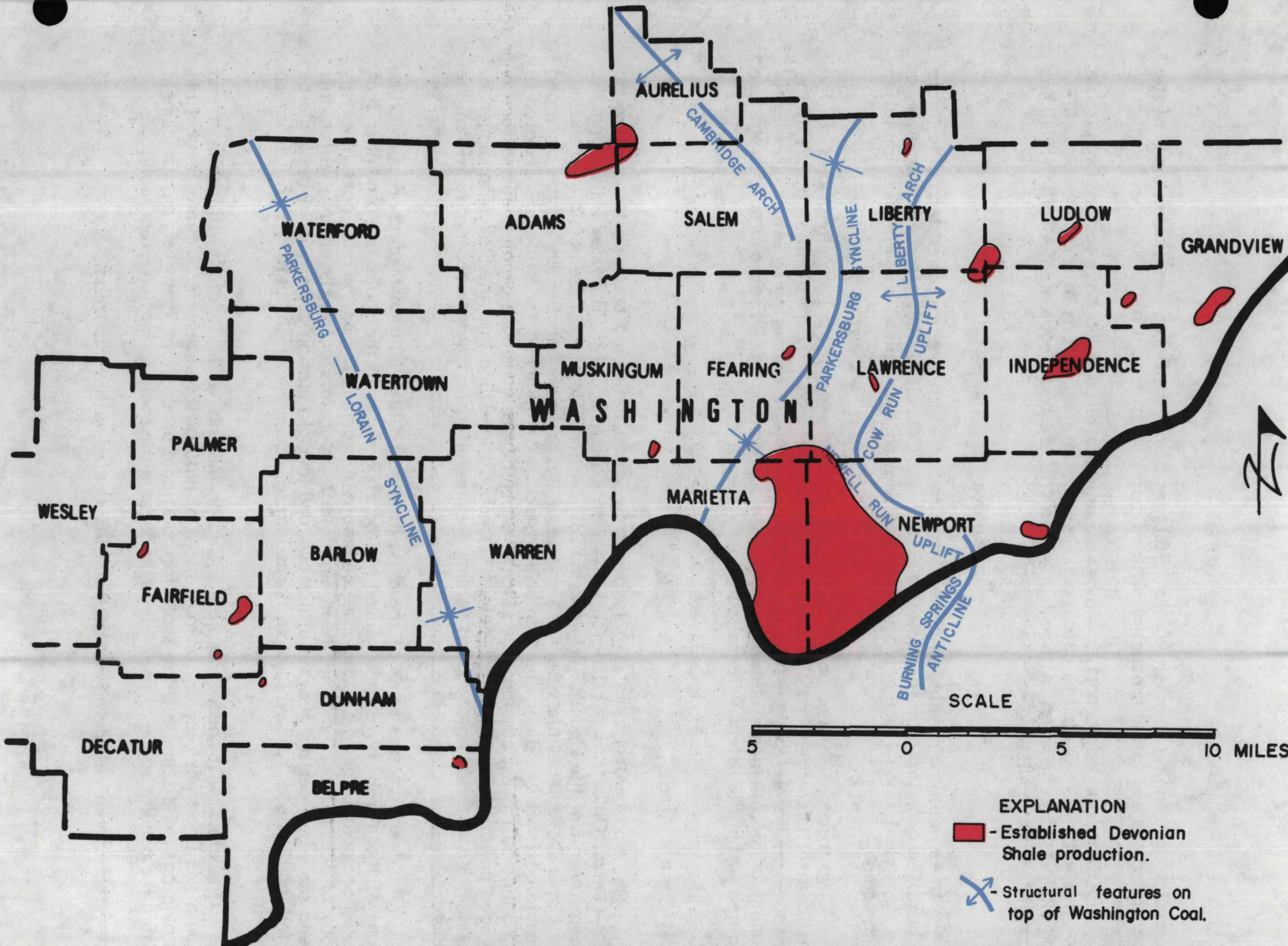


Figure 14. Areas of established Devonian shales production and structural features in Washington County. Based on State of Ohio well records through May 1980. From Honeycutt (1980), and Collins and Smith (1977).

several zones ranging between 400 to 1,700 feet below the Berea Sandstone. Many of the operators are stimulating production with advanced foam fracturing techniques.

DOE has funded, in part, a number of wells scattered throughout eastern Ohio (table 5). The wells were drilled to obtain geochemical data, as well as to test new exploration and exploitation concepts. Although the data still are being evaluated, Manilla (1980) has compiled some results.

Future

An estimate of possible in-place Devonian Shale gas reserves for eastern Ohio (table 6) has been calculated by the National Petroleum Council (1980). Recoverable reserves are dependent upon local geologic and geochemical conditions, as well as stimulation techniques.

Two trends with good potential for gas production from the Devonian shales are the east-central Ohio area and the Lake Erie shoreline area. In these areas (fig. 15), the Devonian shales are thought to have undergone extensive fracturing by either glacial off-loading or decollement-related events. Major portions of these favorable areas are located within the extensively drilled Clinton trend.

East-Central Area

The east-central area is a long narrow trend extending north-northwest through east-central Ohio from Washington County to Lorain County. The area falls along the western limit of the Upper Silurian Salina Salt section. Reservoirs are possible throughout the Upper Devonian shale sequence because of the probably decollement in the shale and associated fractures along the Cambridge Arch. Thin-skinned thrusting is postulated in the Salina Salt beds, causing a decollement surface near the base of the salt beds which ramped upward through the competent Onondaga Limestone into the Devonian sequence. Bedding plane thrusting produced folding that resulted in fracture reservoirs within the shale.

This trend crosses some of the most intensely drilled Clinton-Medina areas in Ohio. Many of these wells have encountered hydrocarbon shows in the shale, and a number that have been completed in the shale are commercial producers. For the most part, however, many of these shows have not been evaluated. Operators currently drilling within this trend should be certain that natural shows and lost-circulation zones within the shale be noted and logged for evaluation, since these occurrences indicate natural fracture systems.

Operators with nearly depleted Clinton-Medina wells located within this trend should examine their records for indications of natural fractures, since it may be possible to plug back and stimulate the shale for additional production. However, any fluids held within the annular space of the well could damage the shale formation irreparably.

Table 7 contains details on the counties located within this trend.

Table 5. Partial list of EGSP wells in Ohio.

County	Operator/Well name	Wells in program	Objective
Ashtabula	Monsanto Research Corporation Bessemer & Lake Erie Railroad Co. No. 3	1	Acquire geochemical data
Carroll	Canton Oil & Gas Glen-Gery No. 5-745	1	Acquire geochemical data
Carroll	Mitchell Energy Corporation	1	Test recompletion techniques in existing well
Gallia	Mitchell Energy Corporation	5	5-well program to test exploration rationale
Knox	Thurlow Weed & Associates Louise Beckholt No. 1	1	Test stimulation techniques and acquire geochemical data
Lorain	Columbia Gas Transmission Corporation	5	5-well program to test stimulation techniques and acquire geochemical data
Noble	Donohue, Anstey & Morrill Schockling No. 1	1	Test seismic exploration rationale
Trumbull	Tetra Tech, Inc., and Bois d'Arc Corp. W. Berg No. 1	1	Test dual completion techniques
Trumbull	Columbia Gas Transmission Corporation	5	5-well program to test stimulation techniques and acquire geochemical data
Washington	River Gas Company F. House No. R-109	1	Acquire geochemical data

Table 6. Devonian Shale resource assessment for eastern Ohio (after National Petroleum Council, 1980).

	LOG DATA			SAMPLE DATA		
	Average Thickness (Feet)	Land Area* (Sq Mi)	Total (TCF)	Average Thickness (Feet)	Land Area* (Sq Mi)	Total (TCF)
Black Shale	157	21,892	58	426	21,892	156
Gray Shale	1,442	21,892	88	1,173	21,892	72

	LOG DATA			SAMPLE DATA		
	Average Depth (Feet)	Total (TCF)	Average (BCF/Sq Mi)	Average Depth (Feet)	Total (TCF)	Average (BCF/Sq Mi)
Total Shale Resource	2,500	146	7	2,500	228	10

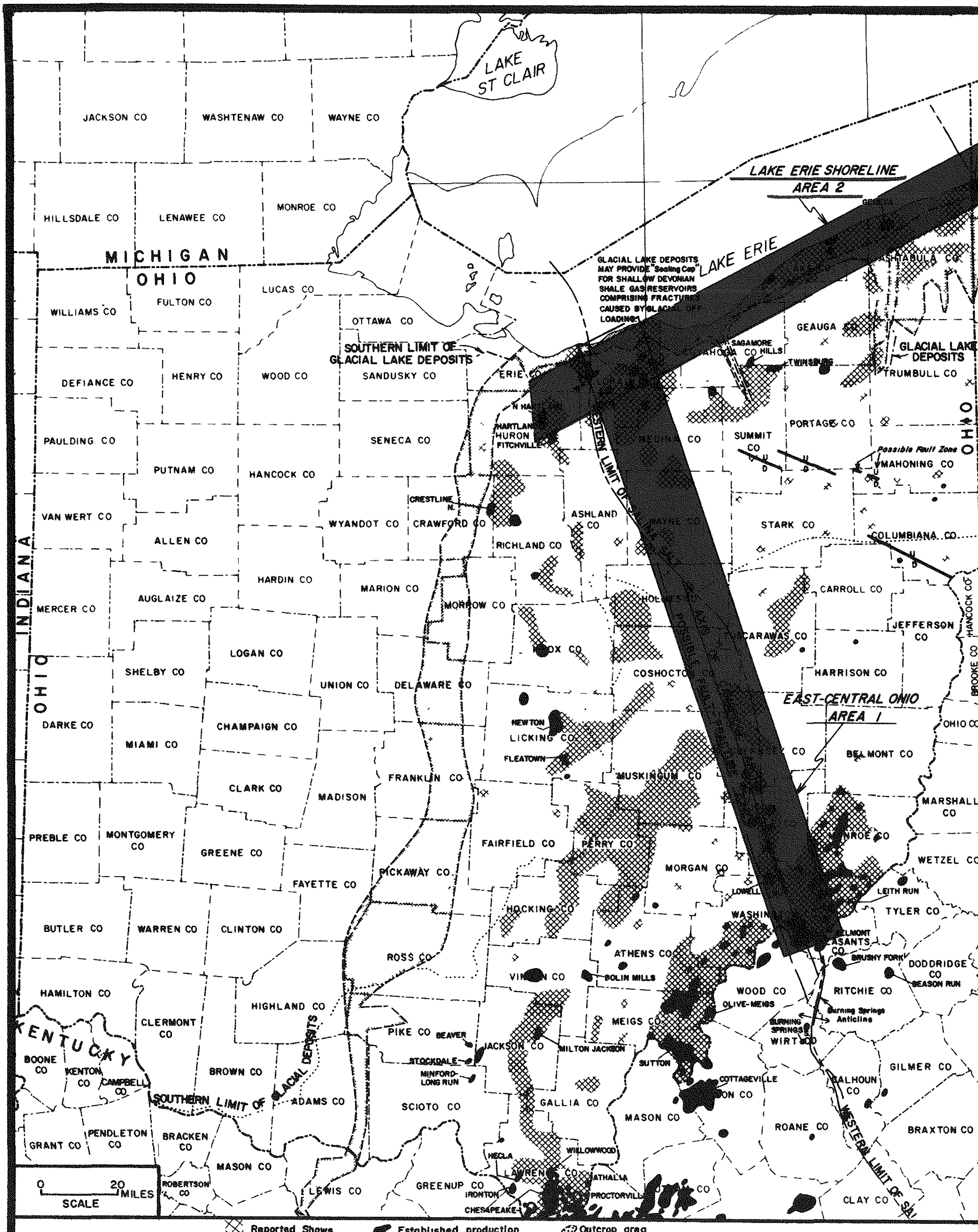


Figure 15. Map showing favorable areas for Devonian Shale exploration.

Lake Erie Shoreline Area

The Lake Erie shoreline trend is a long narrow area along the southern shore of Lake Erie from Lorain County to the Pennsylvania line. Hundreds of shallow wells were drilled into the shale within this area beginning in the early 1860s. These shale wells typically were low-pressure domestic wells with initial gas flows of 1 to 50 Mcf per day, and were long-lived.

In this trend, most of the gas-productive shales are not black, are not highly radioactive, and do not have especially low density or high porosity. Production is best related to shale types rather than source rock evaluation, burial depth, and the thermal maturity of the organic matter. Based on detailed study of the shale's lithology along the lake by Broadhead and others (1979), concentrations of gas shows were correlated to stratigraphic units that contained more than 20 percent mudshale, siltshale, and siltstone (Potter, et al., 1980). The thick quartz laminae of these lithologies are thought to act as permeable reservoirs for gas.

Gas production is probably enhanced by natural fractures caused by Pleistocene glacial on-loading and off-loading. Extension fractures are believed to have developed due to rock expansion after the removal of the glacial ice sheets. Such fractures are thought to form perpendicular to the glaciated surface. They are caused by the release of compressional forces and hence called "release fractures." The fractures occur at relatively shallow depths and are not expected to occur below 800 feet. Impermeable clays within glacial lake deposits and tills have provided an impermeable seal over the fractured gas reservoirs.

The Lake Erie shoreline trend is undergoing considerable developmental drilling to the Clinton-Medina sandstones. As expected, many of these wells are encountering shows of gas in the Devonian Shale. Preliminary investigations indicate that eastern Lorain County, Ohio, is an area with high potential for producing economic quantities of Devonian shale gas. Dual objective prospects not only include the Clinton-Medina sandstones, but also the Newburg, Knox, and sub-Knox horizons.

Table 8 contains details on the counties located within this trend.

Exploiting the Devonian Shales Through Dual Completions

In many areas of Ohio, the marginal volume of gas production obtained from shale reservoirs places an economic constraint on any developmental drilling. However, Ohio operators that are willing to include dual completions in their drilling programs could realize a low cost means of exploiting the Devonian shales in conjunction with other reservoirs. With the exception of commingling Devonian Shale and Berea Sandstone production in Washington County, dual completions are not widely used in Ohio.

The lowest-cost completion technique having the most practicality for use in the Appalachian basin is the single string, single packer configuration (fig. 16). This is a single dual completion system that allows both tubing and annulus flow, and it permits two reservoirs to be produced simultaneously, but separately, in the same well. A production packer on tubing is set between the two reservoirs. This configuration is especially applicable when the upper reservoir is long lived and flowing. An excellent opportunity to utilize this method is afforded in wells that are drilled to objectives overlying and underlying the Devonian shale sequence (Tarr, 1980).

Table 7. Counties within the East-Central Ohio Area.

County	Objective	Depth	Thickness
Washington	Chagrin	3500-5500	1700-3700
Monroe	Chagrin	4500-6000	3000-3800
Noble	Chagrin	3500-4500	2000-2900
Guernsey	Chagrin	3000-4500	2000-2700
Coshocton	Chagrin/Huron	2000-3000	1100-1800
Muskingum	Chagrin/Huron	2000-3500	1200-2000
Holmes	Chagrin/Huron	2000-3000	1100-1800
Wayne	Chagrin/Huron	1500-2000	1100-1800
Medina	Chagrin/Huron	1500-2000	900-1500

Table 8. Counties within the Lake Erie Shoreline Area.

County	Objective	Depth	Thickness
Ashtabula	Chagrin	1500-2500	1300-2200
Lake	Chagrin	1500-2000	1200-1400
Cuyahoga	Chagrin/Huron	1000-2000	1000-1500
Lorain	Chagrin/Huron	500-1500	500-1000
Erie	Chagrin/Huron	0- 500	0- 500
Huron	Chagrin/Huron	0-1000	0- 700

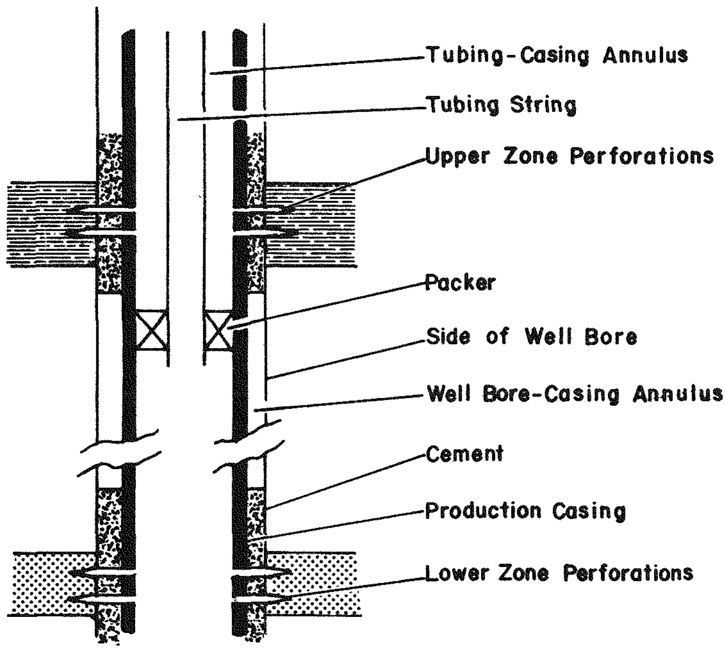


Figure 16. Schematic diagram of a single packer, single tubing dual completion.

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APPENDIX

EVALUATION OF DEVONIAN SHALE POTENTIAL IN OHIO

(Includes Documents, Logs, and Maps in the UGR Information File Concerning Ohio)

This Appendix is cross-referenced by subtopic. UGR File Accession List Numbers are indicated for each entry. The first time a particular entry appears, the complete reference is given. Subsequent references to that entry are only indicated by the UGR File Accession List Number.

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APPENDIX
EVALUATION OF DEVONIAN SHALE POTENTIAL IN THE APPALACHIAN BASIN

(Includes Documents, Logs, and Maps in the UGR Information File Concerning the Appalachian Basin)

This Appendix is cross-referenced by subtopic. UGR File Accession List Numbers are indicated for each entry. The first time a particular entry appears, the complete reference is given. Subsequent references to that entry are only indicated by the UGR File Accession List Number.

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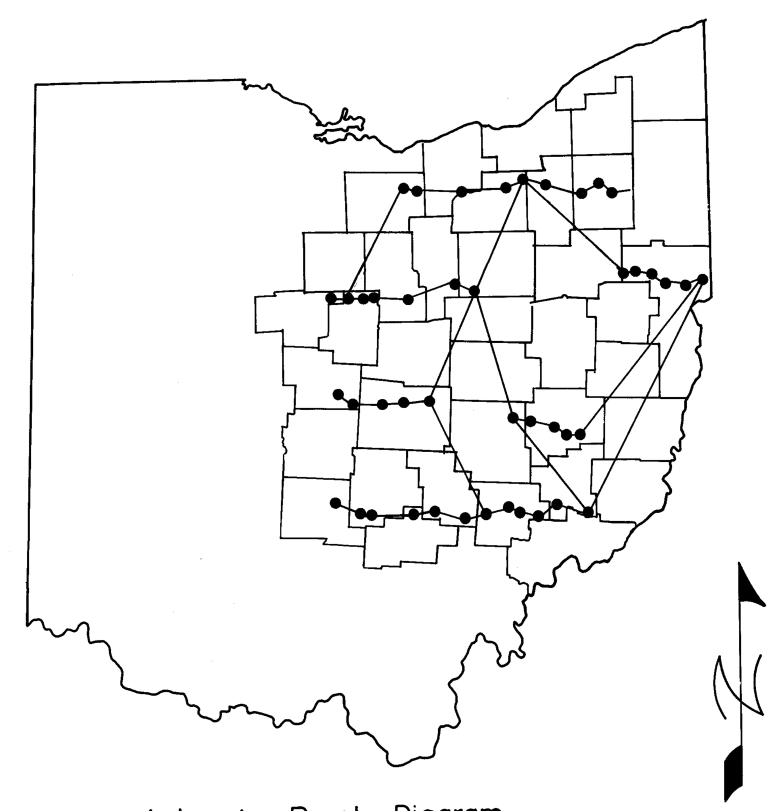

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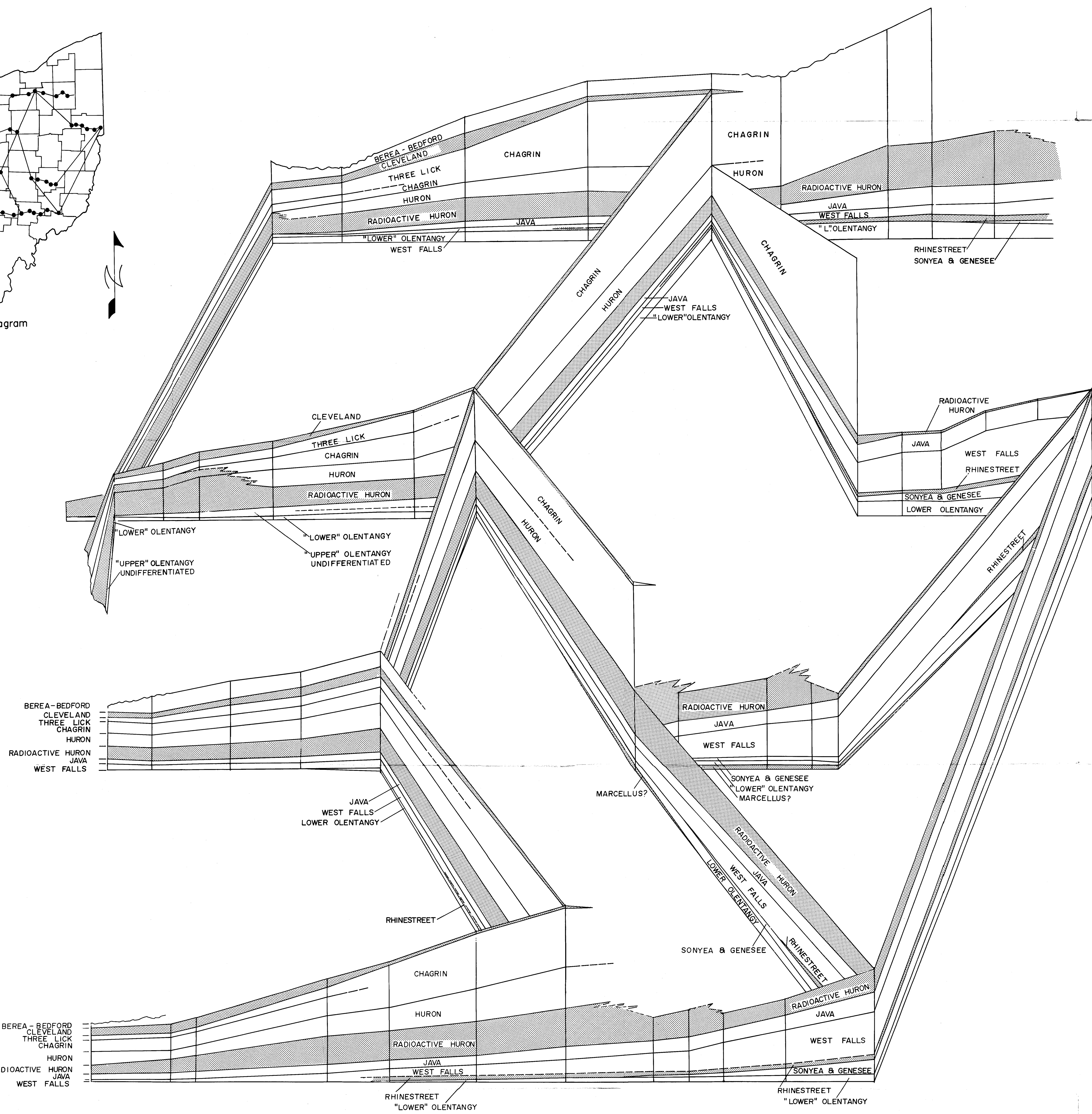

TENTATIVE CORRELATION OF ROCK UNITS AND NOMENCLATURE* USED IN OHIO AND NEW YORK

SYSTEM		OHIO FORMATION	OHIO MEMBER	NEW YORK GROUP OR FORMATION	NEW YORK MEMBER
MISSISSIPPIAN		Sunbury Shale Berea Sandstone Bedford Shale	Cussewago Sandstone		
DEVONIAN	Upper	Ohio Shale	Cleveland Shale Chagrin Shale Huron Shale	Perrysburg Formation	Dunkirk Shale
		Olentangy Shale	"Upper" Olentangy	Java Formation	Hanover Shale Pipe Creek Shale
				West Falls Formation	Angola Shale Rhinestreet Shale
				Sonyea Formation	Cashaqua Shale Middlesex Shale
				Genesee Formation	West River Shale Penn Yan Shale Geneseo Shale
	Middle		"Lower" Olentangy	Hamilton Group	
		Delaware Limestone Columbus Limestone Bois Blanc Formation	"Onondaga Lime" (Drillers' term)	Onondaga Formation	

* The nomenclature in this report is that accepted by the Ohio Division of Geological Survey and does not necessarily conform to U.S. Geological Survey usage.

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EXPLANATION

Predominantly radioactive shale facies.

Vertical Scale: 1 inch is equal to approximately 400 feet

TETRA TECH INC.
ENERGY MANAGEMENT DIVISION
COLUMBUS, OHIO

INTEGRATED PROGRAM TO IDENTIFY AND TEST THE NATURAL GAS PRODUCTIVITY OF DEVONIAN SHALE PROSPECTS IN THE APPALACHIAN, MICHIGAN AND ILLINOIS BASINS.
FOR
UNITED STATES DEPARTMENT OF ENERGY
MORGANTOWN ENERGY TECHNOLOGY CENTER

FENCE DIAGRAM OF THE DEVONIAN SHALES IN EASTERN OHIO.

PROGRAM MANAGER: E.G. Tarr	CONTRACT NO.
INTERPRETATION BY: Science Applications, Inc.	MODIFICATION NO.
DATE: January, 1981 **DRAWN BY:** L.Y. Clements	REVISED DATE / INITIAL
CONTOUR INT: **DATUM:**	DWG. NO.

PLATE 1