IV. The Resource

IV. The Resource

Geographic Extent

Sedimentary rocks of the geological age known as Devonian are present in the Appalachian region from New York to Alabama, in an area of some 209,000 square miles. The region includes two geological provinces of unequal size. in the smaller of these, an eastern belt known as the Valley and Ridge province, all rocks have been so intensely folded and faulted that few geologists consider them important sources of oil or gas, although recent studies indicate that the southern part of the Valley and Ridge has considerable potential for gas production. In the larger area, the Appalachian Plateaus immediately to the west, the rocks are flat-lying or only gently folded. Furthermore, the upper part of the Devonian system of rocks in this province contains dark brown or black shale, rich in organic matter, that yields some natural gas at present and reportedly has the potential of yielding a great deal more. The area of the Appalachian plateaus is 163,000 square miles.[1] These shales are covered by younger rocks but can be readily reached by the drill, and are located in southwestern New York, western Pennsylvania, eastern Ohio, most of West Virginia, and eastern Kentucky (figure 3). In addition, Devonian dark brown or black shales outcrop at the surface or beneath a few feet of glacially deposited debris in western New York, in a belt extending from Cleveland southward through central Ohio, and in a series of disconnected outcrops in north-central Kentucky.

Terminology

The term Devonian *shales* refers to all the shale strata that lie beneath a widespread younger formation known as Berea sandstone and above an older limestone termed Onondaga or Corniferous. The shales are found in one-half dozen Appalachian States; similar strata are known in Indiana, Illinois, and Michigan. They occur in the subsurface, where they are encountered in wells, and at the surface, where they have been mapped and studied. Over time, they have acquired a variety of geographically based names: Chattanooga shale in the Appalachian States; Marcellus shale in New York; Ohio shale in Ohio; and New Albany shale in Kentucky and Indiana. In this report, these terms are considered to be synonymous.

The Devonian shales include strata that are gray, greenish gray, grayish brown, and deep brown to black. The deep brown to black shales contain much organic matter, and are locally productive of gas. In most reports, including this one, they are called Brown *shale.* It is important to keep in mind the distinction between the whole thickness of Devonian shales and those parts—the Brown shale—that are richer in organic matter and of greater interest as a source of gas.

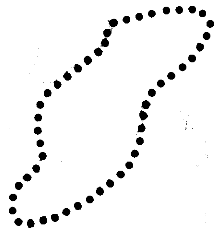
Origin

The position of the Devonian shales in the Appalachian Basin, and their relation to other rocks, can best be understood by looking briefly at their origin. To do this, it is necessary to erase one's mental image of present-day Appalachian geography for a moment and substitute Late Devonian geography of some 350 million years

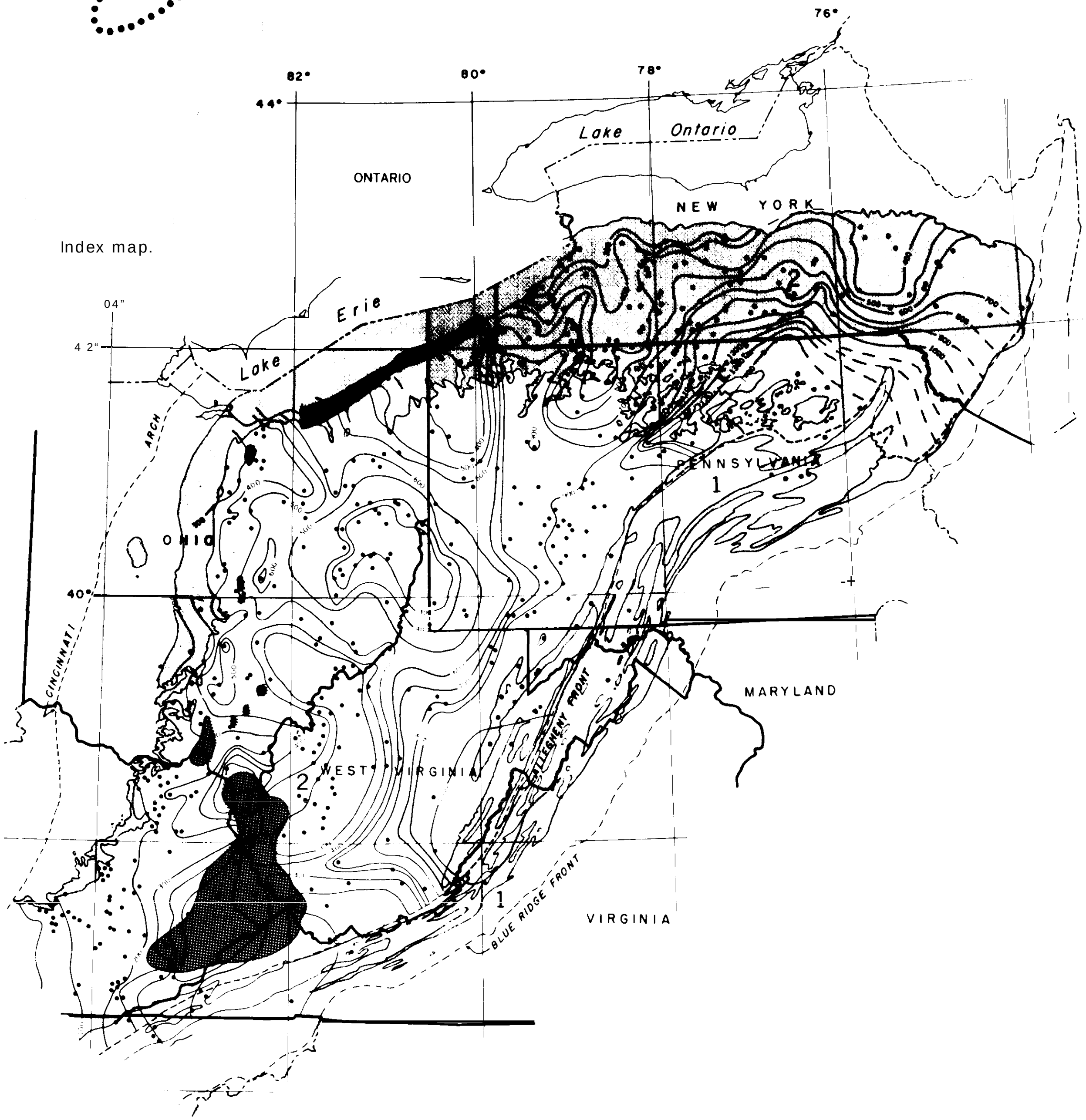
NOTE: All references to footnotes in this chapter appear on page 27.

Figure 3. The Appalachian Basin

In gray areas Devonian rock outcrop at the surface. Numbered lines give total thickness of all beds of Brown shale in the Devonian shale sequence. In cross-ruled areas gas has been or is being produced from Brown shales. (From deWitt et al., 1976, U.S. Geol. Survey Map I-917 B)



Index map.



ago. To the east of the region shown in figure 3, in a position roughly parallel to that of the present-day coastline, was a lofty range of mountains. Erosion of these mountains produced immense volumes of mud, silt, and sand, which were carried westward by streams and deposited in a great compound delta, the Catskill Delta. The Delta was built out into a seaway that covered parts of what is now the Appalachian Basin. In this sea, black organic-rich muds accumulated. The Devonian shoreline was not fixed: at times the sea level rose and marine muds were spread across the seaward parts of the Delta; at other times deltaic sands and silts flooded westward into the seaway, displacing the shoreline far to the west. As a result of these fluctuating conditions, the Brown shale interfinger to the east with much thicker and coarser deltaic rocks (figure 4). To the west, the black-mud bottomed sea was at times restricted by a lowland area termed the Cincinnati arch, and at other times it flooded across this feature to merge with seas in the Michigan basin and the Illinois basin. Although Brown shale deposition of Late Devonian time was not restricted to the Appalachian Basin, this region appears to be most important from the viewpoint of potential gas supply. In the long stretch of geologic time since the Devonian period, both the deltaic rocks and the shales have been buried by younger sediments. Around their edges they have been partially uncovered by uplift and erosion, but they remain under cover of younger rocks in much of the Appalachian Basin.

Thickness

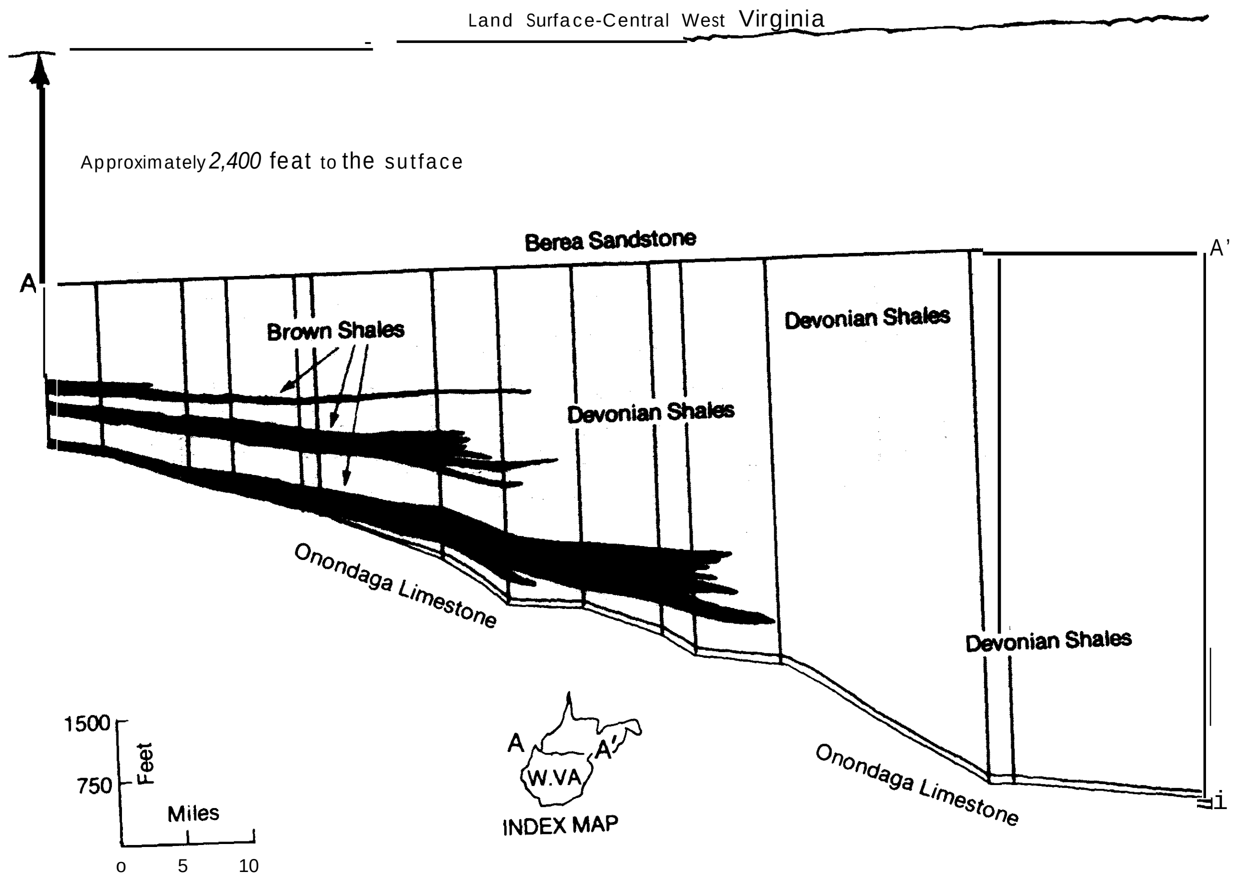
As indicated on figure 4, Upper Devonian rocks are a great wedge-shaped deposit, thin and shaly on the west and becoming thicker and more sandy toward the east. In south-central Kentucky, the section consists of about 20 feet of black shale.[2] This section thickens to about 400 feet at about the Kentucky-West Virginia line, and merges into a mass of siltstone, black silt, and sandstone some 7,OOO feet thick still farther east near the West Virginia-Virginia line. The shale section increases in thickness from less than **500** feet at the outcrop in southern Ohio to about **4,200** feet at the eastern edge of the State.[3]

Only a fraction of these thicknesses, however, represents Brown shale of potential interest as a commercial source of gas. A generalized log of the shale section penetrated by wells in eastern Kentucky, for example, shows an overall shale thickness of 677 feet, of which only an average thickness of 228 feet was Brown shaled[4]—One-third of the section. Of the eastern shales in general, "a 1 ,000-foot interval generally contains approximately 600 feet of light-colored shales and 400 feet of dark shales."[5] A general idea of Brown shale thicknesses in the Appalachian Basin is given by the contours on the map, figure 3. The thickness values on this map are stated to represent net thickness of Brown shale beds only;[6] the values are higher in the eastern part of the Basin than is suggested on the cross section, figure 4, because the geologists who compiled the map included more shale as Brown shale than those who made the cross section. Gas has been found through the entire Devonian shale, although the Brown shale has the highest concentration.

Attitude and Depth

In common with the other rocks in the Appalachian Basin, the Devonian shales have a gentle inclination, or dip, to the southeast. In eastern Kentucky, for example, they dip southeast at **30 to 50** feet per mile.[7] At the surface in central Ohio, the top of the shale section has an elevation of about 800 feet, but in southeastern Ohio this surface is some 1,400 feet below sea level. a This is a decline of 2,200 feet in 85 miles, or a dip of 26 feet per mile. It places the top of the shale section at a depth of about 2,000 feet in the Ohio River Valley between Ohio and West Virginia. A well in Carter County, northeastern Kentucky, near the common corner of Kentucky, West Virginia, and Ohio, reached the top of the shale section at 1,173 feet; in Pike County, easternmost Kentucky, the top of the shale lies at about 5,000 feet; the top of the shale is 12,000

Figure 4. West-East Cross Section Across Central **West Virginia**



Thickness of the total Devonian shales is about 2,000 feet at the west end of the section and 6,600 feet at the east end. Brown shales disappear into thicker strata toward the east. (Modified from Martin and Nuckols, 1976, ERDA Pub. MERC/SP-76/2. Fig. 4.)

feet below the surface of northeastern Pennsylvania. At no place in the Appalachian Basin is depth to the shale too great to be reached by the drill; indeed, many wells in parts of the Basin are drilled through the shale to deeper oil- or gas-bearing strata. There are minor variations in the southeastward dip, but these do not seem to have had a significant effect on accumulation of gas.

Composition

The basic unit of the Brown shale is a pair, or couplet, of microscopically thin layers: one rich in mineral matter and the other made up chiefly of organic matter. The fineness of the resulting lamination is hard to appreciate. Samples of Ohio shale taken from the outcrop in central Ohio were found to have as many as 230 laminae (couplets) in a 5-inch thickness.[9] References to "hairline bedding planes" and "paper-thin laminations" in published descriptions of the Brown shale from cores makes it clear that this characteristic persists in the subsurface as well.

Core samples of dark brown organic-rich shale from a producing gas well in the Cottageville Field, Jackson County, W.Va., were analyzed.[10] The inorganic part of the rock was found to consist chiefly of clay minerals, mainly illite, with the extremely fine grain size that is typical of clay (less than 0.004 mm). Silt-size grains of quartz and feldspar were present in amounts of 5 percent or more, and there were small amounts of calcite, dolomite, and pyrite. Another core from the same field analyzed at 60 percent clay minerals, 35 percent quartz and feldspar, and the remainder mostly pyrite and dolomite.[11] The grains of quartz and feldspar, mostly coarser than 0.004 mm, tend to occur in very thin laminae or lenses.

The organic fraction, reddish brown to chocolate brown in color, is made up of particles of coal-like material in the micron size range (0.001 mm). There are also minute shreds of coalified woody substance, and of spores and algae. The evidence from the organic material shows that it was mostly derived from plants, and this conclusion is supported by carbon-isotope studies. In the jargon of the coal petrologist the material consists largely of "humic degradation products," which were washed into the sea from lands to the east and possibly from lowlands on the Cincinnati arch. There must have been a "density stratification" in the waters of the Devonian Sea, a stagnant condition that inhibited vertical circulation and prevented the organic matter from being oxidized and destroyed as it accumulated on the bottom. A reasonable assumption is that each couplet of mineral-rich and organic-rich sediment may represent an annual accumulation. Organic matter typically makes up 10 to 20 percent of the rock by weight, or 40 to 60 percent by volume.[12]

It should be noted that the Brown shale is not "oil shale" like that of Colorado and Wyoming.[13] The organic matter is not the type of kerogen that characterizes such oil shales; rather, as noted above, the Brown shale are coal-like.

At outcrops, shales almost always split into thin flakes and plates parallel to the bedding. Another interesting aspect of the Brown shale is their content of uranium. Little is known of the reasons for this, except that the association of organic matter and uranium is evidently primary—the uranium was present at the time the muddy sediment was deposited, and was not introduced in later time.[14] The uranium content of the Brown shale, which ranges from 0.005 percent to slightly more than 0.007 percent, has not yet allowed them to be of use as a commercial source of uranium, although it is conceivable that they may be of such use in the future. The radioactivity of these shales, however, is a highly useful characteristic in the search for gas, as the radioactivity makes Brown shale readily recognizable on gamma-ray logs of drilled wells.

Fractures

A feature of the Devonian shales, which is of special significance in the gas-bearing Brown shale, is a system of near-vertical fractures (also known as joints). Most of these are only a fraction of a millimeter wide. In well cores, some fractures have been observed to be filled with brown crystalline dolomite, which helps make the fracture porous and permeable. Spacing of the fractures is variable, but they may occur close enough together so that two or more are often intersected in a 6-inch well bore. The fractures are not randomly oriented, but occur in "sets" that are alined in certain directions.

The relationship between fractures and gas production is well shown by cores taken from two wells in the Cottageville Field, Jackson County, W. Va.[15 16] The cores intersect numerous fractures and a study of the orientation of these fractures resulted in two important findings. First, the dominant direction of the fractures is North 40° to 50° East. This is the regional trend of the Appalachian Mountains (though the significance of the parallelism is not well understood); more practically, it is also the direction in which the most productive gas wells in the Cottageville Field are alined. This clearly suggests a relation between gas production and this set of fractures. Second, in the well from which the larger flow of gas comes, there is a wide variation in fracture alinement. Only 21 percent of the fractures are alined North 40° to 50° East; other preferred directions are slightly west of north, slightly east of north, and nearly east-west. parts of the core from this well are "completely shattered" by fractures, and the well had a natural flow of more than 1 million cubic feet (MMcf) of gas per day. The core from the second well showed few fractures, and the well had no open flow at all. The conclusion seems clear that here, as elsewhere in the Appalachian Basin, gas production from the Brown shale is controlled largely by fractures, with the production rate dependent on the number, length, openness, and direction of these fractures.17

Although mapping of fracture patterns and intersections may well be the best guide to gas accumulation, mapping is a very difficult task. The cause of fracturing is not well understood, and at least nine theories have been suggested,[18] The fracture systems may be related, for example, to the deformation that produced the Appalachian Mountains; to settling above deep-lying faults, thousands of feet below the Devonian shales (figure 5); or to major zones of fracturing ("lineaments"), scores or even hundreds of miles long, that are known or suspected to exist in the region. Until the origin is known, a rational search for fracture-controlled gas accumulations will be difficult. A few fractures extend upward through overlying rocks and reach the surface, and their patterns can be detected by remote-sensing techniques (LANDSAT imagery). This is probably the best current approach to the problem.

Natural Gas in the Brown Shale

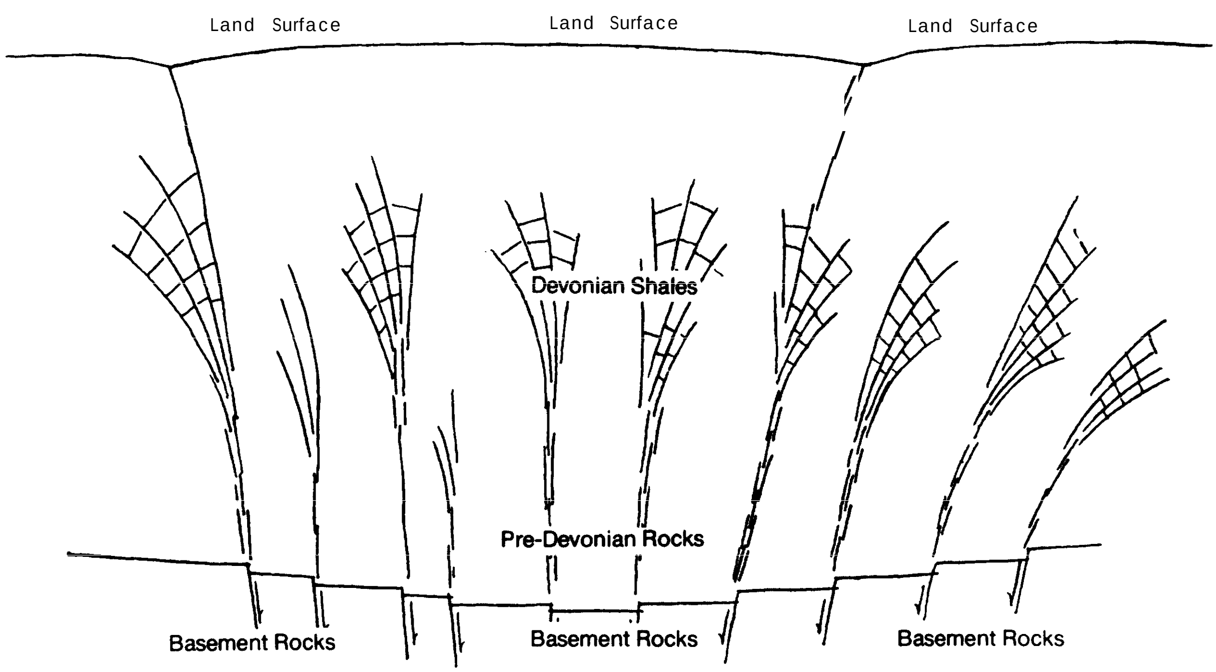
Although it has been known for more than 150 years that shallow wells drilled into the Devonian shales along their belt of outcrop would yield natural gas, the Brown shale was not generally considered a primary objective in exploration for natural gas until recently. In most parts of the Appalachian Basin, wells were drilled to deeper, more promising formations. If those failed to produce, the wells were "plugged back" to the Brown shale and attempts were made to stimulate enough gas from the formation to make a productive well,[19]

Drilling for gas started in western New York as early as 1820, and moved westward along the south shore of Lake Erie across northwestern Pennsylvania and into Ohio as far as Cleveland.[20] Shallow wells in the Brown shale supplied Louisville, Ky., with gas in the 1880's.[21] Two facts about this early production stand out. First, the rate of gas production was low; only enough to supply a small local industry, or a small cluster of households for heating and cooking could be expected from a given well. Second, the wells were very long-lived. Two wells at Fredonia, N.Y.—one drilled in 1821 and the other in 1850—had a combined annual production of only 6 MMcf (16,400 cubic feet per day), but when plugged 60 years later they were still producing 6 MMcf per year.[22] It was clear from this early experience that there was gas in the shale, but that the shale would yield it only at a low rate over a long time period. Today we know that gas moves readily only in fractures, and perhaps along some of the more silty bedding surfaces. The vast bulk of the gas is held in the shale mass, or "matrix," from which it will move into fractures and well bores at very low rates and over long time periods.

Estimates of the total amount of gas in the Devonian shales of the Appalachian Basin range from a few Tcf to many hundreds of Tcf.[23] Although the magnitude of the total resource is not known, there can be no doubt that it is large enough to be of potential importance to the Eastern United States.

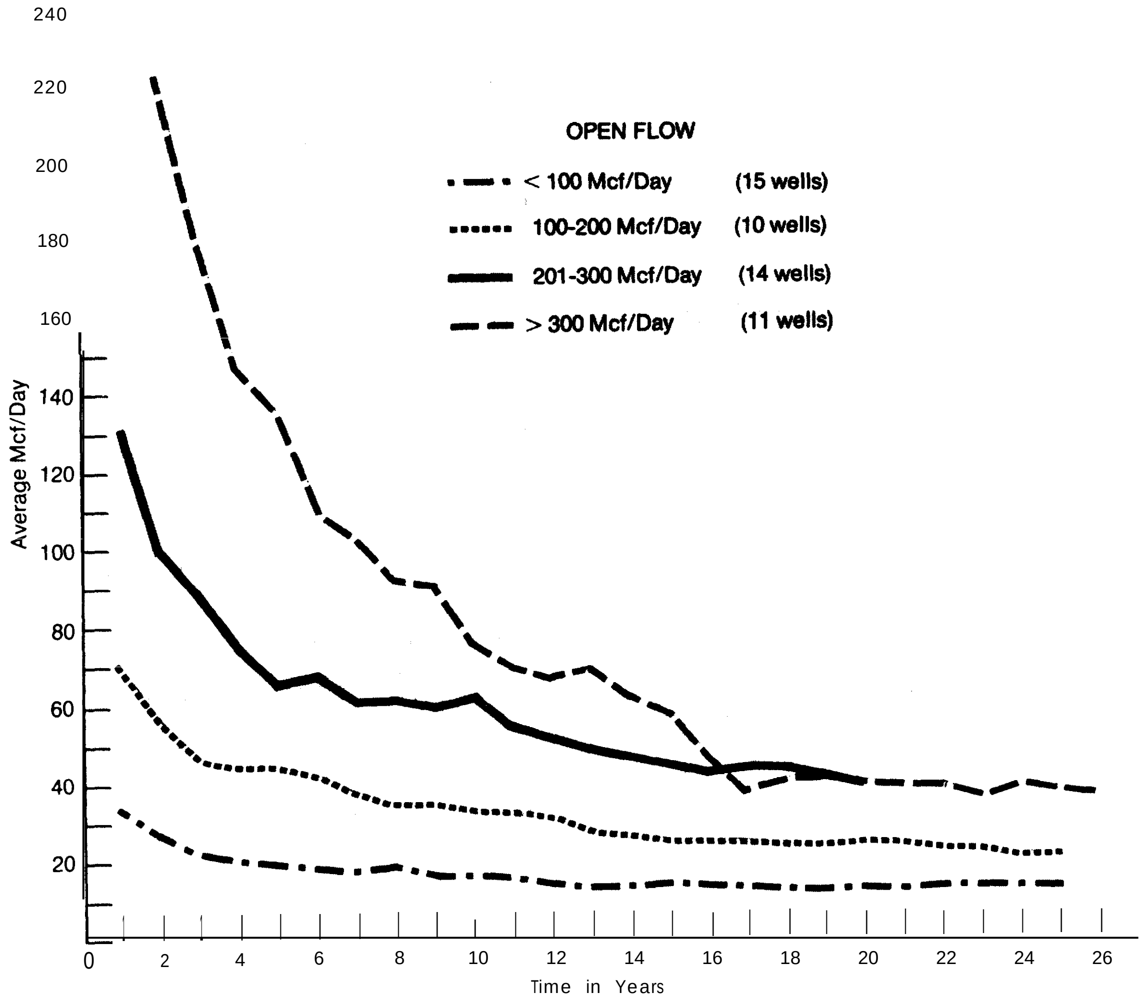
Present-day wells producing gas from the Brown shale recover only 2 to 10 percent of the original gas in place; 90 to 98 percent is left in the ground. The history of production in 50 Brown shale wells is indicated by the "decline curves" on figure **6.** Initial production is relatively high, as free gas in fractures moves to the well bore, but the flow decreases steadily to some value determined by the slow rate at which the gas in the shale matrix is released. Various techniques are being applied to the shale in an attempt to create artificial fractures extending outward from the well bore, thus potentially increasing the amount and rate of gas recovery by connecting more fracture systems to the well and exposing more surface area.

Figure 5. Model Showing Fractures Generated by Deep Seated Basement Faulting and Propagated Upwards Into the Devonian Shales



Source Overbey, 1976, Energy Research and Development Administration Pub. MERC/SP-76/2, Fig. 9

Figure 6. Averaged Production Decline Curves for 50 Devonian Shale Gas Wells



Lincoln, Mingo, and Wayne counties, West Virginia. Wells were metered on open flow after shooting or fracturing of the shale pay zone. Mcf = thousand cubic feet. (From Bagnall and Ryan, 1976, ERDA Pub. MERC/SP-76/2, Fig. 11; and W. D. Bagnall, personal communication.)

FOOTNOTES

[1]Wallace deWitt, Jr., et al., "Oil and Gas Data From Devonian and Silurian Rocks in the Appalachian Basin, " U.S. Gee!. Survey Map I-91 7 B, 1975.

[2]L.J. Provo, "Upper Devonian Black Shale—Worldwide Distribution and What It Means (abstract) ," *Devonian Shale* Produc-[fen *and Potential,* ERDA Pub. MERC/SP-76/2, pp. 1-3, 1976,

[3]A. Janssens, "Potential Reserves of Natural Gas in the Ohio Shale in Ohio, " Ohio Geol. Survey, prepared at the request of the Joint Select Committee on Energy of the Ohio Legislature, p. 18, 1975.

[4]John Avila, "Devonian Shale as Source of Gas, " Natural *Gas* from *Unconventional Geologic Sources,* Nat. Acad. Sci. Pub. FE-2271 -1, pp. 73-85, 1976.

[5]P.J. Brown, "Energy From Shale—A Little Used Natural **Resource,** *Natural* **Gas** From *Unconventional Geologic* Sources, Nat. Acad. Sci. Pub. FE-2271 -1, pp 86-99, 1976.

[6]Wallace deWitt, Jr. personal communication, 1976.

[7]E. O. Ray, "Devonian Shale Development in Eastern Kentucky, " *Natural Gas From Unconventional Geologic* Sources, Nat. Acad. Sci. Pub. FE-2271 -1, pp. 100-112, 1976.

[8]A. Janssens, "Potential Reserves of Natural Gas in the Ohio Shale in Ohio, " Ohio Geol. Survey prepared at the request of the Joint Select Committee on Energy of the Ohio Legislature, p. 18, 1975.

[9]J. M. Schopf. Personal communication, 1976.

[10]D G. Patchen, and R.E. Larese, "Stratigraphy and Petrology of the Devonian 'Brown' Shale in West Virginia," Devon/an *Shale Production* and *Potential,* ERDA Pub. MERC/SP-76/2, pp. 4-19, 1976.

[11]P. Martin, and E.B. Nuckols, III, "Geology and Oil and Gas 0(currence in the Devonian Shales: Northern West Virginia," *Devonian Shale Production and Potential,* ERDA Pub, MERC/SP-76/2, pp. 20-40, 1976.

[12]J.M. Schopf, Personal communication, 1976.

[13]Maurice Deul, "Discussion, " Natural *Gas* from *Unconventional* **Geologic** Sources, Nat, Acad. Sci. Pub. FE-2271 -1, p. 123, 1976.

[14]L.C. Conant and V.C. Swanson, "Chattanooga Shale and Related Rocks of Central Tennessee and Nearby Areas, " U.S. Geological Survey, p. 357, 1961.

[15]P Martin and E.B. Nuckols, III, "Geology and Oil and Gas Occurrence in the Devonian Shales: Northern West Virginia, " *Devonian Shale Production and Potential,* ERDA Pub. MERC/SP-76/2, pp. 20-40, 1976.

[16]D.G. Patchen and R.E. Larese, "Stratigraphy and Petrology of the Devonian 'Brown' Shale in West Virginia, " Devonian *Shale Production and Potential,* ERDA Pub, MERC/SP-76/2, pp. 4-19, 1976.

[17]W. D. Bagnall and W.M. Ryan, "The Geology, Reserves, and Production Characteristics of the Devonian Shale in Southwestern West Virginia, " Devon/an *Shale* Production *and* Potential, ERDA Pub. MERC/SP-76 /2, pp. 41-53, 1976.

[18]R.A. Hodgson, "Fracture Systems: Characteristics and Origin, " *Devonian Shale Production* and *Potential,* ERDA Pub. MERC/SP-76/2, pp. 54-74, 1976.

[19]John Avila, "Devonlan Shale as Source of Gas, " *Natural* Gas from *Unconventional Geologic* Sources, Nat. Acad. Sci. Pub. FE-2271 -1, pp. 73-85, 1976.

[20]Wallace deWitt, Jr., "Current Investigation of Devonian Shale by the U.S. Geological Survey, " *Natural Gas* from *Unconventional Geologic* Sources, Nat. Acad. Sci. Pub. FE-2271 -1, pp. 113-115, 1976.

[21]John Avila, "Devonian Shale as Source of Gas, " *Natural* Gas From Unconventional Geologic Sources, Nat. Acad. Sci. Pub. FE-2271-I pp. 73-85, 1976.

[22]Wallace deWitt, Jr., "Current Investigation of Devonian Shale by the U.S. Geological Survey, Natural *Gas* from *Unconventional Geologic* Sources, Nat. A cad. Sc i. Pub. FE-2271-I , pp. 113-115, 1976.

[23]J.M. Foster, "A 'New' Gas Supply, " SPE-AIME #5451, 1975.