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SUBSURFACE STRATIGRAPHY AND GAS PRODUCTION OF THE DEVONIAN SHALES IN WEST VIRGINIA

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March 1977

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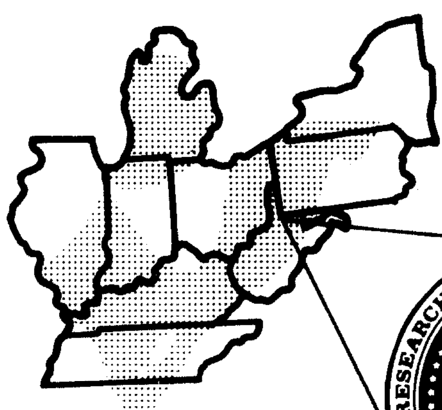

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Douglas G. Patchen
West Virginia Geological and Economic Survey
Morgantown, WV 26505

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Subsurface Stratigraphy and Gas Production of the Devonian Shales in West Virginia

by

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West Virginia Geological Survey
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ABSTRACT

The subsurface Devonian shales are defined as all of the fine clastic rocks between the top of the Onondaga Limestone and the base of the Berea Sandstone. This term is used only in the western one-third of the state where the thickness of these shales ranges from 1000 to 3000 feet. The interval thickens to the east and northeast and facies changes to coarser clastics occur. In north-central West Virginia numerous sandstones and siltstones have replaced much of the shale section, particularly the so-called Brown shales. These shales are actually dark gray to black, organic-rich, generally non-silty shales that yield higher natural radioactivity readings on a gamma-ray log, and low readings on a density log. Sample descriptions, cable-tool drillers' logs, and gamma-ray and density logs are all used to subdivide the Devonian shales into 4 zones: a thick (1100-1200 feet) upper sandy, silty, gray and greenish gray shale; a thinner (300-400 feet) zone consisting of two dark to very dark gray shales (the Brown shales of the driller) separated by a thin gray shale; a greenish gray, generally non-silty shale; and the lowermost interval that consists of very dark to black shales, often calcareous near the base. A thin limestone is often noted within the lowest black shale and is usually referred to by drillers as the Tully. Farther to the west and southwest a fifth zone, a younger Brown shale, is present near the top of the Devonian shale sequence in the approximate stratigraphic position of the Cleveland Shale of Ohio.

Natural gas has been produced for nearly 50 years from relatively shallow-depth, low-volume wells completed in the Brown shales and adjacent units. Although these wells are marginally economic at current costs, prices, and completion techniques, these shales represent a very large gas resource with less than 10 percent of the calculated gas in place ever produced. The production rate is controlled by the presence of natural fractures which allow gas to migrate to the well bore. Although current exploration relies heavily on mapping and drilling areas of thick Brown shales, optimum conditions exist where these thick Brown shales are highly fractured. One such area may be where the Devonian shales overlie the large basement fault-block feature known as the Rome Trough.

INTRODUCTION

One of the oldest, but least studied and least appreciated, gas-producing intervals in West Virginia is the thick shale sequence in the western one-third of the state referred to by drillers as the "Devonian shales" or simply "Brown shales." Shales within this thick section have yielded gas for nearly 50 years from low-volume, shallow-depth wells, but they have never been considered to be one of the state's prime targets. During the past 4 years, however, due to the increasing gas shortage, renewed interest in these shales has been shown by various segments of industry and government. Four or five large energy companies in the United States and Canada, gas utilities in the Appalachian basin, large industrial plants located along the Ohio River faced with gas curtailments, the Appalachian Regional Commission, the National Research Council Board on Mineral Resources, the Federal Power Commission, and the United States Energy Research and Development Administration (ERDA) have all taken a new, hard look at the energy-producing potential of the Devonian shales. Consequently, ERDA has issued a variety of research contracts to State Geological Surveys, Geology Departments at several universities, and gas utilities to characterize the resource potential of the Devonian shales in the Appalachian basin.

As interest in the shales increased within various segments of industry and government, the Oil and Gas Section of the West Virginia Geological Survey began a preliminary study of the shales in West Virginia to determine: 1) a general stratigraphic framework between the thick, previously undivided shale section in the western one-third of the state and the shales, siltstones, and sandstones of Middle and Late Devonian age in the north-central counties and eastern outcrops; and 2) the exact intervals within this thick shale sequence that produce gas, and if these gas-bearing zones are consistent from well-to-well and field-to-field throughout the area where the shales produce.

The initial results of this preliminary study have been presented to various groups (Patchen, 1976, 1976b; Patchen and Larese, 1976) in condensed form. Now, however, as the Survey begins what we hope will be a multi-disciplinary, 5-year study of the shales under an ERDA contract, we thought it best to outline more recent results, even though still preliminary, that will serve as the starting point for continued research. In addition, this report summarizes our current knowledge of gas production from the shales. Most of what we now know is the result of data released by gas utilities in the Appalachian basin.

STRATIGRAPHY

The term "Devonian shale" refers to all the fine clastic rocks between the top of the lower Middle Devonian Onondaga Limestone and the base of the Lower Mississippian Berea Sandstone (Figure 1). As such it includes Bedford equivalents at the top in areas adjacent to Ohio and Kentucky. This name is used only in the western one-third of the state where the Hampshire (Catskill) redbeds, various Hampshire and Chemung sandstones and siltstones, and the Tully Limestone are not present to subdivide the shale sequence. The term "Brown shales," although often used as a synonym of Devonian shales, is more correctly restricted to darker shales within the thicker shale sequence. These darker shales (dark gray to black), which are often finer grained, organic rich, and more radioactive than the gray and greenish-gray, sandy, silty shales that encompass them, usually occur within the lower half of the shale sequence, but younger dark shales are present in southwestern counties in West Virginia and in eastern Kentucky.

As defined, the Devonian shales occupy the same stratigraphic position as 6 clastic formations in the eastern outcrops (Figure 1): the Marcellus, a black shale; the Mahantango (Hamilton of older terminology) siltstones and shales, some dark; the Harrell, a second black or dark gray shale which contains the Tully Limestone Member near its base; the Brallier, siltstones and shales, some of which are dark; the Chemung, greenish, gray, and brown sandstones, siltstones, and shales; and the Hampshire (Catskill facies), redbeds with sandstones, siltstones, and shales, many of non-marine origin. The thickness of this entire Devonian clastic section ranges from less than 1000 feet in the southwestern gas fields to more than 7000 feet in the north-central subsurface area (Figure 2), and up to 10,500 feet in the eastern outcrops. However, the portion of this interval that is occupied by black or dark gray so-called "Brown shales" is much less, ranging from 10 to 60 percent in the southwestern counties with shale gas production. This is shown on a map by Wallace and deWitt (deWitt and others, 1975) which can be summarized as follows: in northern Wayne County where the entire shale section approximates 1000 feet, the dark shales are 600 feet thick (60 percent); these darker shales thin to the east to only 300 feet in northeastern Kanawha County, where the entire section is 3000 feet (10 percent); and east of Kanawha County the dark shales thicken to a maximum of 1000 feet south and east of the area of Upper Devonian sand production where the clastics range from 5000 to 6000 feet (20-16 percent). Therefore, even as the dark shales thicken to the east they occupy a smaller percentage of the stratigraphic section and occur at greater drilling depths. Consequently, few wells have been drilled entirely through the Upper and Middle Devonian sequence in the north-central counties where gas is produced from 17 named Upper Devonian Hampshire (Catskill) and Chemung sandstones. In southwestern counties, however, gas is produced from several shale zones, usually within the middle of the Devonian shale section and often from dark shales immediately above the Onondaga Limestone. Between these two areas, underlying an area of Mississippian gas production, the key facies change from productive sandstones to organic-rich dark shales occurs.

The subsurface data available to document this facies change are shown in Figure 3. In the area with Brown shale gas production to the southwest, approximately 3000 wells have been drilled although many of these did not penetrate the entire shale section down to the Onondaga. Reliable cable tool drillers' logs, samples for several hundred wells, and many good radioactive and density logs are available for some of these wells. Another 1300 or more wells were drilled entirely through the shale section to produce gas from the Oriskany Sandstone, and more recently from the Newburg sand, in the long Sissonville-Elk Poca trend in Jackson, Putnam, and Kanawha Counties, and in other Oriskany fields in Wood, Putnam, Kanawha, and Boone Counties. Cable tool drillers' logs and samples are available from older wells within these fields, but more recent wells drilled by rotary rigs have less reliable logs and samples. Also, mechanical wire-line logs run in these holes often skip the shale section, logging only from the Onondaga and Oriskany down to total depth, and from the Mississippian Berea Sandstone up to the surface.

The third area of concentrated drilling shown on Figure 3 is the so-called "Benson trend" in north-central West Virginia. Although more than 4000 wells have been drilled within this trend to produce from various Upper Devonian sands, 99 percent have penetrated only the upper 2500 feet of Upper Devonian rocks, down to the Benson sand. The lower 3500 to 4500 feet of Upper and Middle Devonian fine clastics are relatively untested in this area.

Scattered deep tests (to the Onondaga or deeper) in areas between trends with concentrated drilling are all shown, with those emphasized for which sample descriptions are available. Wells drilled in recent years that discovered gas in the shale section also are shown. To begin the stratigraphic investigation, we attempted to subdivide the thick shale section based on lithology. Consequently, cross section C-C' (Figure 4) was developed, based entirely on sample descriptions by Martens (1939, 1945). Once C-C' was completed, an attempt was made to extend these lithologic subdivisions east and west along sections A-A' and B-B'.

A rough 4-fold subdivision is apparent on section C-C'. The upper 1100 to 1200 feet consist of gray and greenish-gray, sandy, silty shales. The lower 400 feet of this interval contain less silt and the first spore-bearing dark shale samples. Another 400 foot zone, immediately below, consists of 2 dark gray shales, called Brown shales by the drillers, with medium gray, often silty shales between. The Brown shales are actually dark to very dark gray to black from top to bottom. The silt content generally decreases as the color of the shales becomes darker, and spores were often noted within these two darker shales. The third zone is one of greenish-gray, usually non-silty shales, again about 300 to 400 feet thick. This is a very persistent interval that can be traced from eastern Kentucky (where it is referred to as the Big White Slate by drillers) northward to Wood County, West Virginia, a distance of more than 100 miles. Below this greenish-gray zone, the lowest dark shale occurs. Its thickness ranges from 200 to 400 feet and the rocks are very dark gray to black shales, in general darker than the younger zone of "Brown shales." These older dark shales are often calcareous in the lower 100 to 200 feet (Marcellus?) and sometimes are divided by a thin limestone (the drillers' Tully).

The 4 broad lithologic subdivisions of the Devonian shales, based entirely on sample descriptions, can be extended through a limited area from west to east along A-A' which extends from the Mount Alto (Cottageville) Devonian shale gas field, through the Benson trend to the westernmost Devonian outcrop belt. The results are shown, very generalized, in Figure 5. No attempt was made, due to lateral and vertical scale restrictions and sparcity of control in key areas, to make stratigraphic or lithologic correlation from west to east. Several observations can be made, however. The lowermost dark shale thickens and splits from west to east, and probably is equivalent to dark shales in the Marcellus and Mahantango (Hamilton) formations below the drillers' Tully, and the Harrell and lower Brallier formations above the Tully. The upper dark zone, called Brown shales by the drillers, also thickens and splits toward the east, and appears to interfinger with the Riley-Benson zone (lower Chemung). Dark shales within the Riley-Benson zone are identical to dark shales in the Brown shale zone to the west (Cheema, 1976). The Speechley-Balltown siltstone zone which contains some brownish shales, is apparently younger than the Brown shale interval and in part overlies it toward the west, whereas the Elk-Sycamore siltstone interval is older than the upper Brown shales and more restricted to the east. The older Mahantango (Hamilton) siltstone package is still more restricted to the east.

The same broad stratigraphic generalizations can be drawn from cross section B-B' (Figure 6). The upper Brown shale zone interfingers with the basal Chemung siltstones to the east. These siltstones are present to depths 500 feet below the Benson in Lewis and Randolph County wells and serve as a useful lithologic boundary between the Chemung and Brallier. The youngest Brown shales occur within the Speechley-Balltown zone, and become the dominant shale in the older Riley-Benson zone. The Elk-Sycamore clastic zone is older than the main Brown shale interval and is restricted to the eastern area. The Mahantango siltstone evident on line A-A' below the Tully Limestone is not developed along this more southern line of section.

This regional pinchout of the Mahantango has been noted in outcrop by Dennison and Hasson (1976, 1977). The Hampshire redbeds extend as far west as Kanawha County, above the Chemung siltstones and shales. In the western end of this section a younger brown shale is present near the Berea at the top of the Devonian shales. This youngest brown zone, may be equivalent to the Cleveland Shale of Ohio as described by Schwietering (1970) and the youngest brown shale in eastern Kentucky and southwestern West Virginia shown by Bagnall and Ryan (1976).

These regional correlations and lithologic subdivisions, based entirely on sample descriptions, are confirmed by gamma-ray log stratigraphy. The dark gray to black, organic-rich brown shales that produce in western West Virginia are more radioactive on a gamma-ray log than the lighter gray, often silty shales. Marten and Nuckols (1976) have traced the radioactive shales in the lower part of the main Brown shale zone (Figure 3) into the Benson zone. They also show the lower black shale zone thickening and splitting to the east, equivalent to the Marcellus and post-Tully, pre-Sycamore rocks.

Farther south Bagnall and Ryan (1976) prepared a similar section, based on gamma-ray logs, that extended from Wayne County eastward to Greenbrier County. This section was not published with their report, but is available at the Survey's Devonian Shale Office in Morgantown. Much the same stratigraphic relations are shown. The upper Brown shale zone consists of 2 mappable dark units that thicken and split eastward before reaching an area where they can no longer be mapped using high radioactive readings on the gamma-ray log. The older dark shales overlying the Onondaga also thicken and split and extend farther eastward than the younger dark shales. The presence of the Tully Limestone enables the correlation of these shales with the Marcellus, Mahantango (if present), Harrell, and perhaps lower Brallier formations. In both of these cross sections, the brown shales become less radioactive toward the east and cannot be traced on gamma-ray logs even though they still retain the same dark color. Schwietering (1970) noted the same problem when using gamma-ray logs for regional correlations between Ohio, Pennsylvania, and New York and offered several suggestions to explain this occurrence. The conclusion seems inescapable that the best approach to mapping the thickness and extent of individual dark shales is to combine careful sample descriptions with high-quality gamma-ray and bulk-density or neutron logs.

If new data are made available in the area of Mississippian gas production between the Benson trend and the Brown shale trend, a more detailed stratigraphic framework can be developed. The final picture may be similar to that shown schemetically in Figure 7. This facies diagram was constructed by hanging the section on a horizontal line extending along the top of the oldest Brown shale and eastward through the middle of the upper Brallier - lower Chemung sandstone-siltstone interval. On this facies diagram the oldest dark shales extend farther to the east, and progressively younger dark shales are more restricted to the west. The opposite is true for the sandstone-siltstone packages. The oldest coarse clastic formation (Mahantango) is restricted to the east with progressively younger wedges extending farther to the west. The dark shale fingers tend to separate the clastic packages in this overall regressive sequence. An interesting point to note is that the main gas-bearing zones in the sequence may be facies equivalents: the turbidite sandstones and siltstones of the Riley-Benson interval, and the distal turbidite Brown shale to the west.

BROWN SHALE GAS PRODUCTION AND POTENTIAL

One of the main problems for the resource evaluation study of the Devonian shales is to determine more accurately the thickness and extent of the various Brown shales in West Virginia and to calculate their organic content, amount of gas in place, and producible reserves. To accomplish this it will first be necessary to conduct individual field studies to ascertain if the productive Brown shale sections are the same from well-to-well and field-to-field, and the importance of intervening lighter-colored shales in gas production. Many of the

Brown shale fields (Figure 8) merge together, especially near the Kentucky border, and furthermore most produce from other units as well. Toward the north, however, there are several isolated fields in Putnam County, and another still farther north in Jackson County. In Putnam County where 3 shale fields have been developed (Figure 9), most of the wells were only drilled through the upper Brown shale zone and not to the lower black shale (Figure 10). All of the pays are in this brown zone, although in some deeper wells the entire interval from the top of the Brown shale to the base of the black shales was shot. This cross section (Figure 10) was drawn using old cable-tool drillers' logs as a data source. Furthermore, several hundred well records in these 3 fields were examined and it was concluded that in the absence of better data, i.e., cores, samples, and gamma-ray and density logs, the older cable-tool drillers' logs can be used to map an upper Brown shale interval and a lower black shale zone comparable to those shown in Figure 4.

This same procedure was used in studying the Mt. Alto (Cottageville) Field farther north (Figure 11). This field, which has been described by Martens and Nuckols (1976) and is still being studied under several ERDA contracts, has a general northeast-southwest trend, which parallels the regional surface fracture traces. Furthermore, most of the better wells in the field line up along this same trend, indicating a high degree of fracture control on production. A total of 37 wells were drilled here by Consolidated Gas Supply Corp. (formerly Hope Natural Gas) of which 18 still produce. The average initial open flow was only 133 Mcfpd. The cumulative production for the 18 producing wells averages 313 MMcf per well, whereas the cumulative figure including the 19 wells now abandoned is 185 MMcf per well. More than 6.5 Bcf have been produced by Consolidated, and a total of 15 Bcf by all operators from 90 wells (Martens and Nuckols, 1976).

Most of the wells in this field only penetrate the upper Brown shale zone (Figure 12), but a few have been drilled to the Onondaga. Figure 12 was prepared using older cable-tool drillers' logs (most of these wells were drilled in 1949-1950), and it was possible, using these logs, to subdivide the Brown shale interval into 2 Brown shales and an intervening lighter-colored shale, again corresponding to sample descriptions shown in Figure 4. Most of the wells produce from the lower of the two Brown shales, but many wells were shot in both. The solid rectangles next to Jackson 1369 represent two cored intervals. The core description and high radioactive readings from the gamma-ray log and low readings on the density log all indicate the presence of dark gray, non-silty, organic-rich shales that correlate with the Brown shales noted on the older cable-tool drillers' log.

This Brown shale is the main reservoir in 27 named fields in southwestern West Virginia (Figure 8). These fields cover 500,000 acres (nearly 1500 square miles) and have produced gas from the Brown shales for more than 50 years. Reserves calculated from the 3000 plus producing wells in these fields approach 1 trillion cubic feet (Tcf) of which less than 400 billion cubic feet (Bcf) remain to be produced (Brown, 1976; Bagnall and Ryan, 1976). However, in most of these fields (21 of 27), other shallow pays, usually Mississippian sandstones from the Maxton to Berea or the Greenbrier Limestone, also produce, and often this gas is comingled with gas from the shales. Additionally, in 3 other fields gas is produced from the deeper Onondaga Limestone and Oriskany Sandstone. The net result is that good data do not exist for Devonian shale gas production and reserve calculations. Brown (1976) estimates that 10 to 25 percent of the gas now considered to be from the Devonian shales is actually being produced from Mississippian sandstones and limestones.

The success ratio for Devonian shale gas wells in these fields is quite high, exceeding 90 percent. Furthermore, wells are reasonably shallow with an average total depth of 3500 feet. However, initial open flows are low, averaging only 350 Mcf per day. Per well reserves are estimated at 350 million cubic feet (MMcf) by Brown (1976), assuming 150-acre spacing. Thus, Devonian shale wells are considered to be marginally economic at current well costs and gas prices. Positive factors include the relatively shallow depth, thick pay sections, and fairly steady productive rate over a long period of time.

One of the main points that is made when discussing the potential of the Devonian shales as a future gas source is that the calculated recoverable reserves per well are less than 10 percent of the calculated gas in place in the darker, organic-rich shales (Brown, 1976). This low recovery rate is believed to be due to the manner in which the gas is held within the shales, and the way it is transmitted from the rocks to the well bore. Gas is believed to be held in the shales in three ways (Brown, 1976; Bagnall and Ryan, 1976): 1) as free gas within fractures; 2) adsorbed on fracture surfaces; and 3) adsorbed within the shale matrix in large shale blocks between fractures. Free gas within fractures is the first to be produced to the well bore, followed rather quickly by adsorbed gas on fracture surfaces. The challenge for industry and ERDA research contractors is to develop new stimulation techniques to break up the large blocks of shale between fractures and release the adsorbed gas within these blocks more quickly to the well bore. The importance of this was demonstrated by Bagnall and Ryan (1976) with a presentation of 4 averaged production-decline curves for Brown shale wells in 3 southwestern West Virginia counties. Wells with the highest average initial production (greater than 300 Mcfpd) show a steep decline curve but level off at approximately 50 Mcfpd and continue for years at that rate. Wells ranging from 201 to 300 Mcfpd level off more quickly but at lower rates, as do wells averaging between 100-200 Mcfpd. Wells with average initial flows less than 100 Mcfpd are nearly horizontal lines from year 1 to year 25. The conclusion is: gas production from the shales is controlled by the presence of fractures within the shales. The better initial wells intersect more fractures and produce free gas and adsorbed fracture gas in higher rates than wells that intersect fewer fractures. Once the "flush production" is over - production from free and adsorbed fracture gas - the larger blocks of shale between fractures yield their adsorbed gas very slowly to the fractures and then to the well bore. At this point, the decline curves are nearly horizontal and remain so for many years as this type of gas continues to bleed off very slowly. Wells intersecting more fractures thus level off at higher flow rates than wells intersecting fewer fractures.

SUMMARY AND SUGGESTIONS FOR FUTURE WORK

Gamma-ray logs, density logs, core and sample descriptions, and old cable-tool drillers' logs can all be used to correlate and map Brown shale zones in West Virginia. In the regional approach it is necessary to use samples in conjunction with gamma-ray logs when the Brown shales lose their high radioactive content while retaining their same color as the clastic eastern facies is approached. In areas with concentrated drilling samples and cable-tool logs are adequate to do detailed local mapping.

Before detailed stratigraphic and facies relationships can be determined more data need to become available through deeper drilling in Mississippian gas fields between the Benson and Brown shale trends. Recent drilling patterns (Figure 13) indicate that deeper drilling is now occurring in these areas, with some success (Figure 2). Soon it may be possible to formalize some of the regional stratigraphic and facies relationships suggested in Figure 14 as work continues in Ohio, eastern Kentucky, and West Virginia under separate ERDA grants. As this work continues several problem areas need to be resolved. One of these is choosing a mappable upper boundary for the Devonian shales in north-central West Virginia where the Berea Sandstone and Sunbury Shale are not present. In this area the top of the Gantz sand can be used to approximate the boundary. In southern West Virginia preliminary work indicates that perhaps as many as 6 brown shales may be present in an area of thicker Devonian shale. These brown shales may be equivalent to parts of the Marcellus, Harrell, and Brallier formations, as well as the Chemung. Correlations from this southern subsurface area to outcrops in southeastern West Virginia will be necessary to resolve the problem. When making these correlations, however, the Berea, Sunbury, and Gantz should all be absent, creating a problem in defining the top of the Devonian shale, unless the highest occurrence of Hampshire redbeds can be used in limited areas farther east.

Finally, although the main exploration tool at the present time consists of mapping areas of thick Brown shale and identifying these as primary drilling areas, the outline of Brown shale production in West Virginia shows a striking correlation with the trend of the Rome Trough (Figure 15). Because the gas in the shale is fracture controlled this suggests that movement within this basement fault block was reactivated after shale deposition and has fractured the dark shales that overlie the trough. Therefore, the prime exploration areas should be where thick Brown shales overlie the Rome Trough, particularly where these thick Brown shales are in the middle of the Devonian shale sequence. The cause and time of occurrence of these fractures, and their relation to regional structural patterns below, within and above the Devonian shales, should be subjects of future work.

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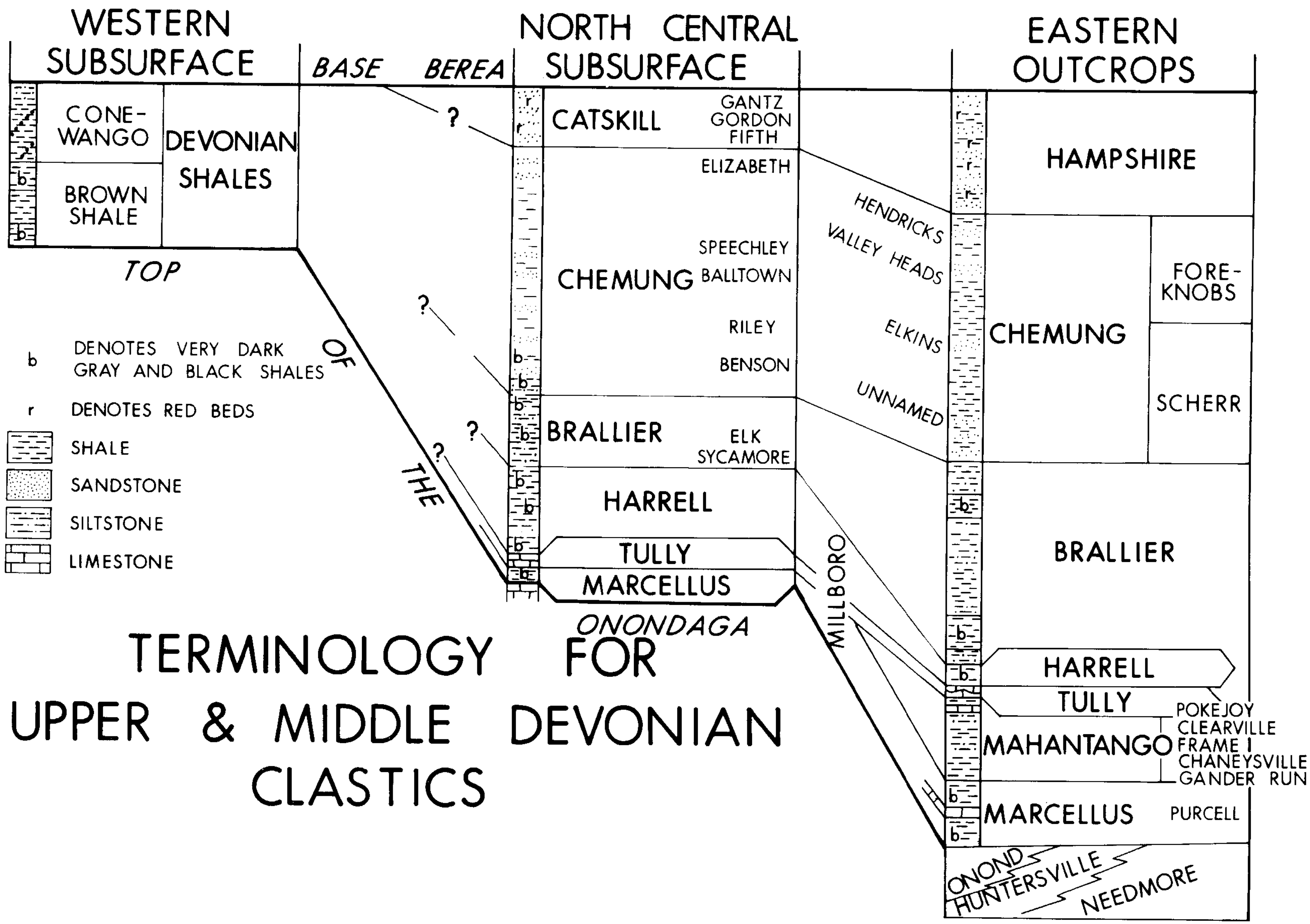
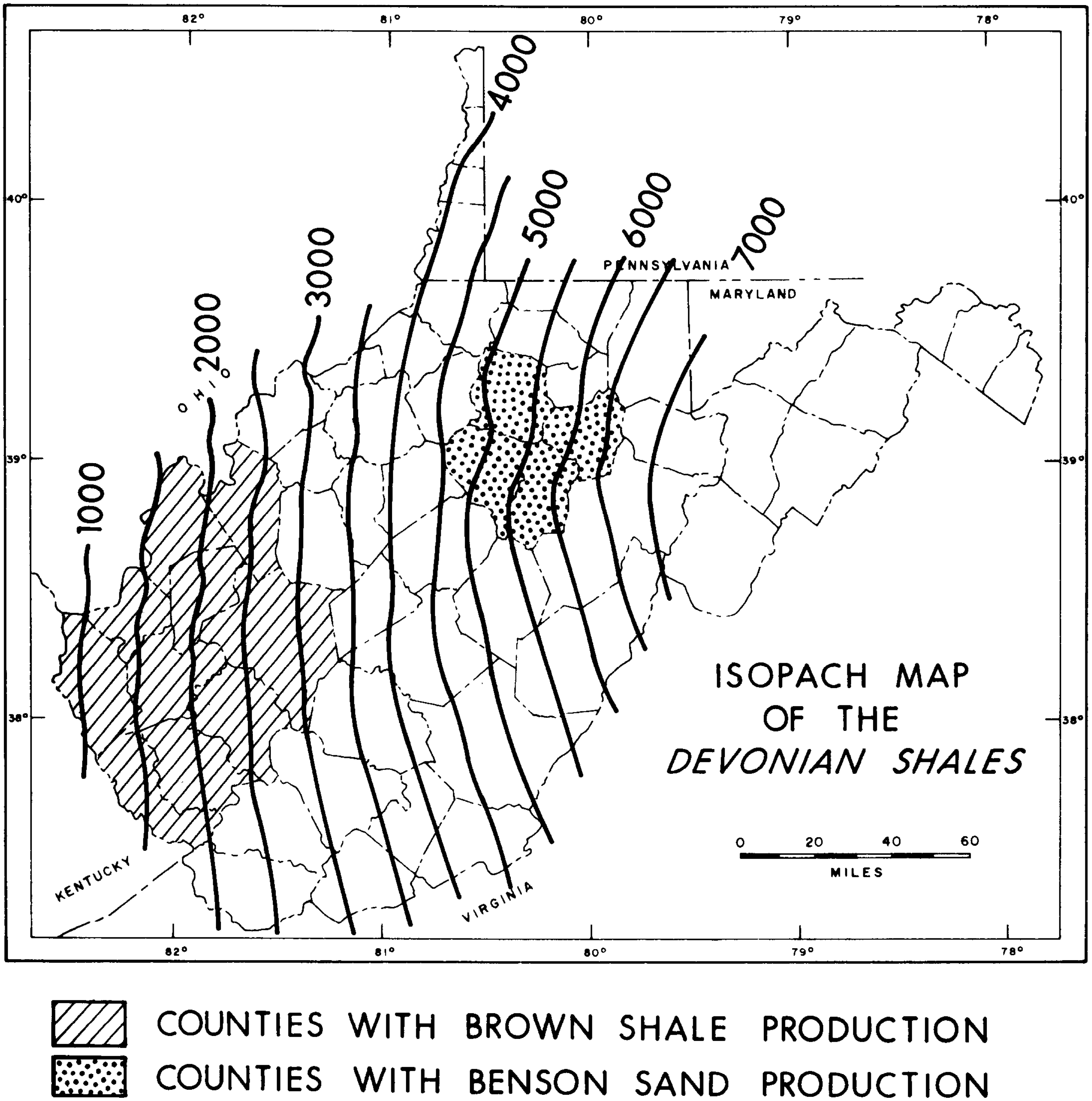
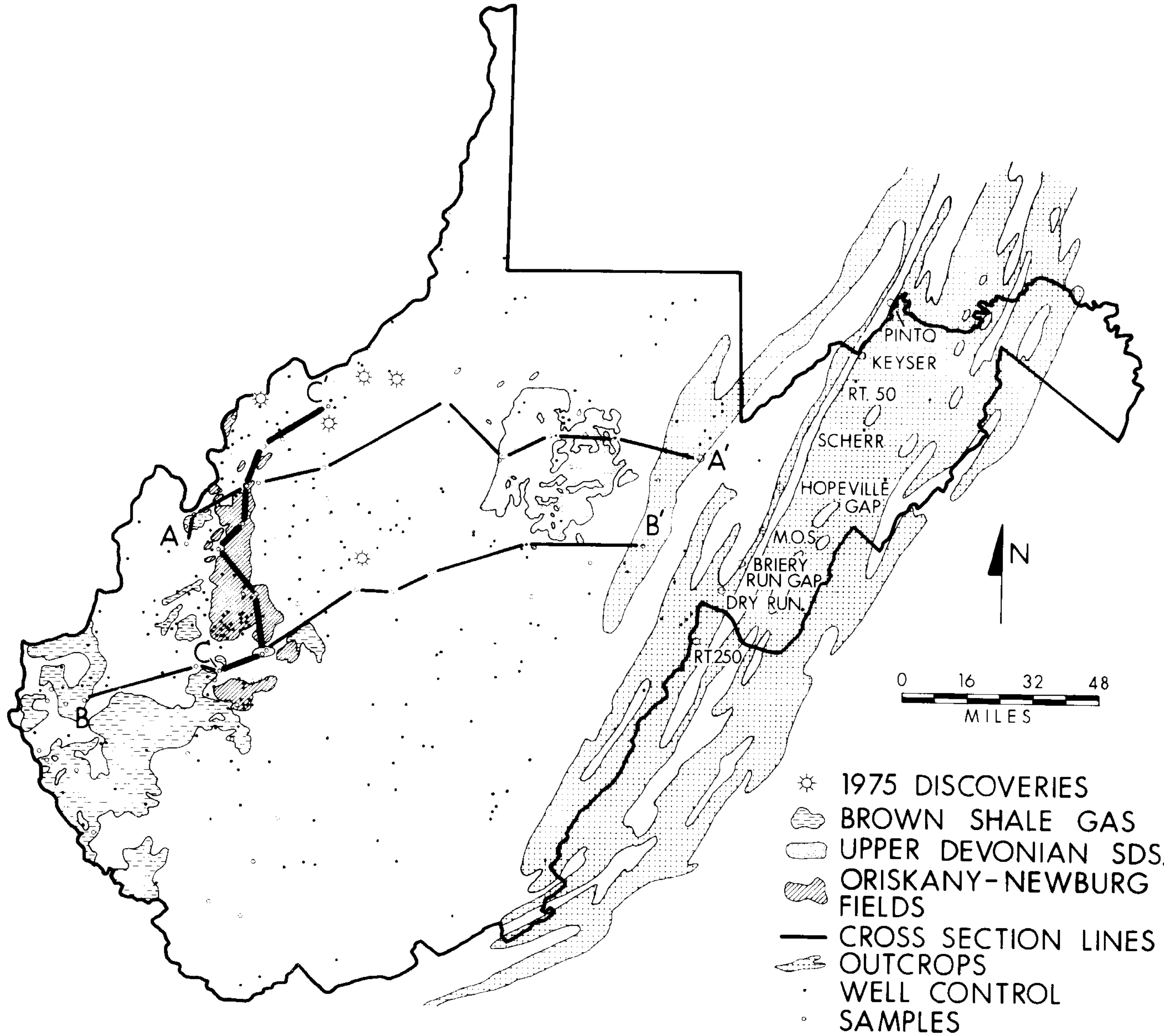


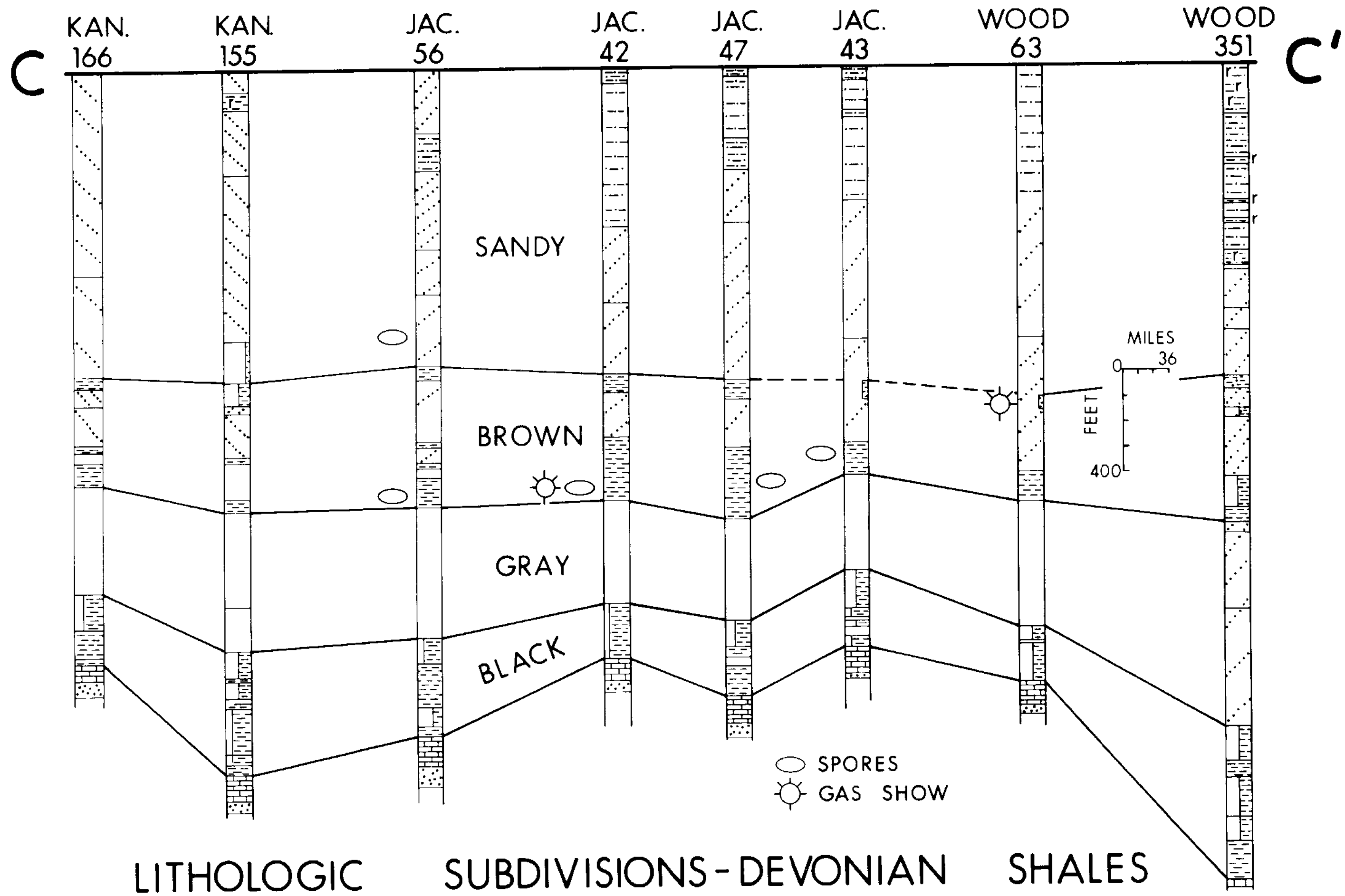
Fig. 1. Formal and informal stratigraphic nomenclature for Middle and Upper Devonian units across West Virginia. Drillers' terms for Upper Devonian sandstones are listed for the north-central subsurface. Eastern terminology compiled from several areas, with Mahantango subdivision after Dennison and Hasson (1976).



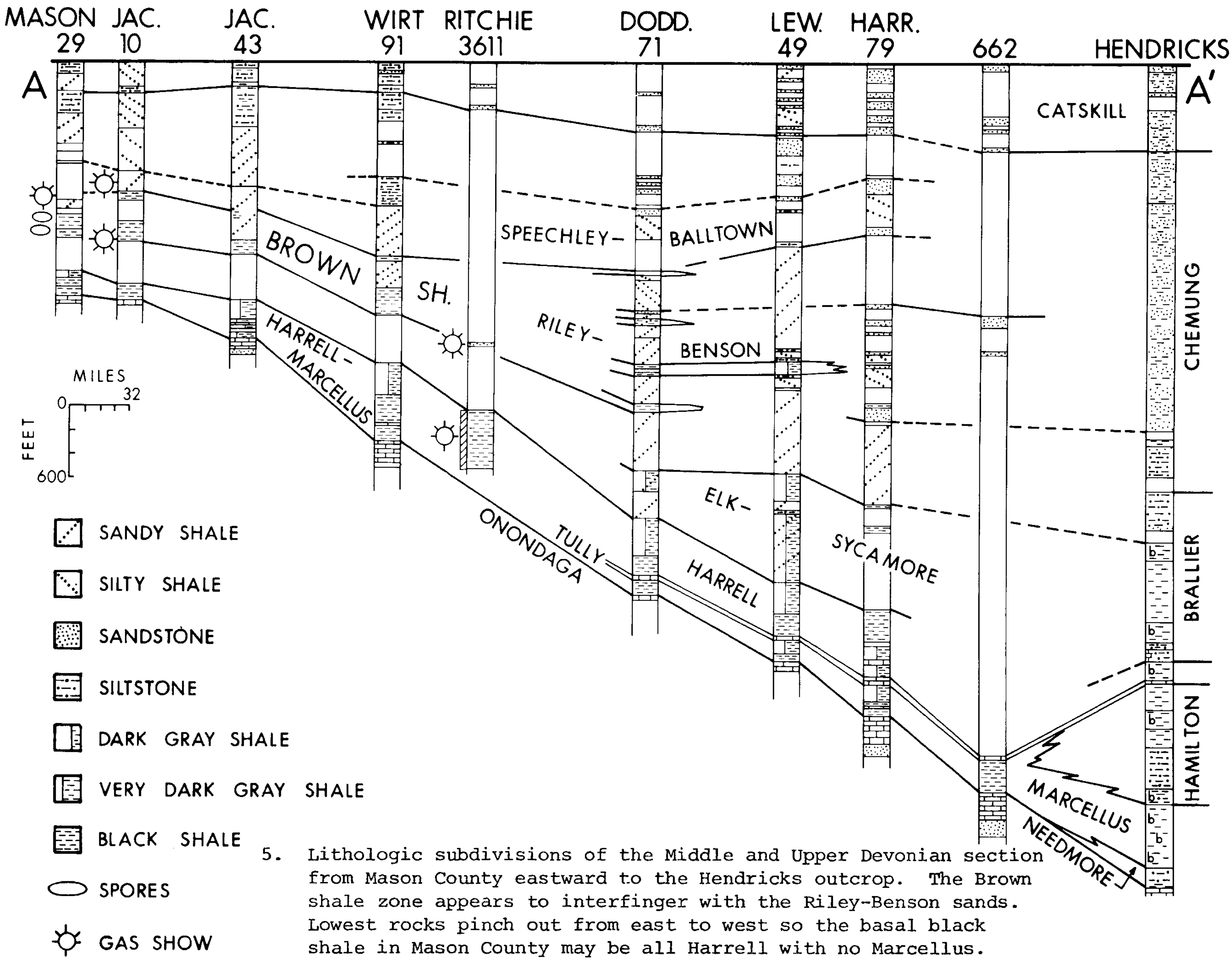
2. Isopach map of the Devonian shales in western West Virginia and their coarser equivalents to the east.



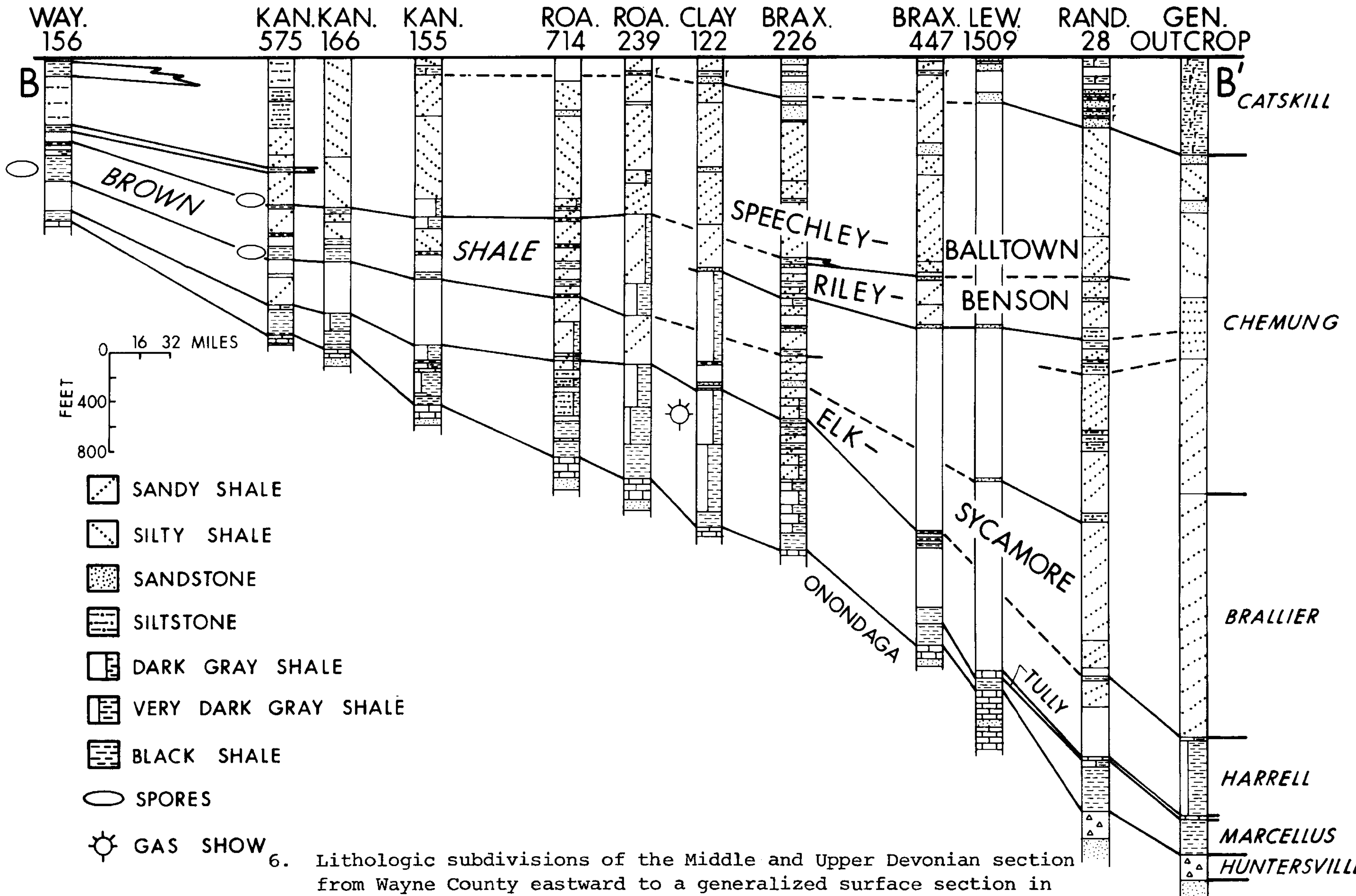
3. Data control points and location of stratigraphic cross sections A-A', B-B', and C-C'. Due to the small scale, most of the wells within fields are not shown. Areas of concentrated drilling, shown by 3 patterns, contain several thousand control points.



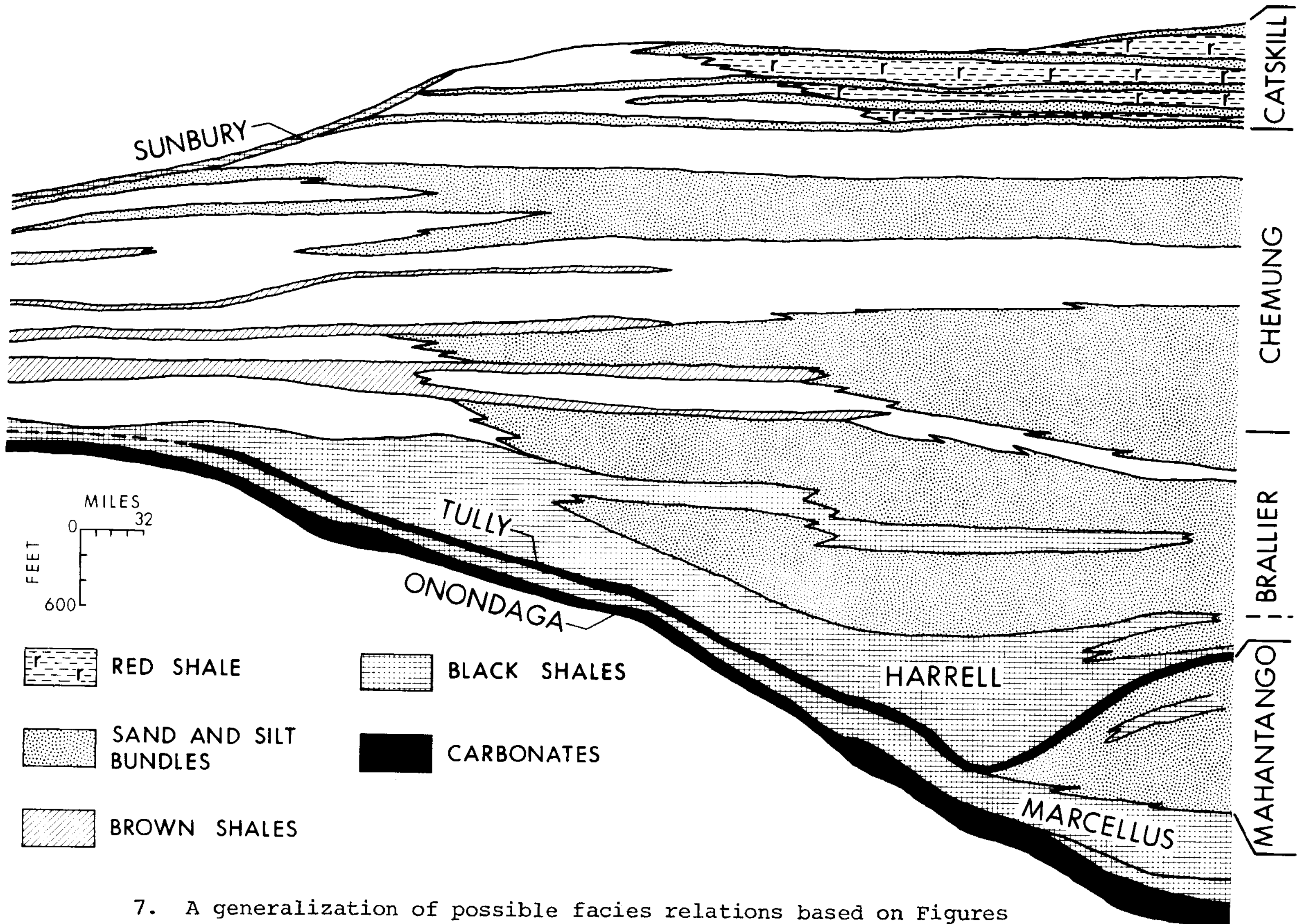
4. Subdivisions of the Devonian shale sequence based on sample descriptions of Martens (1939, 1945). "Sandy" refers to an upper sandy, silty, gray and greenish-gray shale interval, underlain by dark and very dark gray, so-called "Brown shales." The Brown shale zone is separated from the basal very dark gray and black shale zone by an interval of greenish-gray shale. County and permit numbers shown at top.



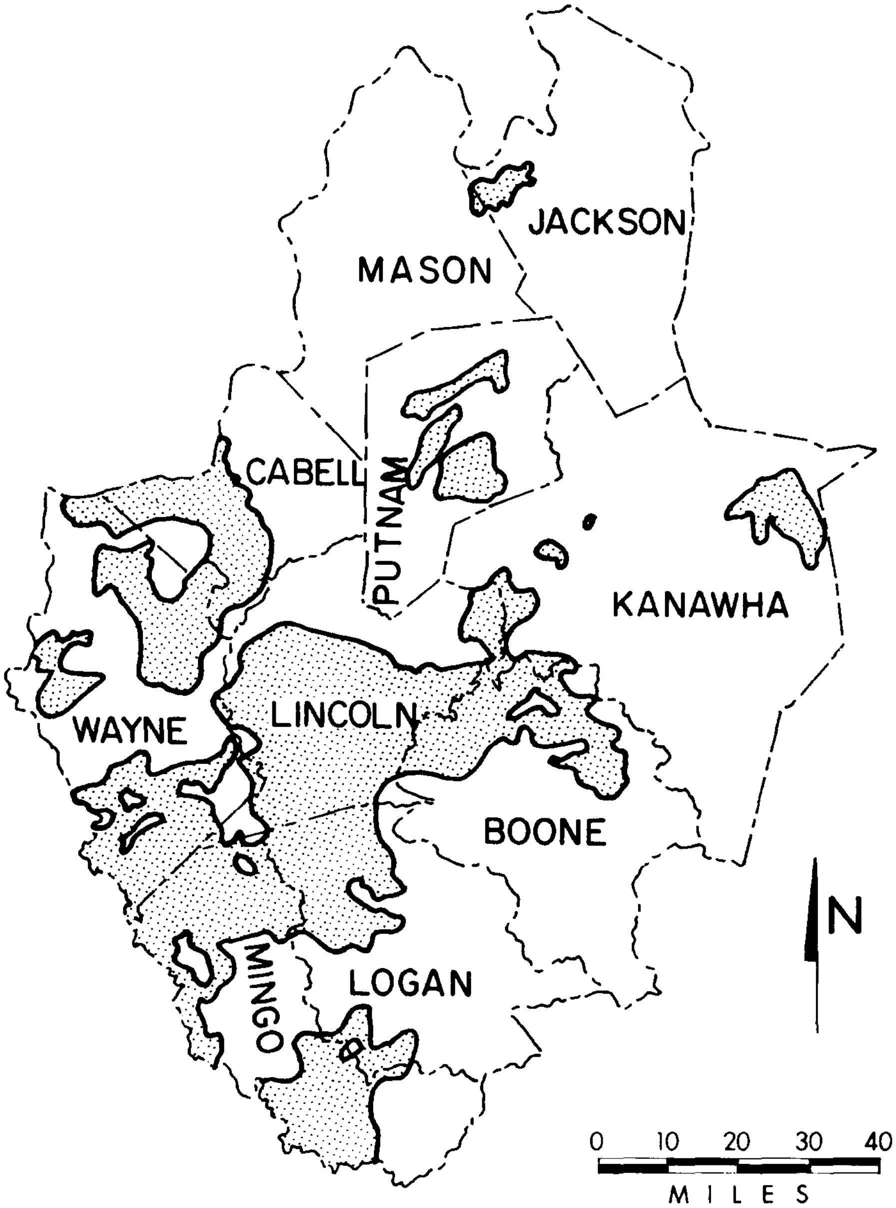
5. Lithologic subdivisions of the Middle and Upper Devonian section from Mason County eastward to the Hendricks outcrop. The Brown shale zone appears to interfinger with the Riley-Benson sands. Lowest rocks pinch out from east to west so the basal black shale in Mason County may be all Harrell with no Marcellus. Hamilton of older usage equals Mahantango.



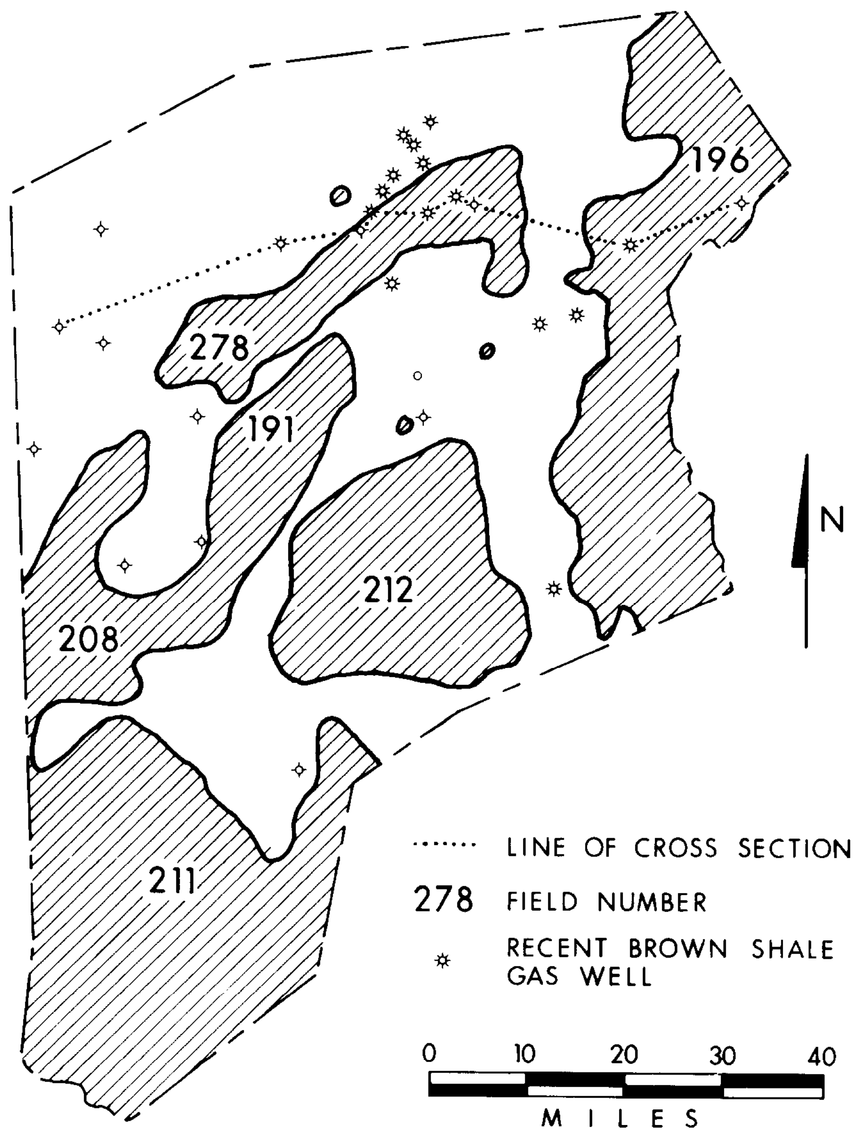
6. Lithologic subdivisions of the Middle and Upper Devonian section from Wayne County eastward to a generalized surface section in Randolph County. A younger Brown shale is present in Wayne County. The main Brown shale zone again appears to be equivalent to lower Chemung. Lowest rocks pinch out with younger units progressively on-lapping to the west.



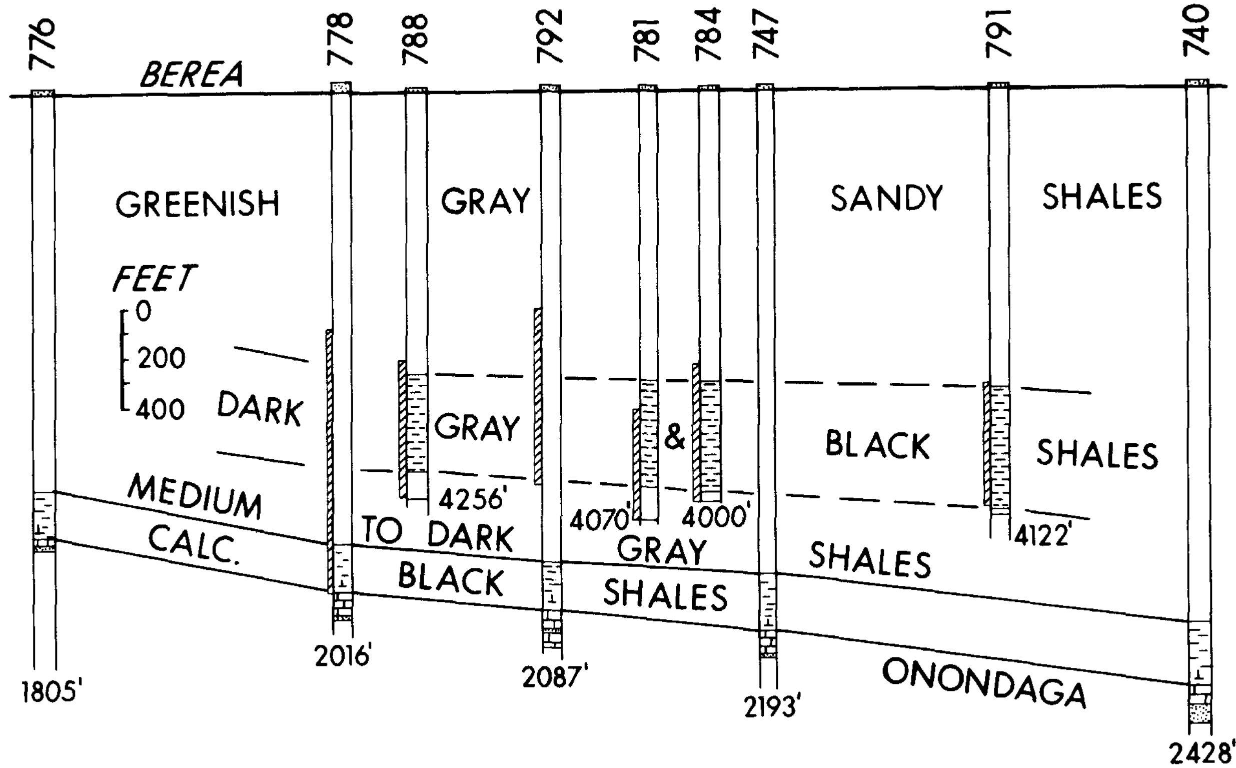
7. A generalization of possible facies relations based on Figures 5 and 6. Younger sandstone units prograde farther westward and older dark shales extend farther eastward.



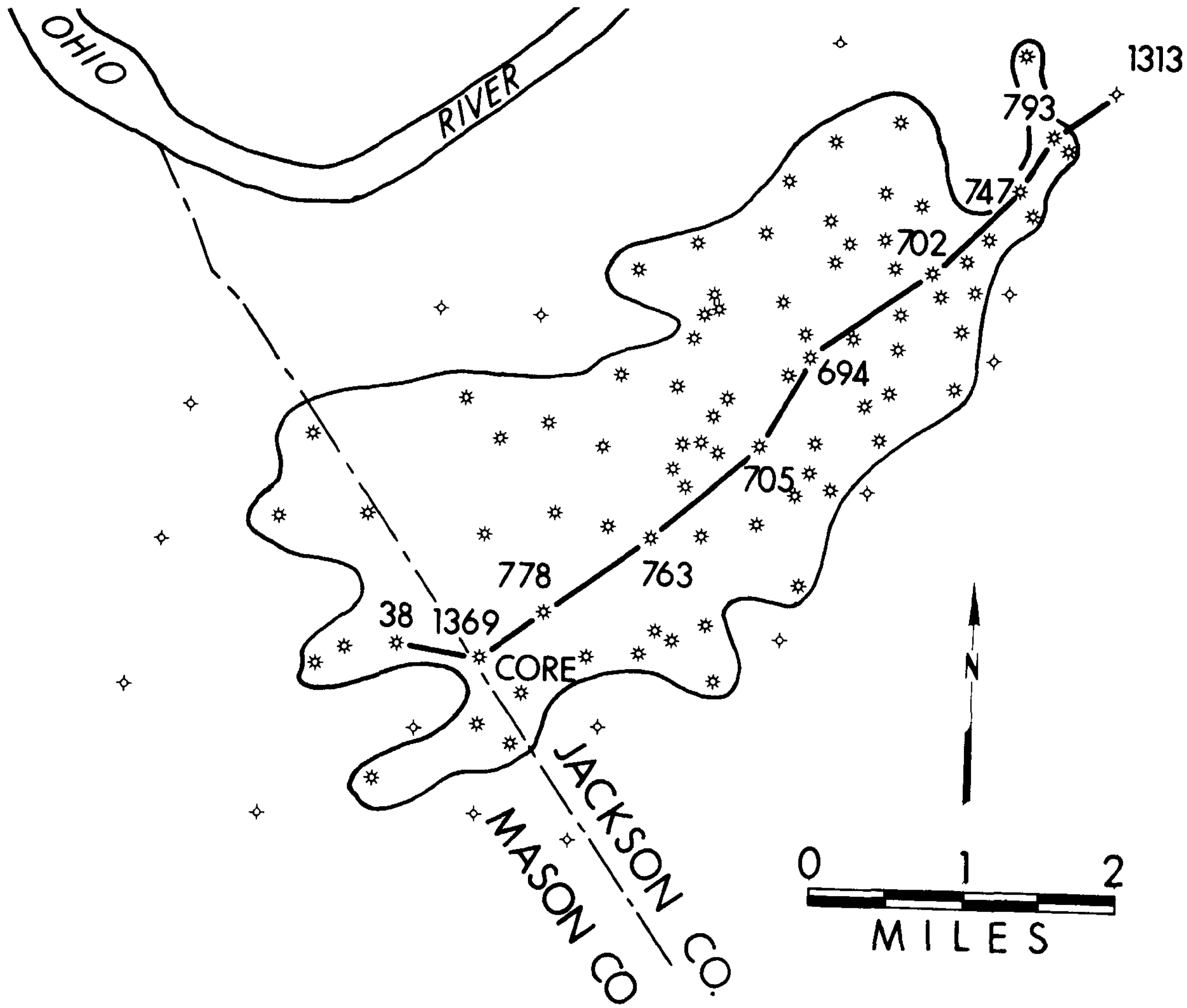
8. Gas fields with production from the Brown shale in southwestern West Virginia. Production extends northward from Cabell County into Ohio, and southwestward from Wayne and Mingo Counties into the Big Sandy Field, eastern Kentucky.



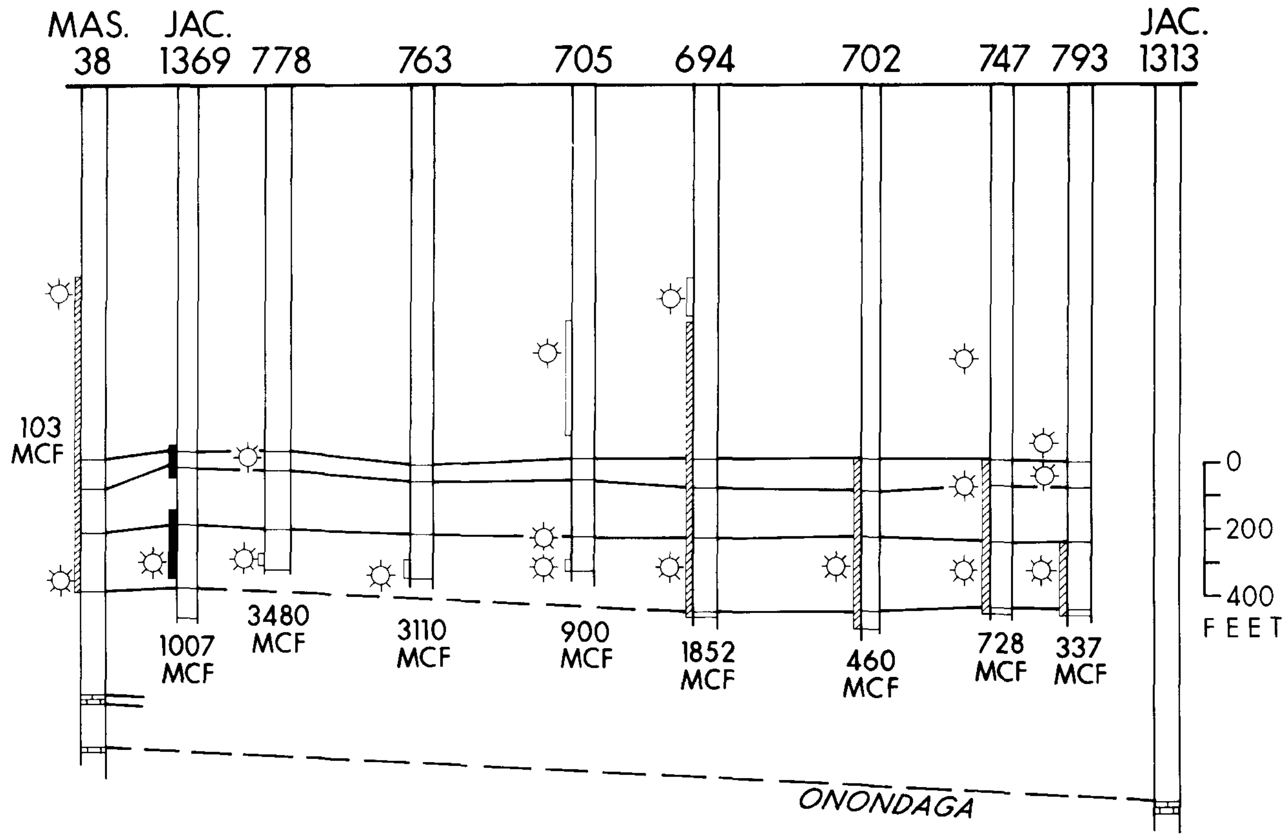
9. Gas fields in Putnam County, W. Va. Field numbers are from the 1970 Oil and Gas Fields Map (Cardwell, et al). Those with Brown shale production are: Midway-Extra (278), Red House (191), and Scott Depot (212). Line of section (Figure 10) also is shown.



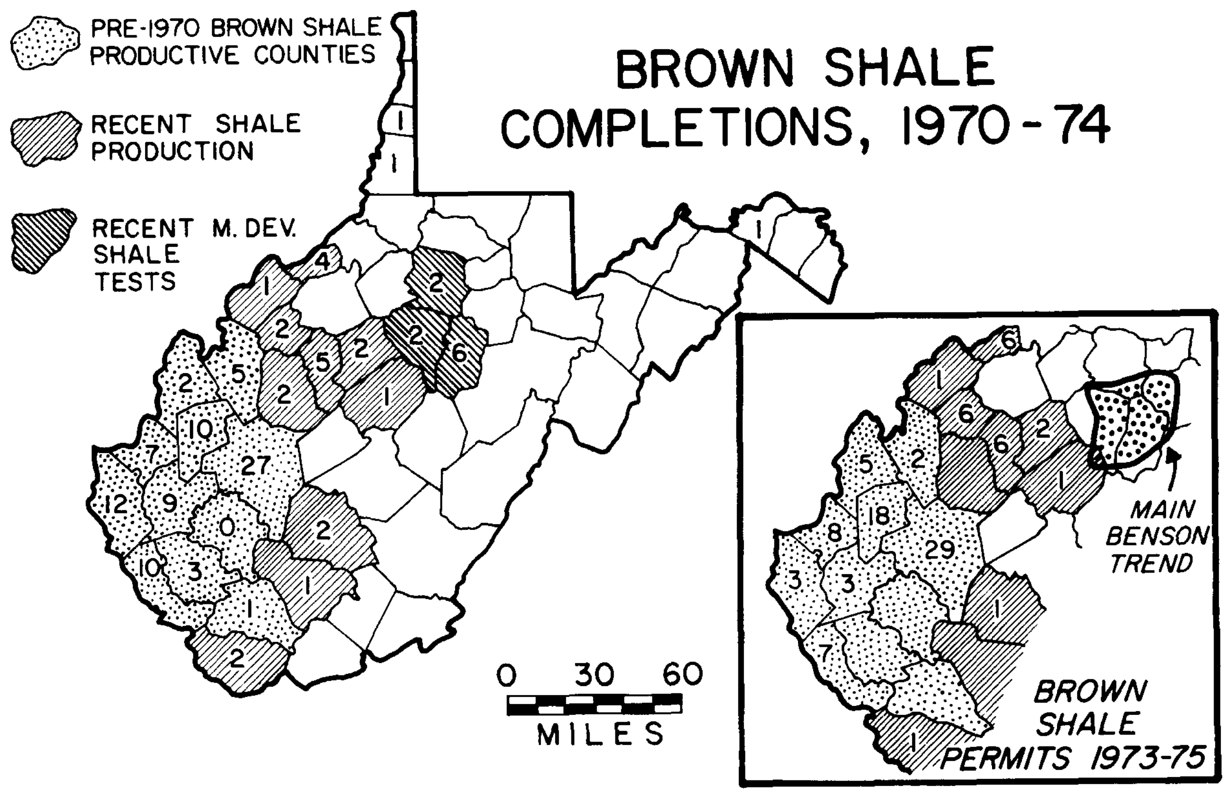
10. Cross section of the Devonian shales in northern Putnam County illustrating a four-fold division of the shales based on cable-tool drillers' logs. These 4 divisions compare well with those shown on Figure 4. Well numbers are state permit numbers; total Devonian shale thickness shown below wells; total depth indicated for wells not penetrating the entire shale sequence. Hachured patterns on the left of wells indicates the interval that was shot.



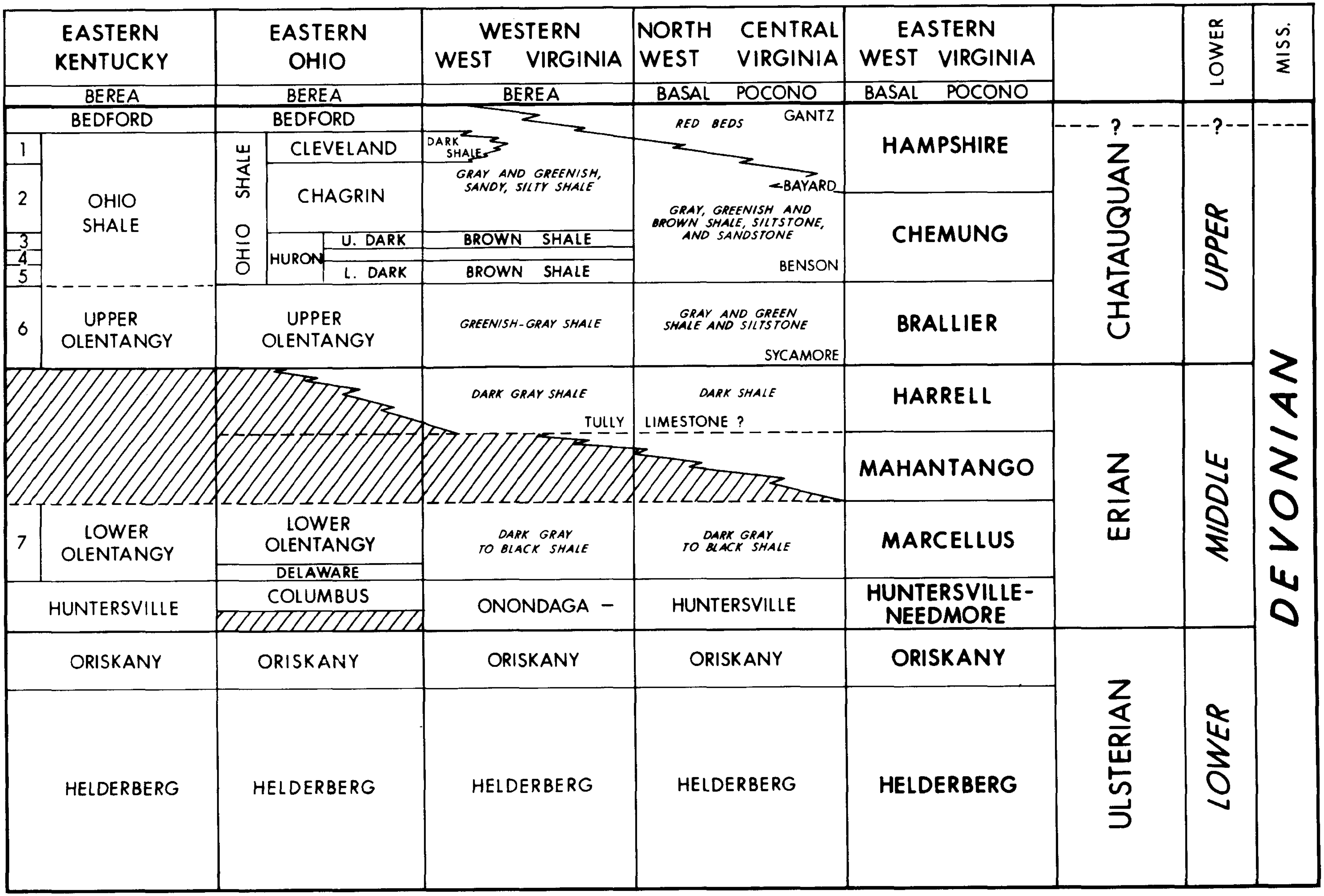
11. The Mt. Alto (Cottageville) Field, Mason and Jackson Counties, W. Va. with line of section (Figure 12) and location of oriented core (#1369).



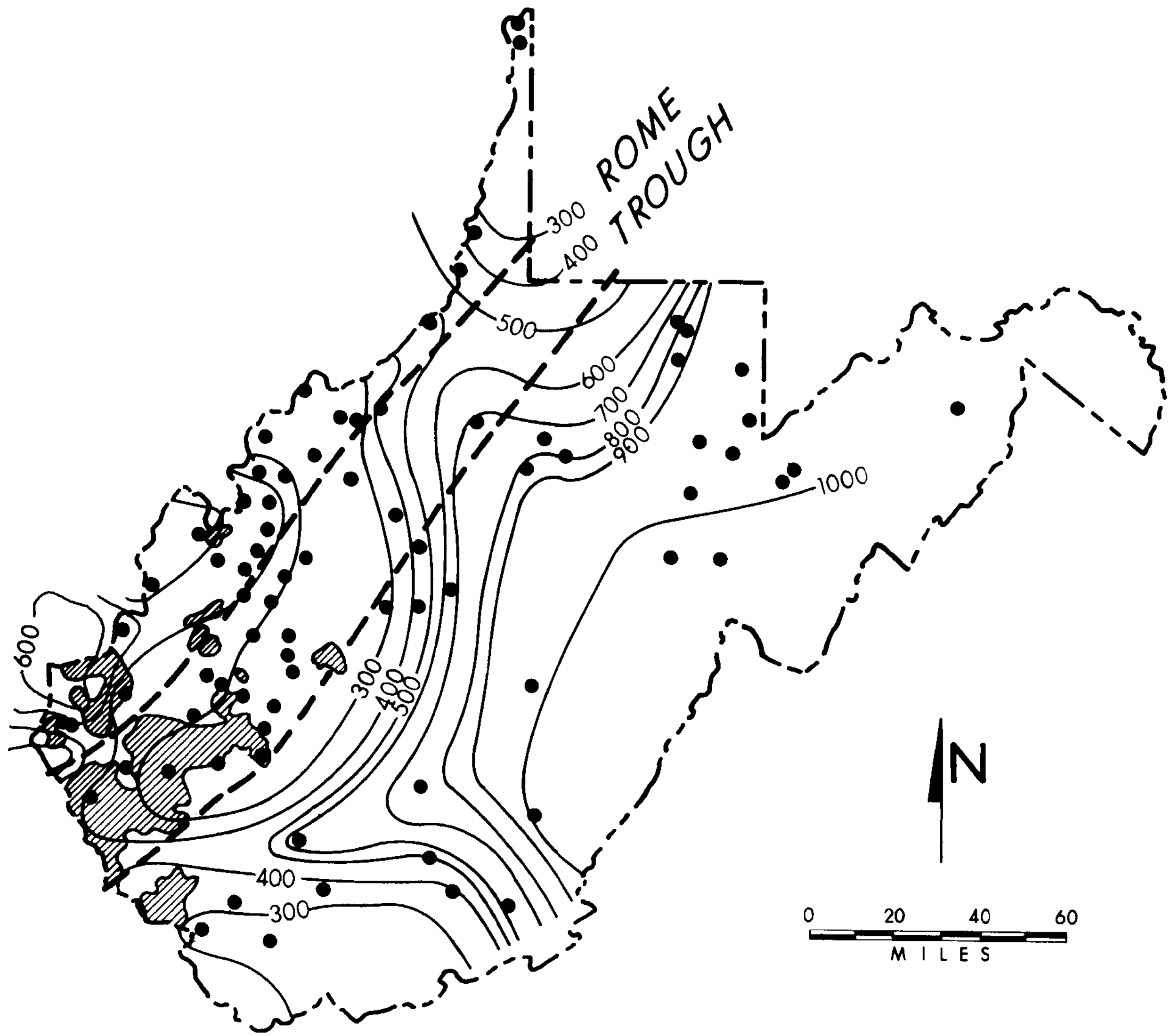
12. Cross section through Mt. Alto (Cottageville) Field illustrating the subdivision of the Brown shale zone based on cable-tool drillers' logs. Gas pays and shows and shot intervals (hachured) also are shown, with final gas flows listed below each well. Solid patterns beside Jac 1369 represent cored intervals.



13. Trends in Brown shale drilling during the past several years. Permits have been issued and wells completed in areas of shallow Mississippian production eastward of Devonian shale production, and deeper tests have been drilled in the Benson sand trend to test Brallier and Middle Devonian clastics. Numbers indicate wells completed and permits issued in each county.



14. Preliminary correlation chart for Middle and Upper Devonian rocks in West Virginia and adjacent areas. Subsurface division in West Virginia (W & NC) based on lithology and gamma-ray log stratigraphy, not formal outcrop terminology. Dark shales in West Virginia are correlated with formal and informal units in Ohio and Kentucky as subdivided by Schwietering (1970) and Provo (1976), respectively. The numbers on the far left refer to the 7 subdivisions of Provo.



15. Brown shale gas fields, thickness of Brown shales (from deWitt, et al, 1975), and approximate position of the Rome Trough in West Virginia. Thick areas of dark organic-rich shale that overlie this Cambrian fault block may be the area of greatest potential for new exploration.