STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY
Horace R. Collins, Chief

Geological Note No. 3

POTENTIAL NATURAL GAS RESOURCES IN THE DEVONIAN SHALES IN OHIO

by

A. Janssens

and

Wallace de Witt, Jr.

Columbus

1976

ODNR

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POTENTIAL NATURAL GAS RESOURCES IN THE DEVONIAN SHALES IN OHIO

by

A. Janssens[1] and

Wallace de Witt, Jr.[2]

ABSTRACT

This report considers the potential natural gas resources of the Devonian shales of eastern Ohio. Under cover of younger rocks these shales increase in thickness eastward from less than 500 feet near the outcrop in central Ohio to more than 4,000 feet in Jefferson County. Their base, exposed in central Ohio, decreases in elevation eastward to more than 4,300 feet below sea level in Belmont County.

Commercial (perhaps marginally so) production of gas has been obtained from the dark-colored portions of the shales in several areas in eastern Ohio, where representative wells have produced about 350 million cubic feet of gas each in 40 years. Gamma ray log cross sections show the stratigraphic and geographic distributions of four major radioactive zones, consisting principally of black and dark-brown shales, found in the Devonian shale sequence. Both oil and gas have been produced from siltstones found in the upper part of the Devonian shales in the eastern third of Ohio.

By extrapolation from the long-established and well-documented production of natural gas in the Big Sandy field in eastern Kentucky, it is calculated that the dark-colored portions of the Devonian shales in Ohio may yield approximately 28 trillion cubic feet of gas; if the entire shale sequence is considered productive, the Devonian shales may yield approximately 67 trillion cubic feet of gas. Both estimates assume significant improvement in the production rates of shale wells through new or improved stimulation techniques.

INTRODUCTION

Impending shortages of natural gas, with the attendant threat of curtailment of supplies of natural gas to industries in Ohio and in other states in the Northeast and Midwest, have led to intensive efforts by manufacturing and processing industries to find additional supplies of gas or to replace or supplement gas purchased from natural-gas utilities. For industries that are incapable of switching to alternate sources of energy—fuel oil or coal—the alternative to private efforts to find supplemental supplies of gas is to slow down manufacturing or to shut down factories, with consequent economic and social dislocations. Recently, considerable interest has been aroused in obtaining supplies of natural gas from the Devonian shale sequence in Ohio and adjacent states. It is the purpose of this report to provide geologic and production background data on the Devonian shales in Ohio and to evaluate roughly the potential resources of natural gas in the shales.

ACKNOWLEDGMENTS

The following individuals have contributed general or specific data for this report, and we gratefully acknowledge their contribution: Gary Bachelor, East Ohio Gas Co.; Porter J. Brown, Columbia Gas Transmission Corp.; Philip Jenkins, Kentucky-West Virginia Gas Co.; T. P. Sanders, Management Control Corp.; R. W. Smith, Columbia Gas Transmission Corp.; and E. N. Wilson, Kentucky Geological Survey.

DEVONIAN SHALES[3]

The Devonian shales of Ohio comprise the dominantly shaly rocks that stratigraphically overlie the Onondaga Limestone (Middle Devonian; Delaware Limestone at the outcrop) and underlie the Berea Sandstone (Lower Mississippian). So defined, the Devonian shales include in the upper part some red or gray shale, the Bedford Shale, which may be in part of Mississippian age. For reasons discussed on page 3, the Bedford is included in the Devonian shales.

The Devonian shales are found in three areas in Ohio (fig. 1). The smallest area, the Bellefontaine outlier, is in Logan and Champaign Counties east of Bellefontaine. A second and somewhat larger area adjoins Michigan in the extreme northwest part of Ohio and includes all or parts of Defiance, Fulton, Henry, Lucas, and Williams Counties. These two areas are here excluded from consideration as

[1] Ohio Division of Geological Survey, Columbus, Ohio.
[2] U.S. Geological Survey, Reston, Virginia.
[3] 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.

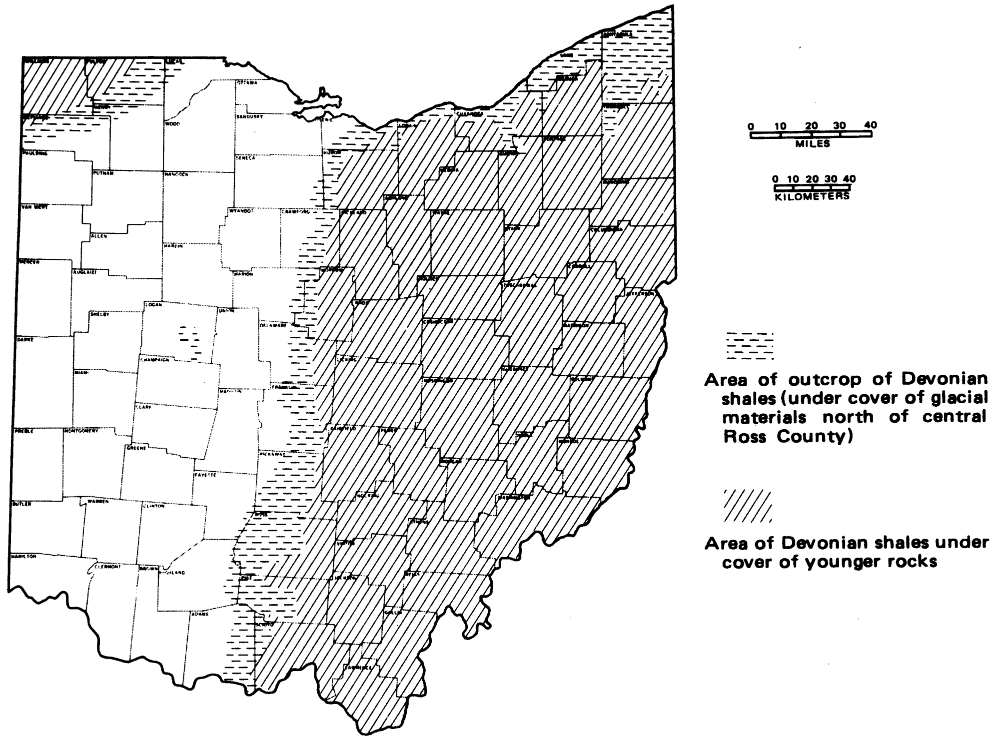

FIGURE 1.–Generalized occurrence of Devonian shales in Ohio.

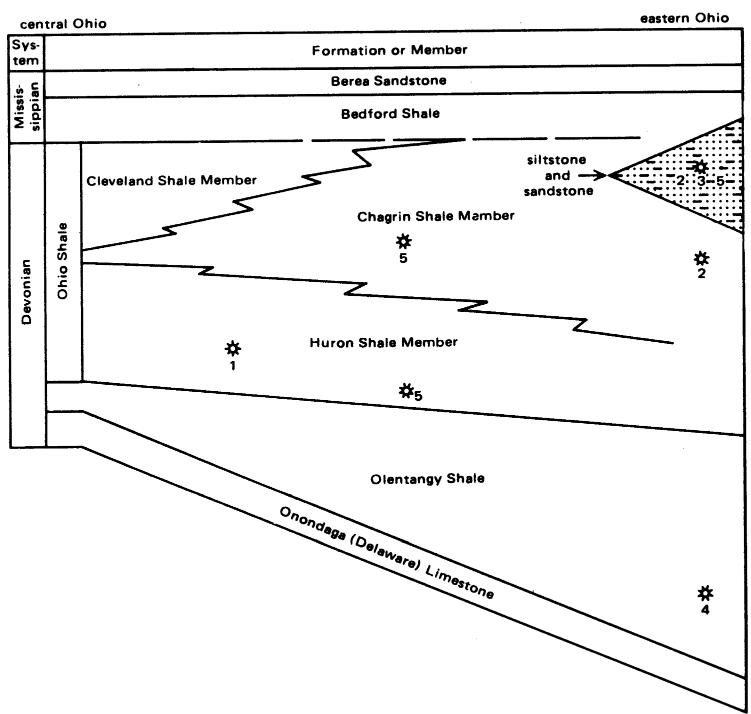

FIGURE 2.–Stratigraphic column and schematic thickness changes of Devonian shales in eastern Ohio. Lens of siltstone and sandstone shown represents the occurrence of these clastic rocks in several stratigraphic positions within the Chagrin Shale Member of the Ohio Shale as far west as Guernsey County. Gas well symbols show approximate stratigraphic position of producing zones in the following areas; 1, Licking and Lawrence Counties, 2, Noble, Washington, and Monroe Counties, 3, Mahoning County, 4, Columbiana County, 5, Summit, Cuyahoga, Lake, and Ashtabula Counties.

potential sources for large supplies of natural gas because they are relatively small and the Devonian shales are relatively thin and only partly capped by a cover of younger rocks; adequate cover is of great importance to successful hydraulic-fracturing treatments for well stimulation.

The largest area underlain by Devonian shales is east of a line from Peebles, Adams County, in the south to Sandusky, Erie County, in the north. The Devonian shales are the bedrock immediately east of this line, although north of central Ross County the bedrock is covered in many places with a blanket of glacial drift. Because the Devonian shales plunge to the east and southeast into the deeper part of the Appalachian Basin, they are found at increasing depth in a southeasterly direction and are covered by a south-easterly-thickening wedge of younger Paleozoic rocks.

The Devonian shales as defined in this report consist, in ascending order, of the Olentangy Shale, Ohio Shale, and Bedford Shale (fig. 2). The Olentangy Shale (Winchell, 1874, p. 287) in outcrop in central Ohio is a greenish-gray shale that is about 30 feet thick at its type section at Delaware, Ohio. Eastward into the subsurface the Olentangy becomes dark gray and black and thickens (Louden, 1965; Schwietering, 1970) to more than 1,200 feet. The Ohio Shale (Andrews, 1871, p. 64) is subdivided in outcrop in north-central Ohio into three members. These are, in ascending order, the Huron Shale Member, the Chagrin Shale Member, and the Cleveland Shale Member. The Huron Shale Member (Newberry, 1870, p. 18) in its type area along the Huron River north of Norwalk, Ohio, consists of about 350 feet of black bituminous shale. The Huron is overlain by the Chagrin Shale Member (Prosser, 1903), which along the Chagrin River in Cuyahoga County consists of greenish-gray or bluish-gray mudstone that is about 500 feet thick where penetrated by the drill (Cushing and others, 1931, p. 33). The uppermost member of the Ohio Shale, the Cleveland Shale Member (Newberry, 1870, p. 19, 21), is made up of black bituminous shale that in its type area along Doan Brook in Cleveland, Ohio, is 20 to 50 feet thick. The Cleveland Shale Member is overlain by the Bedford Shale (Newberry, 1870, p. 21), which in its type area along Tinker's Creek near Bedford, Ohio, is made up of about 60 feet of red and gray shale. Work by Pepper and others (1954, pl. 7) has shown that the red Bedford is restricted to the central part of the state. The formation, which does not contain fossils that permit a definitive age determination, is genetically closely related to the overlying Mississippian-aged Berea Sandstone. Pepper and others (1954, p. 13) therefore assigned the Bedford also to the Mississippian. Eastward from central Ohio the Bedford red shale grades laterally into gray shale containing a few ripple-marked siltstones inter-calated in medium- to medium-dark-gray shale. Because of the impossibility of separating in the subsurface the gray shale of the Bedford from the lithologically similar gray beds in the underlying Chagrin Shale Member, the Bedford Shale has been included in the Devonian shales in this report, although some of the Bedford may well be of Mississippian age.

The tentative relationships between the formations and members that comprise the Devonian shales in Ohio as these units are traced eastward into the subsurface are shown in figure 2. The diagram shows that the Olentangy Shale thickens significantly eastward, whereas the overlying Huron Shale Member maintains a fairly uniform thickness. The Chagrin Shale Member, which is a thin wedge in central Ohio, thickens considerably eastward and, as will be discussed subsequently, contains siltstone in its upper part in eastern Ohio. The Cleveland Shale Member wedges out eastward against the Chagrin and is absent in most of eastern Ohio (Lewis and Schwietering, 1971, fig. 3). The Bedford Shale eastward becomes indistinguishable from the under-lying Chagrin. The name "Ohio Shale" commonly is applied to the entire Devonian shale sequence in the subsurface of eastern Ohio, but in this sense the name is informal and stratigraphically incorrect. The Ohio Shale consists of only the Huron, Chagrin, and Cleveland Shale Members and does not include either the Bedford Shale or the Olentangy Shale.

The Devonian shales thicken eastward from about 400 feet in central Ohio to more than 4,000 feet in the southeastern part of the state (fig. 3), where the Chagrin dominates. Because of the southeasterly regional dip, the top of the Devonian shales dips from about 800 feet above sea level near Cleveland to about 1,500 feet below sea level in southeastern Lawrence, Gallia, and Meigs Counties (fig. 4). As a result of the eastward thickening of the Devonian shales, the base of the shales shows a greater dip to the east. The base is about 600 feet below sea level in Cleveland and descends to more than 4,300 feet below sea level in eastern Belmont County (fig. 5).

OHIO SHALE

The Ohio Shale, which makes up most of the Devonian shales in central Ohio (fig. 2), is a massive unit composed largely of brownish- to grayish-black shale impregnated by a series of complex hydrocarbon compounds called kerogen. Maturation of the kerogen in the black Ohio Shale is believed by many to have supplied the oil and gas which was trapped in the coarser grained rocks in eastern Ohio (in the Chagrin Shale Member) or farther east in the Upper Devonian deltaic sandstones of New York, Pennsylvania, and West Virginia. On exposure the black shale weathers to a mass of sharp-edged iron-stained flakes and chips. Locally in outcrop many spheroidal limestone nodules 1 to 6 feet in diameter are intercalated in the black shale. Some medium- to dark-gray shale is interbedded with the black shale, particularly in north-central Ohio adjacent to Lake Erie. Eastward in both the surface and subsurface the black facies of the Ohio Shale interfinger with and grade laterally into the gray shale and siltstone of the Chagrin Shale Member. Scant data suggest that individual tongues of black shale persist well into eastern Ohio above the Huron and Cleveland Shale Members of the Ohio Shale. Comparison of structure contours on top of the Devonian shales (fig. 4) with structure contours on top of the black shale facies (fig. 6) shows how the boundary between the black facies of the Ohio Shale and the Chagrin Shale Member steps down stratigraphically to the east across the thickening wedge of Devonian shales.

The black facies of the Ohio Shale are present throughout eastern Ohio, and sparse data suggest that they range in thickness from less than 200 feet to more than 600 feet (fig. 7). The thickness values shown in figure 7 are derived from sample studies and are the total of all beds of black shale more than 20 feet thick.

Gas has been produced locally from the black Ohio Shale, mainly along the south shore of Lake Erie and in Licking and Lawrence Counties. Many noncommercial shows of gas have been found in the Ohio Shale in wells

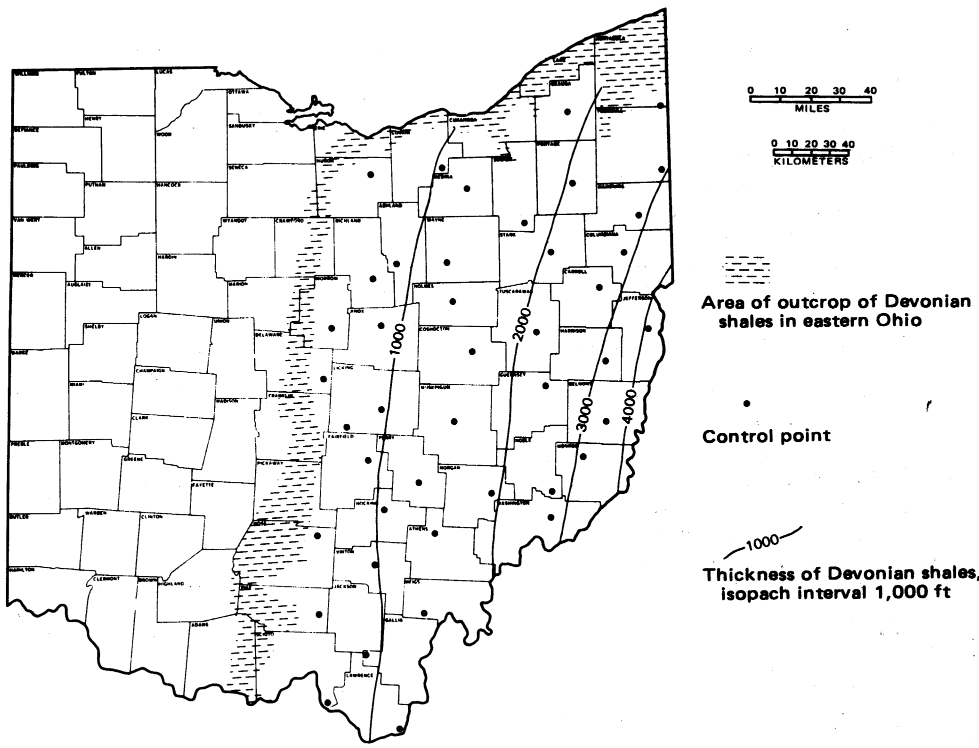

FIGURE 3.–Thickness of the Devonian shales in eastern Ohio.

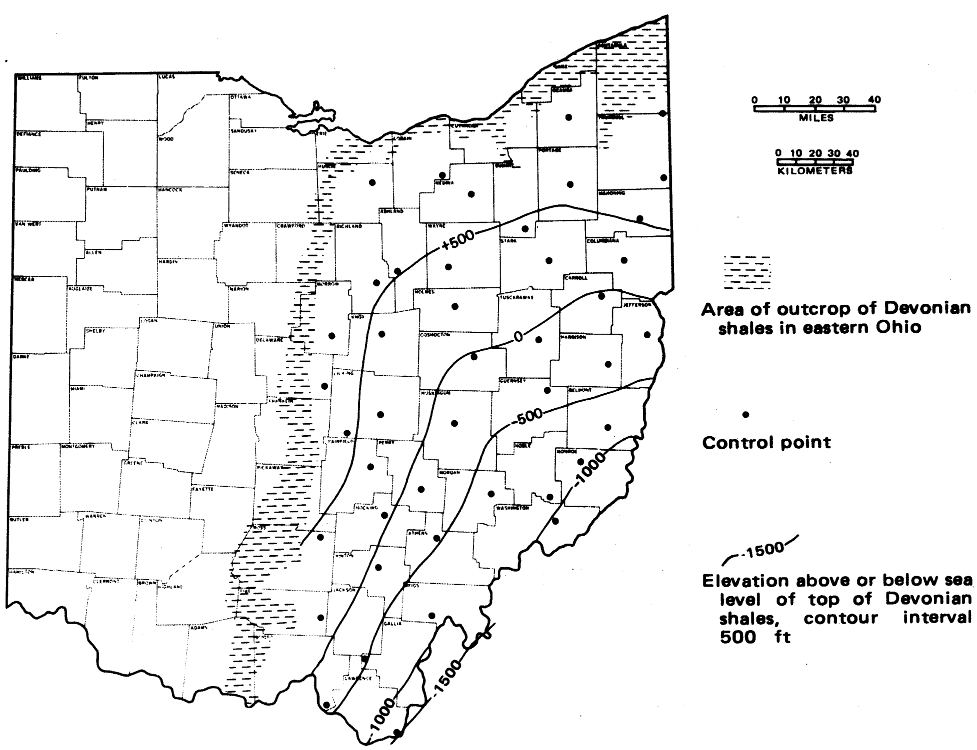

FIGURE 4.–Elevation of the top of the Devonian shales in eastern Ohio.

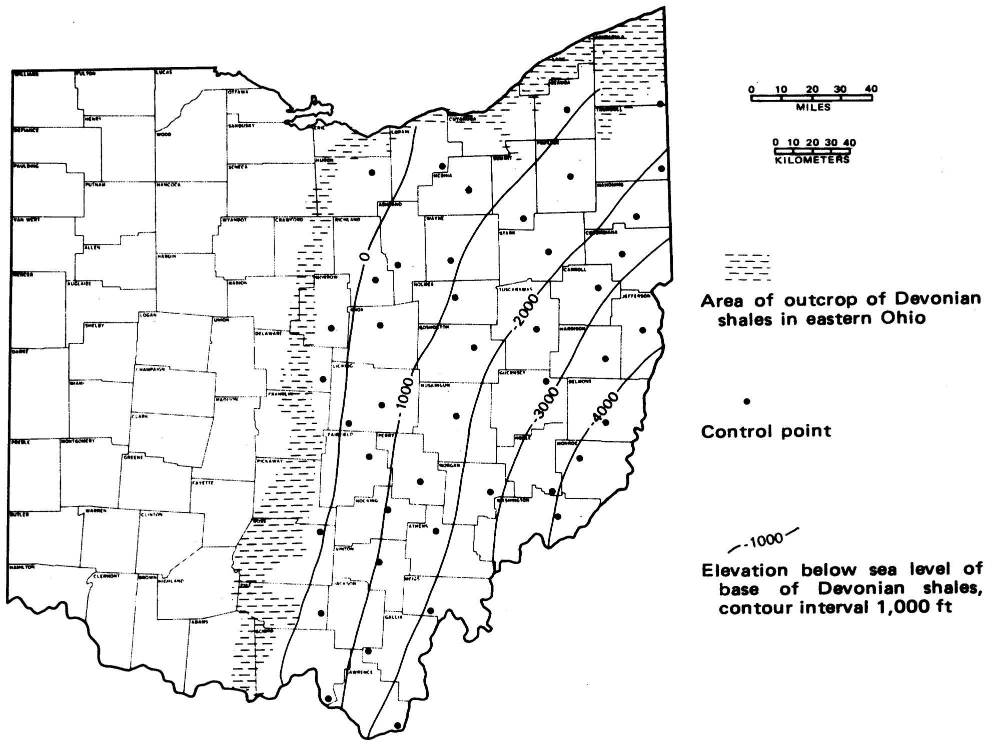

FIGURE 5.–Elevation of the base of the Devonian shales in eastern Ohio.

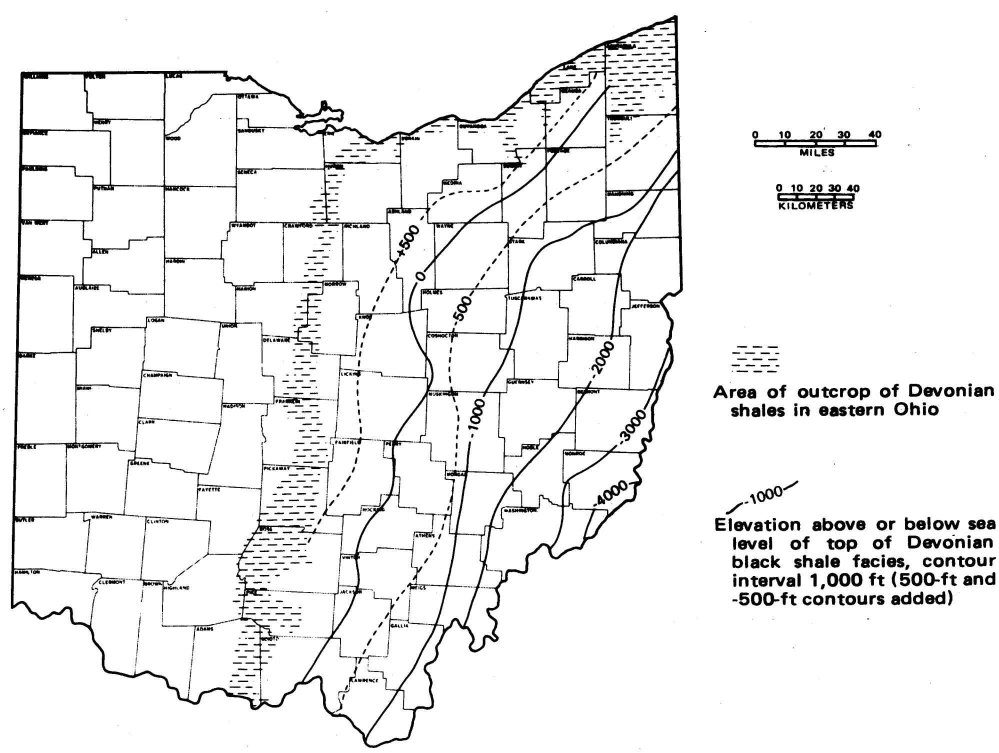

FIGURE 6.–Elevation of the top of the Devonian black shale facies in eastern Ohio.

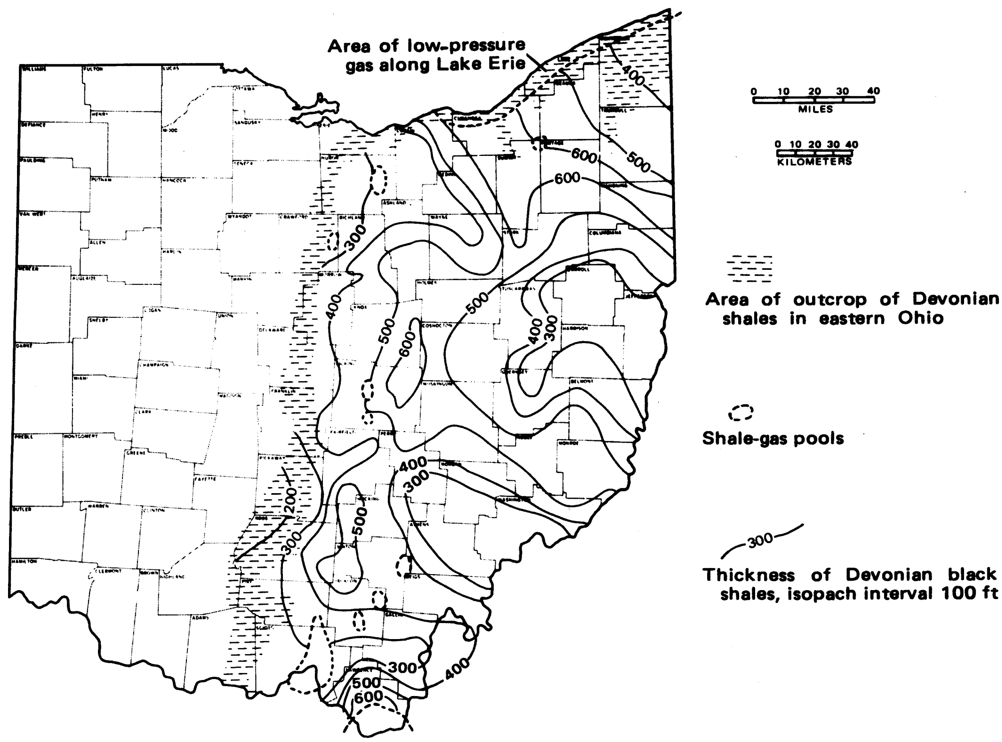

FIGURE 7.—Thickness of the Devonian black shale facies in eastern Ohio. Data on shale-gas pools from Wallace and de Witt (1975).

drilled to the "Clinton" sandstone in central Ohio.

SILTSTONES OF THE CHAGRIN SHALE MEMBER

Although the gray shale, mudstone, and siltstone of the Chagrin Shale Member make up considerably more than half the Devonian shales in much of eastern Ohio, the formation is exposed only in the northeastern part of the state, mainly in Ashtabula, Cuyahoga, Lake, and Trumbull Counties. In outcrop, the Chagrin is composed largely of medium- to light-gray mudstone or shale with some interbedded ripple-marked light-gray siltstone and a scattering of ovoid to discoid limestone concretions 3 to 8 inches in diameter (Cushing and others, 1931, p. 34). Individual tongues of siltstone and very silty shale range in thickness from a few inches to more than 30 feet and thicken eastward; the most massive beds of siltstone crop out in Ashtabula County adjacent to the state line. Similar tongues of siltstone are present in the Chagrin in the subsurface throughout eastern Ohio. These tongues are thickest in extreme eastern Ohio and tend to be concentrated in the upper part of the Chagrin. Locally in their thicker parts these tongues of siltstone contain beds of fine-grained sandstone. The tongues of siltstone in the Chagrin are the distal fringes of extensive thicker sheets of prodelta marine sandstones in New York, Pennsylvania, and West Virginia, where the sandstones have produced more than 2 billion barrels of oil and more than 8 trillion cubic feet of gas in the past 120 years. These Devonian deltaic sandstones were derived from sources on the opposite side of the Appalachian Basin from Ohio; consequently they thin and become finer grained to the west in Ohio and eventually feather out in the westward-thinning sequence of mudstone and shale of the Chagrin Shale Member. Locally gas and in places oil have been found in the thicker tongues of siltstone in the Chagrin in Ashtabula, Belmont, Carroll, Columbiana, Guernsey, Harrison, Jefferson, Mahoning, Monroe, Noble, Trumbull, Tuscarawas, and Washington Counties. The greatest concentration of productive wells has been in Washington, Noble, and Monroe Counties (fig. 8), where more than 100 wells found producible hydrocarbons in the Chagrin. To the west the tongues of siltstone are generally less than 20 feet thick and commonly lack the necessary porosity and permeability to contain commercial concentrations of oil. Nevertheless, the presence of these thin layers of siltstone in the thinning Devonian shales is important with regard to the potential production of gas because the siltstones are much more likely to have better reservoir characteristics, at least locally, than the bituminous shales of the Ohio Shale.

The great thickness of the Chagrin Shale Member in eastern Ohio is viewed by many as an important aspect of potential gas production from the Devonian shale sequence. Most reservoir beds in the Appalachian Basin are only a few tens of feet thick; only a few are several hundred feet thick. However, porosity and permeability, which generally determine the quantity of hydrocarbons present in the reservoir rock and the rate at which they may be extracted, are significantly higher for the fine-grained sandstones and siltstones in the Chagrin than they are for the black shale in the Ohio Shale, which has almost no primary permeability where not naturally fractured. The thickness of several thousand feet of Chagrin in eastern Ohio materially increases the chance of finding either thin layers or zones of layers of siltstone that are susceptible to artificial fracturing in the absence of a primary fracture system.

MAJOR RADIOACTIVE ZONES IN THE DEVONIAN SHALES

The three gamma ray log cross sections on plate 1 show graphically the significant changes in thickness and radiation patterns of the Devonian shales eastward across the state. The gamma ray log is primarily a shale indicator, although it can be used to interpret other lithologies as well. The log in a general way will differentiate between radioactive and nonradioactive shales. In the former the natural gamma radiation increases to the extent that the log trace goes off-scale, as shown in the patterned portions on plate 1. Studies of uraniferous shales have shown that dark-colored organic-rich marine shales have a higher than average uranium content relative to uranium content of lighter colored shales. The reason for this empirical relationship is that the presence of organic matter caused the preferential precipitation of uranium from the sea water (Swanson, 1961, p. 103).

As explained previously in this report, interest centers on the black and other dark-colored shales because they are believed to have been the source beds and to be the important reservoir beds of natural gas found in the shales. Because these dark-colored radioactive shales can be recognized in a general way on a gamma ray log, future studies of, and efforts to realize, the natural-gas potential of the Devonian shales no doubt will include detailed examinations of the geographic and stratigraphic distributions of the radioactive zones. It is emphasized that gamma ray logs show only average thicknesses of the radioactive zones or beds and that these thickness values in most cases will be lower than values obtained from detailed sample studies.

In the westernmost well on cross section A-A' (pl. 1), which extends from central Ohio eastward to Harrison County, three radioactive zones are found; the uppermost one probably represents the Cleveland Shale Member. The thickness and areal distribution of this member of the Ohio Shale have been mapped in eastern Ohio by Lewis and Schwietering (1971, fig. 3). Along the line of section the Cleveland can no longer be recognized near the Licking-Muskingum County line. The middle radioactive zone thins eastward and cannot be recognized beyond western Muskingum County. The middle zone in central Licking County is known to drillers as the "Little Cinnamon," "Cinnamon" being a drillers' name for a dark-brown or black shale. From this middle zone and from the underlying radioactive zone, the drillers' "Big Cinnamon," gas has been produced in Newton, Newark, and Licking Townships, Licking County. The "Big Cinnamon" persists as a recognizable zone as far east as central Guernsey County, beyond which it probably breaks up into an eastward-thickening mass of light-colored shales and interbedded thin radioactive dark-colored shales. A fourth and stratigraphically lowest radioactive zone occurs in the central part of the area of the cross section. The zone is most radioactive between Muskingum County and eastern Harrison County and disappears eastward, probably by facies change, and westward, because of depositional thinning or truncation.

Cross section B-B' (pl. 1) extends from Lawrence County northward through central Ohio to Knox County and then northeastward to easternmost Trumbull County. This section also shows four distinct radioactive zones. The

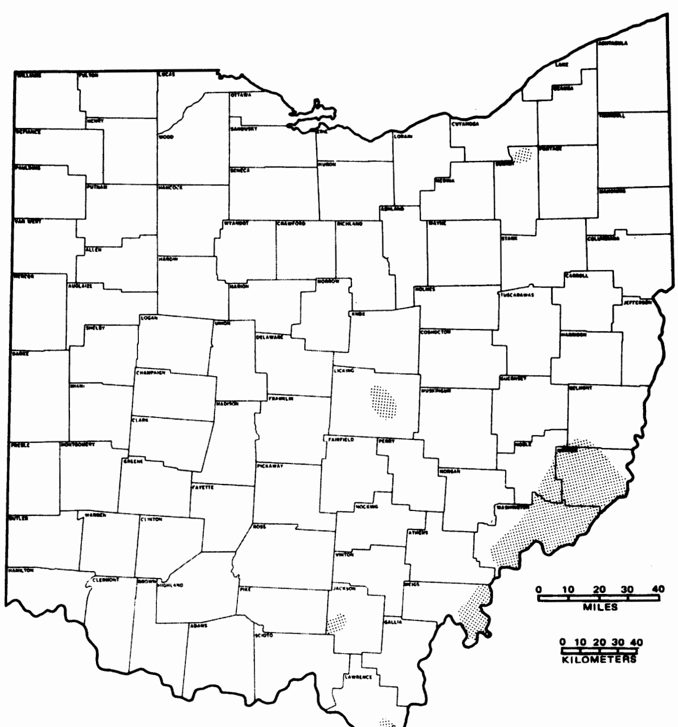

FIGURE 8.–Gas-producing areas in the Ohio Shale. More than 100 wells have been drilled in Noble, Monroe, and Washington Counties.

southernmost well shows a thin upper zone, approximately equivalent to the Cleveland Shale Member. As the zone is traced northward it thickens as the line of section traverses the depositional basin of the Cleveland Member and then thins as the section approaches the eastern edge of the basin as mapped by Lewis and Schwietering (1971). The Cleveland is absent east of central Wayne County. The second radioactive zone is 30 feet thick or less in the southern two wells, is absent, probably by facies change, in the Fairfield County well, and then thickens from Knox County through Richland County (log not shown) into westernmost Wayne County. The zone is absent along the line of section in central Wayne County and areas to the east. The zone is known in Lawrence County to some drillers as the "first Cinnamon" and, together with the drillers' "second Cinnamon," the third and in south-central Ohio the stratigraphically lowest radioactive zone, has produced gas for more than 30 years. The third zone extends with various thickness as far northeast as central Portage County, though it may be locally absent by facies change, as for example in Franklin Township, Summit County (log not shown). East of central Portage County the zone is not recognizable. As in cross section A-A', the fourth and stratigraphically lowest radioactive zone is found within the basal 300 feet of the Devonian shales and thins westward, probably by depositional thinning or truncation, into Wayne County. It is in this zone that a completion recently has been attempted in Columbiana County (p. 9). The shallow (900 to 935 feet below the surface) completions in the Youngstown Sheet and Tube Co. wells in Mahoning County (p. 9) are in siltstone correlatable with the siltstone lying 640 to 740 feet below the surface in the Trumbull County log on cross section B-B'.

The third cross section, C-C' (pl. 1), follows the Devonian shales northeastward from Lawrence County to Washington County. The well in Lawrence County is the same one shown on cross section B-B'. Northeastward the Cleveland Shale Member or its approximate equivalent thickens, possibly through facies change, but is not recognizable beyond Gallia County. The second radioactive zone (the "first Cinnamon") extends only into northeastern Lawrence County or a short distance beyond. The third zone (the "second Cinnamon") is found as far east as easternmost Meigs County, where the unit is producing gas in the eastern two tiers of townships. In the central part of the area covered by the line of cross section a fourth radioactive zone is present, but it disappears eastward, probably by facies change, and westward, probably by depositional thinning.

All three cross sections display essentially the same regional relationship. As the Devonian shales are traced eastward into the thickening section of eastern Ohio, three major radioactive zones disappear through facies change and in a stratigraphic stepdown pattern. A fourth zone, stratigraphically lowest, is found in east-central Ohio and extends farthest east, but disappears through facies change in southeasternmost Ohio.

GAS PRODUCTION FROM THE DEVONIAN SHALE SEQUENCE

At least 1,500 wells have been drilled into the Devonian shale sequence and have produced or are producing gas. Of this estimated number, 1,009 wells are documented by records on file at the Ohio Division of Geological Survey (table 1).

The history of drilling for gas in the Devonian shale sequence can be discussed conveniently in four periods. During the first period, which began about 1860 and ended about 1930, many hundreds of relatively shallow wells were drilled into the Devonian shale sequence in the counties along Lake Erie between Erie County, Ohio, and Erie County, Pennsylvania. Drilling had begun in the late 1850's in Pennsylvania and spread westward into Ohio after 1860 at about the time of the oil boom in northwestern Pennsylvania. During this first period of drilling, a small number of wells were drilled near the outcrop of the Devonian shale sequence in the central part of the state.

These early gas wells in the shale sequence, known colloquially as shale-gas wells, were typically low-pressure domestic gas wells with small initial yields, ranging from 1,000 to 50,000 cubic feet per day, but the wells were extremely long lived. Some wells produced for more than 50 years with little decrease in volume during the period. Although data are very scant, most of these wells appear to have produced from beds within the Ohio Shale, either from

TABLE 1.—*Productive shale-gas wells[1] in Ohio, by county*

County	No. wells	Productive zone
Ashtabula[2]	21	black shale; Chagrin Member
Athens	2	black shale
Belmont	1	Chagrin Member
Columbiana	1	black shale
Cuyahoga[2]	292	black shale
Fairfield[2]	1	black shale
Fulton[2]	11	black shale
Geauga[2]	5	black shale; Chagrin Member
Guernsey	3	Chagrin Member
Hocking[2]	1	black shale
Holmes	1	black shale
Huron[2]	11	black shale
Jackson	5	black shale
Lake[2]	210	black shale; Chagrin Member
Lawrence	135	black shale
Licking	55	black shale
Lorain[2]	9	black shale
Lucas[2]	1	black shale
Mahoning	6	Chagrin Member
Medina[2]	3	black shale
Meigs	70	black shale
Monroe	51	Chagrin Member
Morgan	1	Chagrin Member
Noble	9	Chagrin Member
Perry	3	black shale
Pike[2]	16	black shale
Richland[2]	2	black shale
Ross[2]	2	black shale
Scioto[2]	10	black shale
Summit	13	black shale; Chagrin Member
Washington	58	Chagrin Member

[1] Well production in this table is limited to those wells which can be documented with records on file with the Division of Geological Survey; production has been reported from Carroll, Harrison, Jefferson, Trumbull, and Tuscarawas Counties but cannot be documented with well records.
[2] Probable noncommercial production (domestic gas wells).

black shale or from thin beds of silty gray shale intercalated in the black shale sequence. The black shale undoubtedly was the source rock for the gas found in these shale-gas wells.

The second period of drilling for shale gas began in the 1930's in southern and central Ohio. Since the early 1900's much drilling to the "Clinton" sandstone, of Early Silurian age, had been done in the area between Lorain County and Lawrence County. The "Clinton" sandstone, still Ohio's chief oil- and gas-productive formation, is 500 to 1,000 feet below the base of the Devonian shale sequence in central Ohio. Apparently as the result of encouraging shows of gas in the shale sequence above the "Clinton" and, in the case of Lawrence County, successful shale drilling in neighboring Kentucky, a number of commercial, although perhaps marginally commercial at the prevailing price of gas, shale-gas wells were drilled in the 1930's in Lawrence and Licking Counties. Activity spread into other counties in Ohio, especially Meigs, but no significant pools were found beyond those in Lawrence, Licking, Meigs, and Summit Counties (fig. 8). Data suggest that these pools were producing mainly from the black facies of the Ohio Shale (fig. 2). During the second period of shale-gas drilling, several wells in the eastern part of the state found some gas or oil in the upper part of the shale sequence in the gray siltstone and shale of the Chagrin Shale Member. The W. B. McKinley #1 in Jackson Township, Guernsey County, found 150,000 cubic feet of gas and 2 barrels of oil per day in a silty and sandy zone about 400 feet below the Berea sand, and the Louise Kerr #1 in Center Township, Monroe County, for a short time in 1944 produced 250,000 cubic feet of gas and 50 barrels of oil per day from a silty zone about 900 feet below the Berea. In these and several similar wells production was short lived, and attempts to stimulate the wells by shooting with explosives were unsuccessful. Also, attempts to develop more production in the vicinity of these wells met with little success. Apparently, the lack of an adequate stimulation treatment blocked further development of shale gas in most of Ohio.

The third period of drilling for shale gas and shale oil in the Devonian shale sequence began in 1967 shortly after the Amerada #1 Ullman, the deepest well to date in Ohio, was drilled to a total depth of 11,442 feet in Elk Township, Noble County. The well was dry in the lowest part of the hole and was plugged back and completed as an oil and gas well in the Chagrin Shale Member. By the end of its third year of production, the Ullman well had produced 50 million cubic feet of gas and about 30,000 barrels of oil. Much of the success of this well can be attributed to the proper application of hydraulic-fracturing treatment to silty reservoir rocks in the shale sequence. The discovery in the Ullman well resulted in the drilling of more than 100 wells in Noble, Monroe, and Washington Counties; these wells produced from the Chagrin within the Devonian shale sequence (fig. 2). Production data are not generally available for these wells, but it appears that most wells will, at best, earn only a moderate return on the investment made.

Five shale wells were completed in the southwestern part of Scioto Township, Jackson County (fig. 8), in late 1972 and early 1973, but as far as is known these wells have been shut in.

The fourth and present period of shale-gas drilling began in 1974, when the Youngstown Sheet and Tube Co. drilled its #12 Fee well in Poland Township, Mahoning County, into the Devonian shale sequence and completed it as a gas well in a thick siltstone sequence between 900 and 935 feet (fig. 2) below the surface. The gas-productive beds lie in the upper part of the Chagrin and are probably equivalent to some of the massive siltstones that crop out to the north in Ashtabula County.

A few months prior to drilling the #12 well, Youngstown Sheet and Tube Co. had drilled and completed 15 wells in the "Clinton" sandstone in the same township and has since drilled an additional 5 wells into the Devonian shale sequence to depths comparable to the productive zone in the #12 well. As far as can be determined, this marks the first time in recent history in Ohio that a shale-gas well was drilled directly for industrial use. Personnel of the U.S. Energy Research and Development Administration (ERDA) are cooperating in this project to research and develop hydraulic-fracturing techniques most suitable for the extraction of gas from the Devonian shale sequence.

In the spring of 1975 a well drilled by Management Control Corp. to the "Clinton" sandstone in Franklin Township, Columbiana County, was dry in the "Clinton" and was plugged back to the Olentangy Shale (fig. 2). If treatment results are satisfactory, gas from the black shale in the interval between 3,700 and 3,800 feet will be used directly by local industry.

All published statements regarding the production of natural gas from the Devonian shale sequence in the Appalachian Basin agree that annual production for wells in the black facies of the Ohio Shale is commonly relatively small (on the order of 10 million cubic feet, or a daily production of about 27,000 cubic feet) and at relatively low pressures. However, production is sustained for an unusually long time. The scant data available on production from the Chagrin Shale Member of the Devonian shale sequence suggest a production behavior similar to quartzose sandstone reservoir rocks. For comparison between production from the black facies of the Ohio Shale and a sandstone reservoir rock, the daily delivery of an average "Clinton" well in Ohio is 250,000 cubic feet, with an annual production of 91 million cubic feet during the first year of productive life. Production decreases to about 125,000 cubic feet per day during the second year, and to about 75,000 cubic feet per day during the third year. The first year's flush production makes a "Clinton" well an economically profitable investment. Shale-gas wells commonly lack this flush production and therefore have not been of economic interest to the average gas-exploration company, even though ultimately shale-gas wells may produce as much or more gas than many "Clinton" wells producing from a sandstone reservoir.

Except for Kentucky, where gas is obtained from "brown" shale equivalent to the Ohio Shale of Ohio, information regarding shale-gas production in the Appalachian states is relatively scarce. A large gas field, the Big Sandy field, in southeastern Kentucky, and a small gas field, the Ashland field in Boyd County, northeastern Kentucky (fig. 9), have in recent years produced more than 70 percent of all gas produced in that state. In discussing the Big Sandy field, Ray (1972, p. 7) stated:

> Productive longevity has long been synonymous with "Shale" production. Wells with a productive life in excess of 50 years are still active. Curves relating production to rock-pressure decline are found to stabilize after the initial major pressure decline of the first few years, and then wells produce almost indefinitely at a very meager production-decline rate.

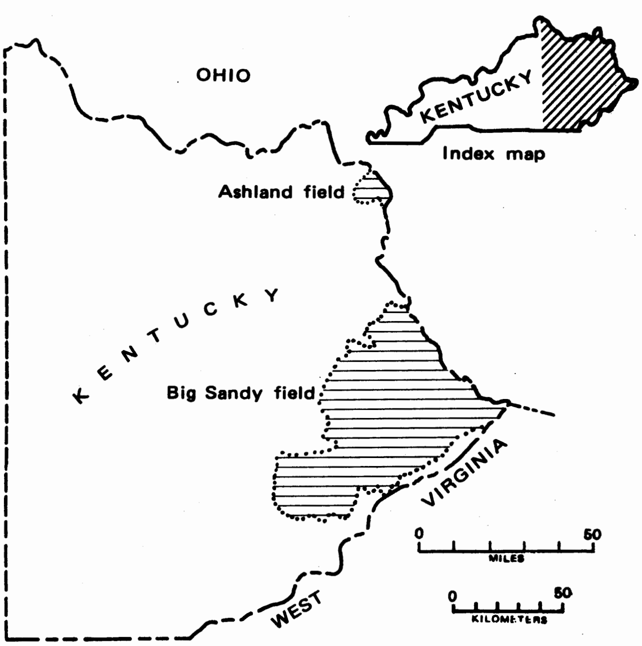

FIGURE 9.–Locations of Ashland and Big Sandy fields, eastern Kentucky.

As of 1961, a total of 4,713 wells in the Big Sandy field had produced 1.508 trillion cubic feet of gas for an average of about 320 million cubic feet of gas per well. The total ultimate recovery for the field was estimated in 1961 (Hunter, 1964, p. 26-29) to be 1.908 trillion cubic feet (405 million cubic feet per well), but in the most recent published estimate (Miller, 1975, p. 19), the figure has been revised upward to more than 2.23 trillion cubic feet. The equivalent in the Big Sandy field of the black Ohio Shale part of the Devonian shale sequence has an average thickness of more than 600 feet.

Production figures (table 2) made available by Columbia Gas Transmission Corp. for 14 of their shale wells in Lawrence County, Ohio, are comparable to those given for Kentucky. Average ultimate production per well is figured by the company to be 355 million cubic feet. Figure 10 shows the production decline curve for the 14 wells.

Few specific data are available for computation of recoverable gas resources from the Devonian shales in Ohio. If we assume that Kentucky's Big Sandy field, including the distribution of natural fractures, may be used as a model, and at this time there is no information to suggest that it is not a valid model for shale-gas production, it is possible to compute the potential production from the shales (see Appendix). If only the black or dark-brown shale is considered productive, the Devonian shales may ultimately yield 28.14 trillion cubic feet of gas. If the entire shale sequence, both light- and dark-colored portions, is considered productive, the Devonian shales may ultimately yield 67.17 trillion cubic feet of gas. At present, sufficient information is not available to resolve the question of which of these two figures is more accurate; the authors are inclined toward the lower one. In either instance, whether the entire Devonian shale sequence or only the black shale is gas productive, the resource potential is large in comparison to the total volume of gas obtained from all reservoir rocks since drilling began in the state more than 100 years ago.

Even the resource values–be they 28 trillion or 67 trillion cubic feet–obtained using the Big Sandy field as a model are small in comparison to the volume of gas obtainable if the shale could be mined and heated in retorts to convert the kerogen in the black shale to gas. Suggested volumes of gas per ton of shale range from 1,000 cubic feet (Ashley, 1917) to 1,300 cubic feet (Duncan and Swanson, 1965) to as much as 4,000 cubic feet (Crouse, 1925). Of course, these large volumes of gas are obtainable only by heating (pyrolysis) of the shale under controlled laboratory conditions. As yet no economically feasible process exists to produce such large quantities of gas from unmined shale. If we use Duncan and Swanson's (1965) reasonably modest value of 1,300 cubic feet of gas per ton of black shale, we find that the 1,675 cubic miles of black Devonian shales in Ohio provide a potential resource of 2.60 quadrillion cubic feet of gas (see Appendix). This extremely large volume indicates that here is a potential resource of great promise *if* techniques can be developed to recover it economically. The

TABLE 2.–*Production figures of 14 shale-gas wells in Lawrence County, Ohio*

Well no.	Years of production	Cumulative production (thousand CF)	Average annual production (thousand CF)	5th-year production (thousand CF)	25th-year production (thousand CF)
1	42	1,404,193	33,433	43,973	34,145
2	42	525,837	12,519	12,857	12,383
3	36	271,607	7,544	12,771	7,018
4	35	328,585	9,388	14,290	10,346
5	35	369,481	10,557	20,510	10,160
6	34	208,214	6,123	11,660	4,062
7	34	243,491	7,161	8,161	11,425
8	34	411,378	12,099	27,321	9,518
9	34	232,926	6,850	7,492	10,622
10	34	311,998	9,176	18,310	8,392
11	34	153,122	4,503	21,968	3,088
12	34	93,402	2,747	8,453	2,166
13	34	117,085	3,443	7,113	2,228
14	26	172,426	6,631	6,525	7,967

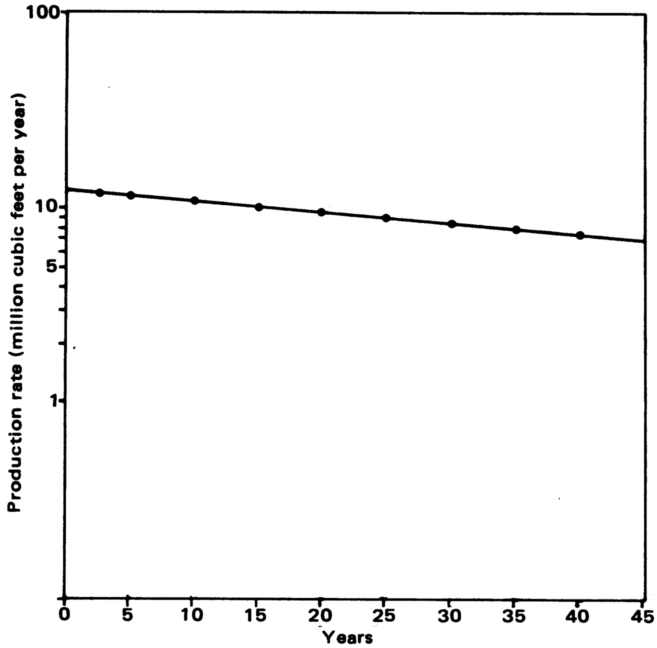

FIGURE 10.–Production decline curve of Ohio Shale wells in Lawrence County, Ohio (averaged for 14 wells).

challenge is great, but so will be the results, if and when the challenge is met.

CONCLUSIONS

Sparse data indicate that the Devonian shale sequence in Ohio has produced gas locally in relatively small volume (1,000 to 50,000 cubic feet per day) at low pressure for many years. Most of these wells were used for domestic supplies. In the past, the low yield per well made shale-gas wells unattractive commercially, except at a few localities in Lawrence, Licking, Meigs, and Summit Counties, where, for reasons that are not well understood, the volume of gas was considerably greater than average.

By using the characteristics of the gas-productive Devonian shale sequence in the Big Sandy field of southeastern Kentucky as a model for possible gas production from the Devonian shale sequence, or at least its black portion, the shales in eastern Ohio have a resource potential of 67 trillion cubic feet of gas for the entire Devonian shale sequence and 28 trillion cubic feet for the Devonian black shale facies. Admittedly the data are sparse, and much experimental work remains to be done to develop advanced stimulation techniques before these potential resources may be converted into measurable recoverable reserves of natural gas.

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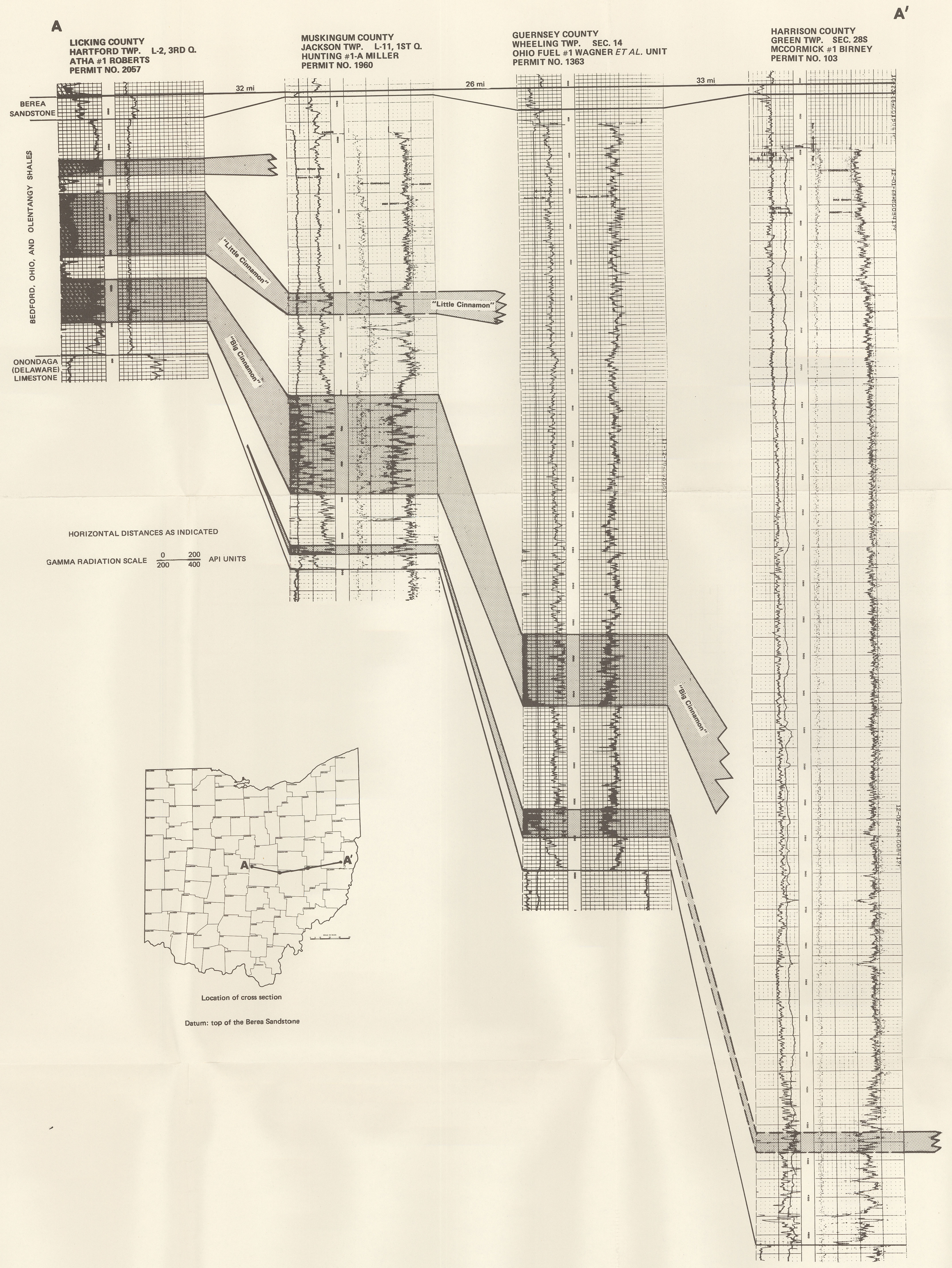
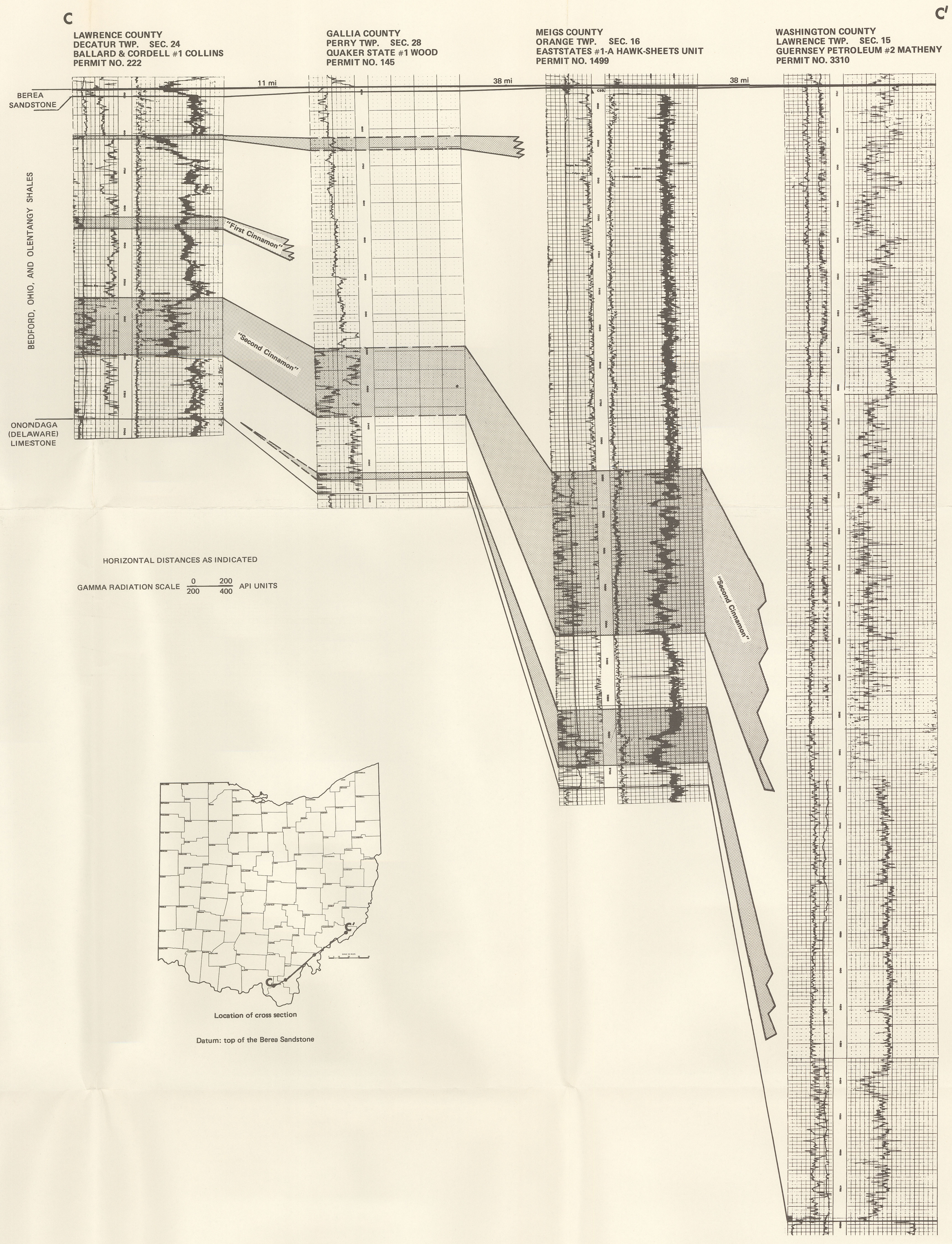
APPENDIX

COMPUTATION OF ESTIMATED ULTIMATE YIELD OF NATURAL GAS FROM THE DEVONIAN SHALES IN OHIO

Data for Kentucky:	
Area of Big Sandy field	2,150 sq mi
Volume of Devonian shale in Big Sandy field	355 cu mi
Volume of black Devonian shale in Big Sandy field	200 cu mi
Industry estimates of ultimate yield of Big Sandy field	
a) 360 x 10^6 cfg in 125 acres	2.88 x 10^6 cfg/acre
b) 320 x 10^6 cfg in 160 acres	2.00 x 10^6 cfg/acre
average yield $\left(\frac{a+b}{2}\right)$	2.44 x 10^6 cfg/acre
Total ultimate yield of Big Sandy field (2,150 sq mi x 640 acres/sq mi x 2.44 x 10^6 cfg/acre)	3.36 x 10^{12} cfg
Total ultimate yield per cu mi of black shale (3.36 x 10^{12} cfg ÷ 200 cu mi black shale)	1.68 x 10^{10} cfg/cu mi
Total ultimate yield per cu mi of all Devonian shale (3.36 x 10^{12} cfg ÷ 355 cu mi Devonian shale)	9.46 x 10^9 cfg/cu mi
Extrapolation to eastern Ohio, black Devonian shale only assumed productive:	
Volume of black Devonian shale in eastern Ohio	1,930 cu mi
Outcrop and near-outcrop volume assumed unfit for fracture treatment	255 cu mi
Volume of potentially productive black Devonian shale in eastern Ohio (1,930 cu mi - 255 cu mi)	1,675 cu mi
Estimated yield for black Devonian shale in eastern Ohio (1,675 cu mi productive black shale x 1.68 x 10^{10} cfg/cu mi)	28.14 x 10^{12} cfg
Extrapolation to eastern Ohio, all Devonian shale assumed productive:	
Volume of Devonian shale in eastern Ohio	7,100 cu mi
Estimated yield for Devonian shale in eastern Ohio (7,100 cu mi productive shale x 9.46 x 10^9 cfg/cu mi)	67.17 x 10^{12} cfg
Potential resource of black Devonian shale in eastern Ohio based upon yield of 1,300 cfg/ton (see text, p. 10):	
Weight of 1 cu ft water	62.5 lbs
Average specific gravity of 1 cu ft black shale	2.6
Weight of 1 cu ft black shale (62.5 lbs x 2.6)	162.5 lbs
Weight of 1 cu mi black shale (162.5 lbs/cu ft x $(5,280)^3$ cu ft/cu mi ÷ 2,000 lbs/ton)	11.96 x 10^9 tons
Estimated yield for black Devonian shale in eastern Ohio (1,675 cu mi productive black shale x 11.96 tons/cu mi x 1,300 cfg/ton)	2.60 x 10^{16} cfg





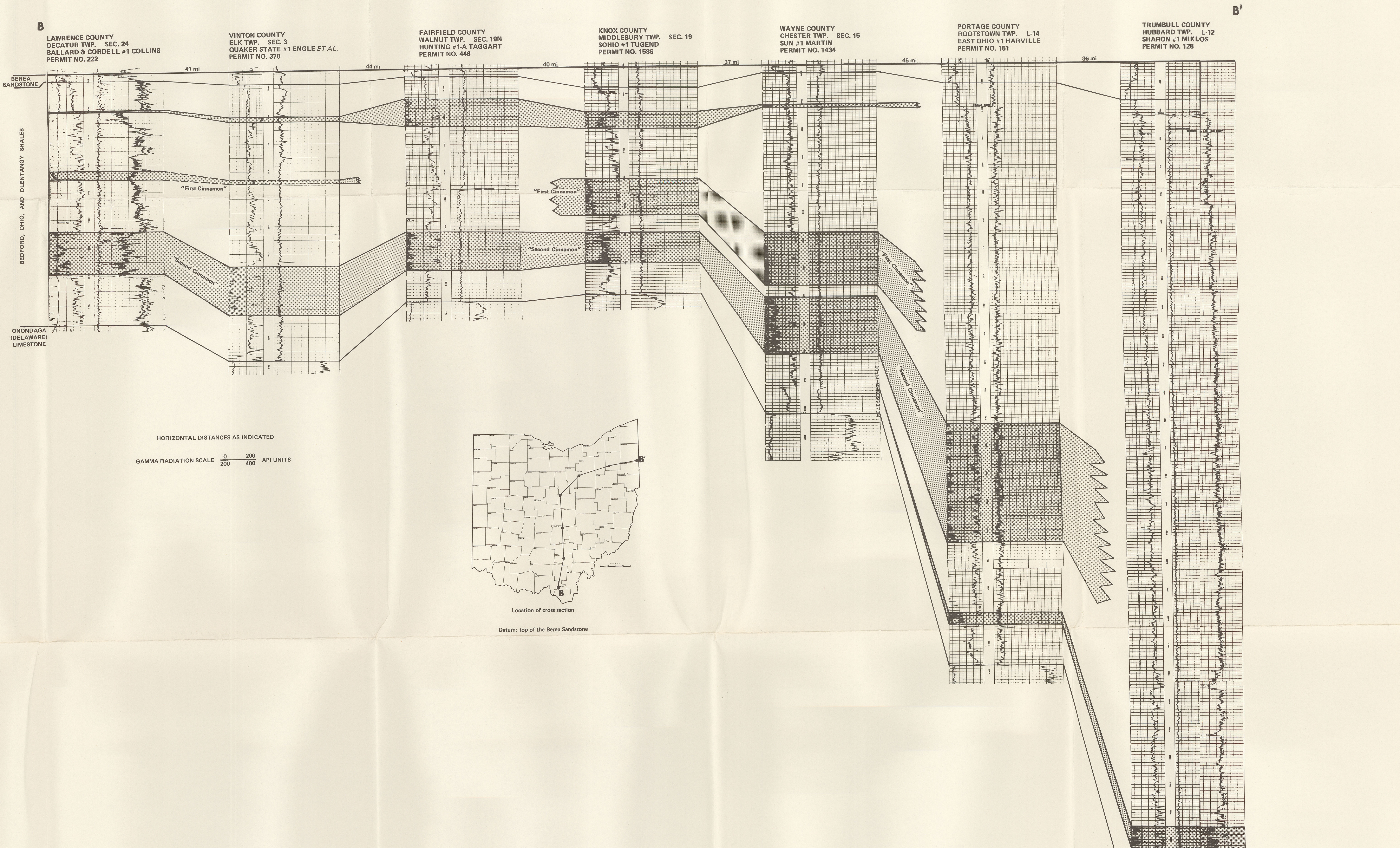


PLATE 1. GAMMA RAY LOG CROSS SECTIONS SHOWING DISTRIBUTION OF MAJOR RADIOACTIVE ZONES IN DEVONIAN SHALES IN EASTERN OHIO. A-A′, EAST-CENTRAL OHIO; B-B′, CENTRAL AND NORTHEASTERN OHIO; C-C′, SOUTHEASTERN OHIO.

Cartographer: Donald R. Camburn

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