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OIL AND GAS WELL ANALYSES OF HYDROCARBON POTENTIAL OF BUCHANAN, DICKENSON AND WISE COUNTIES, VIRGINIA

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OIL AND GAS WELL ANALYSES OF HYDROCARBON POTENTIAL OF BUCHANAN, DICKENSON AND WISE COUNTIES, VIRGINIA

Frank H. Jacobeen, Jr.

ABSTRACT

Correlation of the Devonian and Mississippian section across the coalfield region of southwestern Virginia is made on all of the petrophysical logs available in the files of the Virginia Divisions of Mineral Resources and Gas and Oil, Department of Mines, Minerals and Energy. Ten structure contour maps, nine isopach maps, and five cross sections show that gas production is not related to geologic structure in these counties. Economically recoverable gas occurs in overlapping patches or restricted areas within the various Mississippian units. Most areas have two or more productive zones. Gas in the Devonian shales probably occurs in a similar manner, but production from Devonian shales appears to ubiquitous because of the completion techniques used. Producible undiscovered reserves from all horizons, based on past success statistics, are estimated to be 1,053 billion cubic feet of gas (1 trillion, 53 billion cubic feet).

The strata appear to be almost uniformly deposited across this area, except for slight regional thickening or thinning. Abnormally thick sections encountered in drilling are caused by structural aberrations. Numerous north-trending structures in the region are at a sharp angle to the northeast regional strike of the Appalachians. These anomalous trends are related to lateral ramping of the Pine Mountain fault and its branches from one decollement level to another and the crumpling of the overlying Cumberland Overthrust block. Faults, domal structures, and folds in the Pine Mountain fault and associated rocks are caused by duplex structures present below the top of the Corniferous.

INTRODUCTION

This study covers Buchanan, Dickenson, and Wise Counties in southwestern Virginia between 36°50' and 37°30' north latitudes and 81°30' and 82°45' west longitudes (Figure 1). Most of the area is in the Appalachian Plateaus physiographic province, where Pennsylvanian rocks are present at the surface. About 70,000 acres of southern Wise County, where rocks of Ordovician age are exposed on the Powell Valley anticline, are in the Valley and Ridge province. The topographic surface of the report area is generally rugged and highly dissected by streams. Elevations in these counties range from about 500 feet above sea level in Powell Valley to over 4200 feet at High Knob near the south-central border of Wise County.

PURPOSE

This study was initiated in 1986 because of the increased drilling activity that had occurred in Buchanan, Dickenson, and Wise Counties, Virginia during the previous two years. The established gas production was examined in these counties to identify the geologic parameters that control production, and to determine the remaining hydrocarbon potential of these counties.

This study illustrates the distribution of the potentially gas-bearing rock strata within the Mississippian rocks and the Devonian shales in Buchanan, Dickenson, and Wise Counties, Virginia. It also reviews the apparent relationship between the stratigraphy, geologic structure, and the known occurrences of gas. The structure and thicknesses of Devonian and Mississippian units are mapped, as well as the structure on the underlying Corniferous. A map of the Pine Mountain thrust fault surface is presented.

APPALACHIAN BASIN

Buchanan, Dickenson, and Wise Counties are in the southeastern part of the Paleozoic Appalachian Basin, an elongate sedimentary basin in the eastern United States (Figure 1). This basin is bounded in Canada on the north by the Canadian shield, on the east and southeast by the Blue Ridge Mountains and the Piedmont Plateau, on the west by the Cincinnati-Findlay arches, and on the southwest by the cover of Gulf Coastal Plain sediments. Subsidence and deposition in the southern Appalachian region during the Paleozoic resulted in an accumulation of about 25,000 feet of sediment in this part of the basin during a period of about 280 million years.

At the end of the Paleozoic, this mass of sedimentary rock was compressed perpendicular to the basin's longest axis by forces which were directed from the east and southeast by the collision of the African and North American continents. The intensity of deformation created by these forces decreased progressively from east to west. An apparent

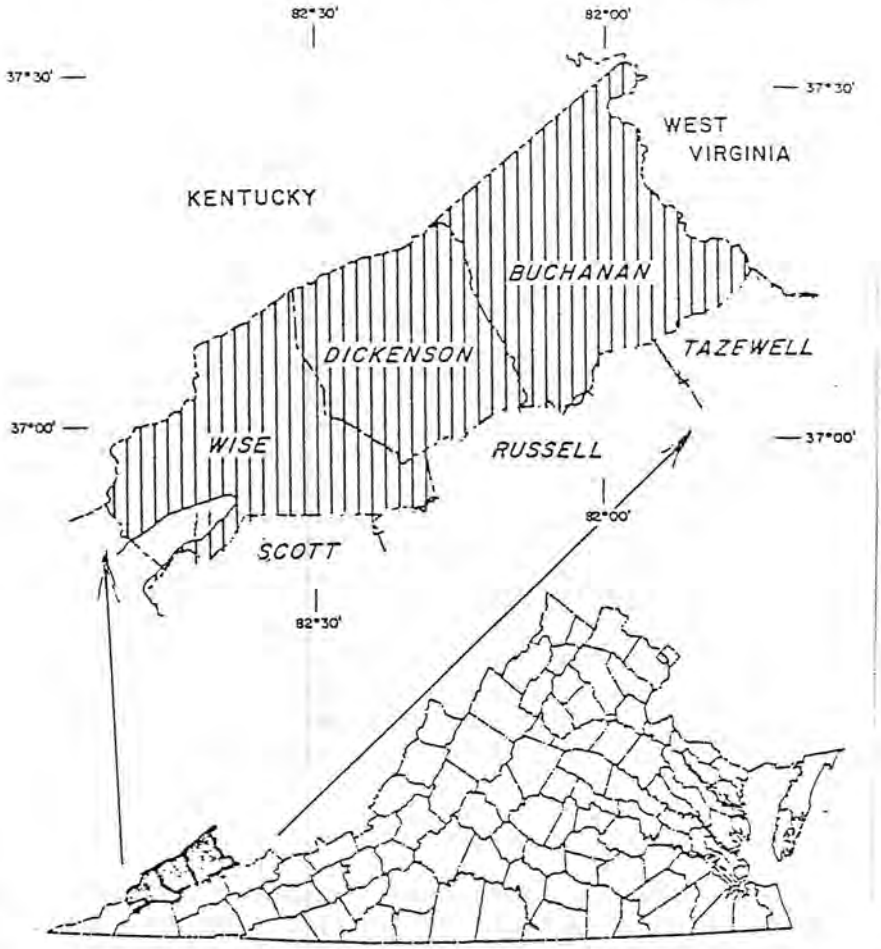


Figure 1. Location map of Buchanan, Dickenson, and Wise Counties, Virginia, in the Appalachian basin.

change in geologic structure occurs on the eastern side of the Appalachian Plateau region, along a line called the Appalachian structural front by Price (1931) and the Alleghany structural front by Rodgers (1953). The Valley and Ridge to the east of this structural and topographic front contains closely spaced thrust faults and/or subparallel folds at the surface. To the west of the front, the character of the folding and thrusting appears different, particularly in Virginia and Tennessee. There, broad, flat-lying thrusts occur in the Plateau which carry relatively undeformed sheets of rock westward for long distances. The surface rocks of Wise, Dickenson, and Buchanan Counties are to the west of the Appalachian structural front and consist of the relatively flat-lying rocks of Pennsylvanian age on and near a great geologic structure called the Cumberland Overthrust block or Pine Mountain block by different authors (Wentworth, 1921; Butts, 1927; Miller, 1973; Harris and Milici, 1977).

PREVIOUS ACTIVITIES

Commercial production of hydrocarbons was established in the north-central part of the Appalachian basin in 1849 with the completion of Colonel Drake's oil well near Titusville, Pennsylvania. Oil and gas production from rocks of Pennsylvanian through Ordovician age has spread throughout the basin in subsequent years. It was not until 1948, however, that gas was discovered in Buchanan County, Virginia, followed in 1949 by Dickenson County and then in 1953 by Wise County (Le Van, 1962). Early development was slow because pipelines were not available to deliver gas to distant markets until 1952 in Buchanan County and 1956 in Dickenson County. Even with these pipelines, development continued slowly until 1973, when activity increased greatly because of increased demand and the sharp rise in the price of natural gas. Some of this production, particularly that from the Devonian shales, appears to be an extension of the Big Sandy field of Kentucky into southwestern Virginia.

Although the oil and gas industry recently has suffered a slump, with drilling greatly reduced, activity in these three counties of Virginia has continued at a high rate. Pipelines completed in the 1980s have increased the outlets to the gas producers in southwest Virginia. This, along with the multiple reservoirs and high completion rates, has given the natural gas industry in this part of Virginia renewed vigor.

METHOD OF STUDY

This study is based on correlations obtained solely from petrophysical logs. Records through 1987 show 891 wells had been drilled in these three counties since 1940. Petrophysical logs were available for only 506 of them. The stratigraphic interval studied extends from the top of the Mississippian Greenbrier Limestone to the base of the Devonian shales (Table 1).

Correlation of formations was started between wells in Buchanan County and carried across Dickenson County into Wise County. Correlating was done in a series of loops. After correlations were confirmed around each loop, adjacent wells were matched to this control. Where wide gaps exist between data points, errors were minimized by making correlations between outlying data points and numerous wells in the network.

Data were transferred from the logs to 1:24,000 scale topographic maps. From this data base, the subsea depths to the individual horizons and the thicknesses were transferred to separate maps at a scale of 1:50,000 and these maps were contoured. The maps were contoured independently first, then compared for consistancy of geologic interpretation, and modified where appropriate. Where gross differences were apparent between horizons of the structure maps, data were checked again and the maps recontoured to produce a more compatible expression, providing that the basic data were not violated. In some areas, the paucity of data enables several valid contour interpretations to be made.

Devonian intervals isopached for Wise County include the Olentangy Shale (Plate 1), lower Huron Shale (Plate 2), middle Huron Shale (Plate 3), the upper Huron - Three Lick Cleveland Shale interval (Plate 4), and the total Devonian shale interval (Plate 5). Where control exists in the three counties in the Mississippian section, isopachs were prepared for the Berea Sandstone (Plate 6), the Sunbury Shale (Plate 7), the interval from the top of the Greenbrier to the top of the Sunbury Shale (Plate 8), and for the Greenbrier Limestone (Plate 9).

Structure contour maps were made in Wise County on tops of the Devonian Corniferous (Plate 10), the Olentangy Shale Member (Plate 11), the lower Huron and middle Huron Shale members (Plates 12 and 13). Structure maps covering parts of Buchanan, Dickenson and Wise Counties were constructed on the top of the Berea Sandstone (Plate 14), Sunbury Shale (Plate 15), the base of the Greenbrier Limestone (Plate 16), and on top of the Greenbrier Limestone (Plate 17). A structure map on the Pine Mountain fault surface was prepared, also (Plate 18).

Stratigraphic cross section, A-A', was drawn across the three counties (Plate 19) using 26 wells to show the gross stratigraphic relationships of the beds in the Devonian, Mississippian, and overlying Pennsylvanian formations. Wide gaps exist between some of the control points. The wells used in this section were selected carefully to show good correlations and to provide good coverage of the productive areas. The most consistent correlation is the top of the Sunbury Shale and this is used as a datum for the stratigraphic cross section (Plate 19).

Four structural sections in Wise County were made using gamma-ray and density logs; B-B', generally west to east along structural strike; C-C', a dip section northwest to southeast; D-D', generally north to south and E-E', generally west to east. The locations of these lines are shown on Plate 1.

Tabulation of all data used in this study and the Oil and Gas Summary Reports for all of the wells used on the cross sections are on open file at the Virginia Division of Mineral Resources, Charlottesville, Virginia.

STRATIGRAPHY

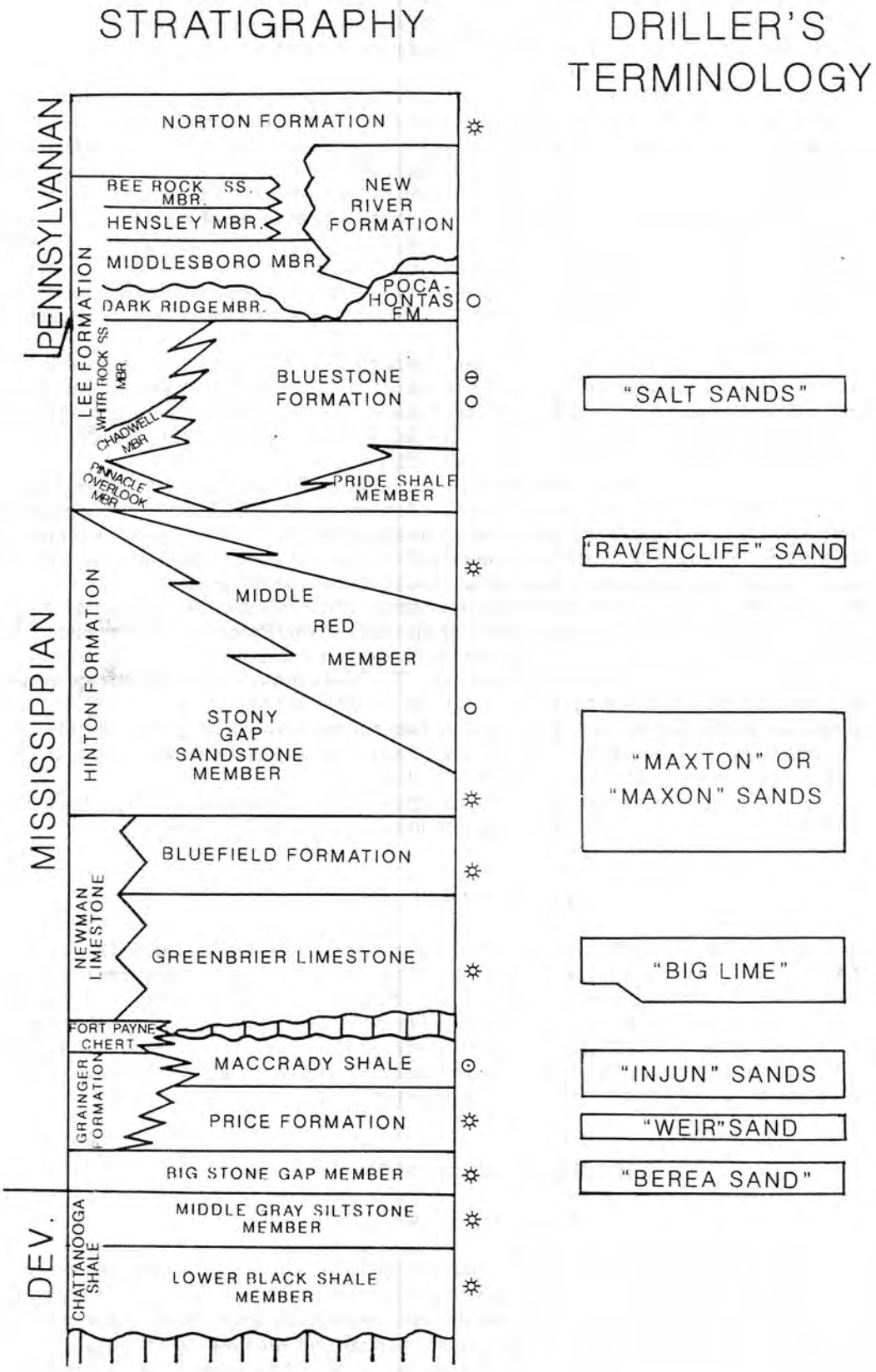
There are insufficient petrophysical log data to make a complete stratigraphic cross section of the Devonian rocks to the northeast of Wise County along Section A-A' (Plate 2). The stratigraphic cross section across Buchanan, Dickenson, and Wise Counties is presented that includes rocks from the Devonian Shale interval through the Pennsylvanian section, which crops out at the surface. The Pennsylvanian rocks were not studied for this report. The location and changes in orientation of the line for A-A' should be considered when viewing this section. Abrupt changes in thickness in the Pennsylvanian interval coincide with sharp changes in direction of the line of section. Apparent thickness anomalies, however, are not present in the Mississippian strata on this section.

MISSISSIPPIAN-DEVONIAN STRATA

CHATTANOOGA SHALE

The Mississippian-Devonian shale interval in Wise County is equivalent to the lower black shale member, the middle gray siltstone member, and the lower part of the Big Stone Gap Member of the Chattanooga Shale as mapped nearby on the surface (Kepferle and Roen, 1981). The Devonian shales are typically gray to black, made up of highly compacted, clay, and clay-sized quartz rich particles in organic material, and silt-sized quartz particles. In the subsurface, different names have been used within this interval throughout the Appalachian basin. The names used in this report are those generally accepted by industry for this area (Table 1). In ascending order these names are: the Olentangy Shale, the lower Huron Shale Member (equivalent to the lower black shale member of the Chattanooga

Table 1. Stratigraphic Nomenclature of Devonian and Mississippian Strata in Southwestern Virginia.



Shale), the middle Huron Shale Member, the upper Huron Shale Member and the Three Lick Bed (equivalent to the middle gray siltstone member of the Chattanooga Shale), and the Cleveland Member (equivalent to the lower part of the Big Stone Gap Member of the Chattanooga Shale as mapped on the surface). The Cleveland Member lies immediately below the Mississippian Bedford Shale or the Berea Sandstone, where the Bedford is absent.

On the gamma-ray logs, the lower Huron Shale Member, upper Huron Shale Member and Cleveland Member are represented by a very high gamma count (on the log the curve moves to the right). This suggests that these units have a higher-than-average content of organic material that is associated with radioactive minerals and that they are, in fact, black shales with only minor amounts coarser silicic clastics. These units also exhibit relatively lower bulk densities, as shown by the bulk density logs. This is also an indication of the characteristic relatively high porosity of pure shale.

The isopach map of the total Devonian Shale thickness (Plate 5) shows that the shales are less than 600 feet thick in western Wise County, thicken gradually to the area just east of Roaring Fork, and then thicken greatly in short distances, from 800 feet to over 1400 feet thick in the central part of the county. This thick trend strikes slightly east of north along a line through the towns of Josephine and Lipps. A short distance to the east, the total unit appears thin to less than 1000 feet. There are no data for the central third of the county. In the eastern third of the Wise County, sparse data suggest that this unit again thickens from west to east, from less than 900 feet to an excess of 1100 feet. Thus, it is concluded that the undrilled area lying between the Indian Creek and Cranes Nest Rivers contains less than 900 feet of Devonian shale. In an attempt to understand how and why this thickening and thinning occurs, the Olentangy, lower Huron and middle Huron were isopached separately.

The isopach of the Olentangy Shale (Plate 1) in Wise County demonstrates a pattern similar to that shown by the isopach of the total thickness of the Devonian shales (Plate 5). The only significant variation is the presence in the Olentangy of a north trending thin nose near the western edge of the County.

The pattern in the isopach of the lower Huron (Plate 2) varies greatly from those of the total Devonian shale and Olentangy isopachs. The pattern of the lower Huron consists of a dome in the western-most portion of the Wise County replaced eastward by a series of narrow, north-northeast-to north-trending thicks and thins. These apparently are unrelated to the trends in the total shale thickness or to the features present within the underlying Olentangy. Overall thickness appears to be increasing eastward beyond the last data points.

The middle Huron isopach (Plate 3) reveals yet another pattern different from that of the Olentangy. A broad area of relatively uniform thickness has replaced the pattern of adjacent thick and thin areas seen in the underlying unit. Eastward, however, a gradual thickening appears to be occurring in the middle Huron toward the center of the county, similar to that in the Olentangy.

A review of the tabulated data of the remaining intervals suggests that little variation exists in the thickness of the individual beds; therefore, the upper Huron, Three Lick and Cleveland shales were isopached as one unit (Plate 4). Although this composite section is thin, not exceeding 235 feet, a series of northeast-trending thicks and thins appears to be developed. Thickness of the total section of those three units appears to be generally increasing to the southwest beyond the last data points.

The isopach maps of the Devonian shale units in Wise County (Plate 5) indicate the presence of an axis of thickening in the eastern part of Wise County, along Trace Fork Creek. In this feature, the Devonian shale thickness exceeds 1100 feet and the total interval appears to be thickening southward.

MISSISSIPPIAN STRATA

BEREA SANDSTONE

The stratigraphic cross section (Plate 19) of the Mississippian rocks does not show any significant variations in thicknesses across Buchanan, Dickenson, and Wise Counties. Isopachs, however, indicate that variations in thicknesses are present, but structural studies suggest that the anomalies are a result of faulting and folding rather than sedimentary processes.

The basal Mississippian Berea Sandstone interval attains a thickness of slightly over 70 feet in several areas in the western part of Wise County (Plate 6). The thickest areas appear to be in structurally high areas. This suggests that structure and stratigraphy of this unit are related, but in a manner that is not clear. The contact of the top of the Devonian shale and the base of the Mississippian Berea Sandstone is generally marked by a sharp decrease in radioactivity upward. This indicates that a reduction in the amount of relatively radioactive black muds being deposited occurred at this time and that there was a rapid influx of silt-sized siliceous clastics. In some local areas, however, this change is gradual and the contact between these two units is transitional rather than sharp and, thus, more difficult to pick.

The stratigraphic interval called Berea Sandstone in this report is less radioactive than the enclosing shales and is identified by this characteristic on the petrophysical logs. Potter, and others (1983) distinguished the Bedford Shale from the Berea Sandstone. Kepferle and Roen (1981) called this interval Bedford Shale in Wise County. It is difficult, by looking at a petrophysical log, to define the difference between a siltstone or fine sand containing an abundance of organic material and a kerogen-rich black shale. The interval called Berea Sandstone in this report may be equivalent

to or include part of the Bedford Shale, with shale or siltstone laterally replacing the Berea sandstone lithology.

The general interval mapped as Berea has been identified as a deep shelf deposit from two cores (Potter and others, 1983) in Buchanan and Dickenson Counties (BU-83-United Fuel Gas No. 9140T, Pocahontas Mining and DK-59-United Fuel Gas No. 7, Pittston Company [Columbia Gas 9588]). Pepper and others (1954) identified the possible occurrence of a Berea river delta along the northeast edge of Buchanan County based on scarce outcrop data and the similarity of the sediments in Buchanan County to those of the Gay-Fink delta to the north in West Virginia. They named this southern delta the Virginia-Carolina delta. The isopach data, although limited, indicate that this fine-grained sand was deposited under variable conditions across the area. Sparse data in northeastern Buchanan County seem to indicate the presence of a delta lobe or crevasse splay that was modified by southeastward flowing currents. The patterns in western Buchanan and Dickenson Counties are clearly different from this eastern system. On the west, there is a series of relatively thick, narrow, linear sandstone trends that strike south-southwest. The pattern and log characteristics suggest that these are a series of deep water distributary channel fills or submarine canyon fans. Data are not sufficiently clear, however, to rule out the possibility that these may be deep water bars on the edge of the Virginia-Carolina delta. Farther southwest, in western Wise County, the deposits are thinner and have an amoebic pattern, suggesting relatively quiet water deposition. Thickness data in this area also can be contoured as a series of very narrow, northeast-southwest trending features which suggest deep-water oscillation mega-ripples. The thickness of sandstone (100 feet plus) along the east edge of the Jess Fork fault in Buchanan County suggests that there may be stratigraphic control for the location of this fault.

GRAINGER, PRICE, AND SUNBURY FORMATIONS

Above the Berea, Sunbury black shales range in thickness from about 125 feet in western Wise County to over 350 feet in southeastern Dickenson County and eastern Buchanan County (Plate 7). There is a general west-to-east thickening of this unit, with a general north-south strike. There are not enough data available, however, to describe any significant depositional features. The contact of the Berea with the base of the overlying Sunbury Formation is distinctive in most areas. It is commonly picked at the base of a series of very carbonaceous (highly radioactive) fining-upward units. The top of Sunbury is less well defined and is marked by the noticeably lower radioactivity of the overlying Price or its lateral equivalent, the Grainger Formation. There are, however, some localities where it is unclear whether a 20-40 foot unit at the contact belongs to the Price or Sunbury.

Generally, the Price becomes less radioactive upward (decreasing shale content) in units above this contact. Within the upper part of the Price, sandstone units occur that are termed Weir, Keener, and Injun by some operators. These units are correlative in local areas, but they are present or identifiable over the whole area studied. Therefore, they were not mapped in this regional study.

MACCRADY SHALE

The Maccrady Shale overlies the Price Formation. Based on petrophysical log correlations, the Maccrady is thin to absent in Wise County and thickens in Dickenson and Buchanan Counties. This formation does not have a very uniform or distinctive character on the petrophysical logs (Figure 2). In some areas, the Maccrady Shale is similar in character to the Price or is even less radioactive than the upper part of the Price. The contact between the Maccrady Shale and the overlying Greenbrier Limestone is picked on the petrophysical logs at the base of the low radioactivity unit above the Maccrady. This break is generally sharp, but in some areas the pick is arbitrary because the contact is gradational.

GREENBRIER LIMESTONE

The Greenbrier Limestone, although composed of several units and containing numerous higher radioactivity shale breaks, has an overall low radioactivity and a blocky appearance on the logs. The top of the Greenbrier Limestone is recognized easily on the gamma ray logs in most areas. The contact is represented by an abrupt shift to the right of the gamma ray curve as it enters the overlying unit. This overlying unit, the Little Lime, is composed of interbedded limestones and calcareous shales. This shaleness causes the shift to the right, which indicates the increase in radioactivity. In some areas, the contact is a thin shale break on the log (high radioactivity) and this is overlain by a fairly thick limestone unit. The Little Lime is almost always broken by shaley interbeds and the total unit has an overall higher radioactivity that the Greenbrier Limestone. In Wise County, however, it is difficult to distinguish between the Little Lime and the upper 100 to 150 feet of the Greenbrier Limestone. In this area, the upper section of Greenbrier may appear very similar to the lower Little Lime in other areas and careful correlation from well to well is necessary.

The thickness of the combined Greenbrier-Price interval ranges from less than 600 feet in northern Dickenson County and western Buchanan County to more than 850 feet in eastern Buchanan County and southeastern Wise County (Plate 8). The combined thickness of these units is fairly constant in southwestern Wise County, but increases slightly in the vicinity of the Buck Knob anticline. From southeastern Wise County to southwestern Buchanan County, isopachs

trend progressively to the northeast-southwest. Thicknesses increase from about 650 feet in northwestern Dickenson County and southwestern Buchanan County to over 850 feet in the southern corner of Dickenson County. The data are scattered but they indicate that there is a similar trend in eastern Buchanan County.

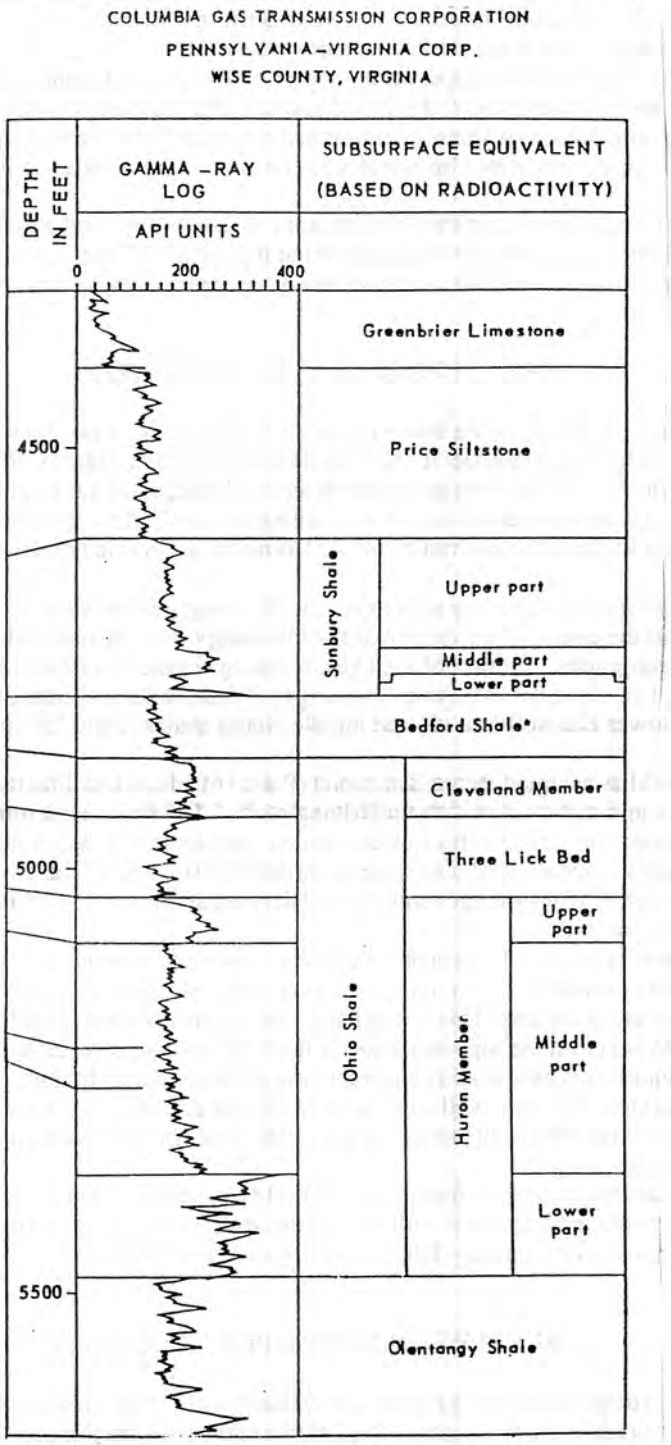


Figure 2. Stratigraphy and radioactivity of the Chattanooga Shale and Price Formation in Southwestern Virginia.

The Greenbrier isopach (Plate 9) shows a general increase in thickness from northwest to southeast across the three-county area, with a well developed northeast strike. Data strongly suggest, however, that there is an anomalous area between the Buck Knob anticline in Wise County and the Coeburn fault along the Wise-Dickenson County line. The Greenbrier appears to be thickening into a re-entrant east of the Buck Knob anticline, where there are no data. No other significant anomalies are present.

GEOLOGIC STRUCTURE

Wise, Dickenson, and much of Buchanan County are on the Cumberland overthrust block, which is underlain by the Pine Mountain thrust fault. This thrust has been described as sub-horizontal and lying mostly within the Devonian shales. This fault ramps upward and is exposed at the surface by erosion. Its trace extends from Tennessee, across easternmost Kentucky into Virginia in the most northern part of Dickenson County and into the western corner of Buchanan County. In southern Wise County, the Pine Mountain fault is buried under the Powell Valley anticline. Investigators have mapped anticlines, synclines, and faults at the surface in these counties and these features are shown on Plates 1-18. Detailed mapping of surface lineaments has been done from aerial photographs (T. M. Gathright, in preparation).

Contouring on subsurface horizons confirms the presence at depth of several structures that have been mapped on the surface and also shows features that are not apparent at the surface. There are no subsurface data along some surface features and, therefore, their structure at depth cannot be determined accurately.

STRUCTURE ON DEVONIAN HORIZONS

A structure-contour map on the top of the lower Devonian Corniferous formation in western Wise County (Plate 10) indicates a dip to the south of about 65 feet to the mile (less than 3/4 of a degree). Where Roaring Fork meets the Powell River, the strike of the formations swings sharply to the northeast, almost at a right angle. A northeast-striking, northeast-plunging syncline mapped in the subsurface on the top of the Corniferous lies under the axial trace of Buck Knob anticline. Sparse data suggest that elevations on the Corniferous continue to rise toward the east in the central part of Wise County.

The structure map in western Wise County on top of the Olentangy Shale Member (Plate 11) appears similar to that of the Corniferous, but the axis of the syncline at the Olentangy level has moved two miles to the west of the Corniferous axis. At the geographic position of the Corniferous syncline, a northeast-striking, southwest-plunging anticlinal nose is developed on top of the overlying Olentangy. Dip at the eastern edge of the area descends eastward. Structure at the top of the lower Huron (Plate 12) and middle Huron shales (Plate 13) appears similar to the structure on top of the Olentangy.

Mapping on top of the Mississippian Berea Sandstone (Plate 14) which lies directly above the Devonian shales, shows only minor changes in structure from the underlying rocks. The broad anticlinal nose or dome flank which plunges southward dominates the western third of the county. Eastward of that, a northeast-striking, southward-plunging, broad synclinal area is apparent which replaces the better defined synclinal area of the underlying Devonian rocks. The anticlinal area east of that syncline remains well defined at this level, with its axis beneath the axis of the Buck Knob anticline on the surface.

The Pine Mountain fault appears to be expressed as a very low density zone in the Devonian shales on the bulk density logs. This zone, shown on the cross sections, usually occurs forty to fifty feet below where it is identified from samples and gas blow-outs during drilling. This low density zone is generally traceable from well to well. Other zones of very low bulk density do occur on the logs and some of them are shown as possible faults or zones of movement. If these zones are truly faults, the low bulk density may represent development of fracture porosity, gouge, or brecciated material along the fault surface. In some well logs, no low density zone exists which is correlatable with the Pine Mountain fault, even though it is certain that the fault must cut the well. In these wells, it is assumed that the fault zone is tight and without significant gouge.

The structure map on the Pine Mountain fault plane (Plate 18) is similar to that on the Corniferous, with the broad domal area in the western part of the County and with a northeast-striking synclinal area developed with its axis through well no. WS-121 (ANR Production Company-Penn Va. 21 Well No. 10081).

STRUCTURE ON MISSISSIPPIAN HORIZONS

In Buchanan County, petrophysical logs of wells are available only in the westernmost corner of the county and within a belt parallelling the northeastern boundary. Duplication of the stratigraphic section in two wells in the western area (BU 93, United Fuel Gas, R. D. Bell No. 9518 and BU 134, Columbia Gas, E. Clevinger No. 9826T, Elkhorn City Quadrangle) confirms the presence of the Jess Fork fault parallel to and six miles northeast of the Russell Fork fault. Interpretation of subsurface data along the northeastern boundary of this county indicates that a series of northeast-trending anticlinal and synclinal noses are present. These features are different, both in character and orientation, from any other structures mapped in these three counties. In eastern Buchanan County, the beds have been folded into simple parallel folds. Young (1957) discussed the presence of the Pine Mountain thrust in the subsurface between the Russell Fork and Jess Fork faults. It is proposed that this folding in eastern Buchanan County is evidence that the Pine Mountain thrust is present to the northeast of the Pine Mountain block, under all of Buchanan County. No wells have been drilled deep enough to confirm this premise, but if it is correct the Pine Mountain fault, although with only slight displacement,

continues eastward at least 25 miles beyond the Jess Fork fault to the Canebrake fault in McDowell County, West Virginia.

In the northern part of Dickenson County, duplication of part of the stratigraphic section in one well (DI 66, Columbia Gas, Pittston No. 22-9714T) clearly locates the Pine Mountain fault in the subsurface. The fault is exposed at the surface to the west near Breaks.

In the northeastern part of Dickenson County, the subsurface presence of the Russell Fork fault is apparent in the vicinity of Haysi. Data points are not close enough, however, to determine accurately the amount of lateral displacement on this fault.

The Little Paw Paw fault along the Dickenson-Buchanan County line is a surface-mapped feature. Other than a synclinal re-entrant north of Vicey, there is no subsurface evidence of this fault.

East-trending anticlinal and synclinal noses have been interpreted in the central portion of Dickenson County from the subsurface data. These structures, particularly the intense low in the southern part of the county, could be in part the result of faulting. A simple no-faulting interpretation is shown because faulting has not been encountered in the wells.

In the central part of Wise County, subsurface control in the Mississippian from petrophysical logs, although sparse, clearly indicates the presence of the north-south trending Buck Knob anticline. At the surface, the eastward plunge and termination of the Powell Valley anticline in the southern part of the county is indicated by the steep dips which separate this anticline from the comparatively flat-lying and gently folded rocks of the Pine Mountain sheet to the west. Faulting has not been mapped on the surface along this structural front. These steep dips strongly suggest, however, that faults exist in the subsurface. There are no subsurface data relating to this structural front, or to the Dorchester syncline, Gladeville anticline, Glamorgan fault, or Middlesboro syncline.

In Wise, Dickenson, and Buchanan Counties, similarity of folding and structural strike of all formations from the top of the Berea (Plate 14), to the top of the Sunbury (Plate 15) and top of the Greenbrier (Plate 17) indicate that there is no significant detachment or decoupling within these beds and that they have all moved as a lithotectonic unit above the Pine Mountain thrust. Several significant differences and anomalies were noted between the interpretations herein and the published interpretations of several other workers on the Mississippian and Pennsylvanian structure in Buchanan, Dickenson, and Wise Counties. These differences are pointed out below as subjects which need further study.

Wilpolt (1959) shows left-lateral movement on the Russell Fork fault, both on the base of the Greenbrier Limestone and at the top of the limestone member of the Hinton (Avis limestone, Little Stone Gap Limestone). All subsequent authors show this fault as a right-lateral fault. Wilpolt (1959) also maps a broad, northwest-plunging synclinal re-entrant striking northwest across the center of Buchanan County on the Avis limestone. This structure is not present on his map on the base of the Greenbrier Limestone. Miller (1974) shows a narrow syncline in Buchanan County on top of the Pocahontas No. 3 and the War Creek coal beds that is similar to Wilpolt's Avis structure. On the Kennedy coalbed (Norton Formation), higher in this section, only a suggestion of this feature remains. Miller (1974) also interprets the presence of a sharp synclinal feature striking southeast across southern Dickenson County and northern Russell County in several Pennsylvanian units. He does not show either of these synclines on the map of the base of the Greenbrier. This present study shows that these synclines mapped on the Pennsylvanian rocks are not present at the top of the Greenbrier. If, indeed, these synclines are present in the rocks of upper Mississippian and Pennsylvanian age and not in the Greenbrier Limestone, then one or more detachments may be present above the Greenbrier. Milici and others (1982) described decollements within Pennsylvanian coalbeds of southwestern Virginia. These decollements contribute to the development of coal mine roof falls in the region. In addition, McLoughlin (1986) states that "evidence was found which suggests that, at least locally, the Dorchester, Imboden, Banner and Raven coal seam horizons also served as surfaces of incipient decollements with undetermined distances of transport".

The anomalies in the Pennsylvanian rocks which are present on the stratigraphic cross section (Plate 19) do not carry downward into the Mississippian rocks. These apparent anomalies may be a result of the telescoping of the section. If they are real, however, they may be further indication of a structural separation of the Mississippian strata from some of the Pennsylvanian by one or a series of small decollements.

Miller (1974) states that "along the Russell Fork fault the Pocahontas No. 3 coal has been laterally displaced about four miles and along the Jess Fork fault about one mile". This displacement of the Russell Fork fault is shown on his maps of various Pennsylvanian units as well as on his map of pre-Lee geology (Mississippian-Pennsylvanian contact). He also shows comparable displacement in his interpretation of the structure at the base of the Greenbrier. Other investigators (Wentworth, 1921; Butts, 1927) indicate that the movement along the Russell Fork fault was about two miles.

This study of the Mississippian, although not definitive at the Russell Fork fault, suggests that the magnitude of the right-lateral displacement may be on the order of two miles or less on the top of the Berea Sandstone, Sunbury Shale, and Greenbrier Limestone.

CROSS SECTIONS

West-East structural cross section B-B' (Plate 20) crosses the southern part of the heavily drilled western third of Wise County. This section roughly parallels the regional structural strike. In the western half of this section, stratigraphic units appear to be relatively uniform in thickness and correlative. The greatest variation in thickness is within the lower Huron shale which contains the Pine Mountain thrust fault. The eastern half of the section shows substantial thickness changes below the top of the middle Huron shale. This change from a gradual regional variation in thicknesses of the units appears to be created by tectonics rather than by depositional processes. Thickening of various members within the Devonian shales in this area may be due to repetition, faulting, or folding. The thickening, at least in part, might only be apparent, due to the well bore intersecting rocks that are dipping at high angles, or the thickening may be apparent and due to several factors combined. Directional surveys on wells scattered throughout the area, however, indicate that deviation of the well bores from vertical is not a major problem. Few wells deviate more than three degrees. The obvious anomaly on this cross section is the structure depicted at well No. WS-121 (ANR Production Company, Penn. VA, Well No. 10081). In this well and on the structure maps, a syncline that is present on top of the Corniferous is overlain by anticlinal structure at all other stratigraphic levels mapped: Olentangy, lower Huron, middle Huron and Berea Sandstone. This anticlinal structural variation is created by the thickening of the Olentangy and lower Huron shales by faulting and folding along this axis.

On the northwest-southeast cross section, C-C' (Plate 21), the regularity of the stratigraphic units is apparent except for the gradual regional changes in thickness across the county. Structural elevation of the rocks rises northward. The Pine Mountain fault, which is wholly within the lower Huron shale in this section, has a discrete zone in which movement took place. The fault is parallel to bedding and has little apparent effect on structure. Movement on the fault in this section displaces the rocks above it generally to the northwest.

Cross section, D-D' (Plate 22), a section which runs almost north-south through the west flank of the interpreted synclinal zone, shows disruption and irregularities in the stratigraphic intervals from the Olentangy shale through the middle Huron shales. If the low density zones are truly representative of zones of movement, then in well no. WS-43 (Wise Oil & Gas Exploration, Penn. Va. Resources No. 10001), displacement zones may extend as high in the section as the Three Lick Bed. Disruption, thickening, and duplication of beds may be partially apparent rather than real. These anomalies may in part be due to the angle at which the cross section D-D' intersects the structure. The direction of fault movement in this section is unclear. However, between wells WS-26 and WS-43 on this section there is a component of movement to the northwest.

The Pine Mountain fault has been picked in the Devonian shales in most wells at the lowest major low density zone; in some areas, such as the north-south syncline, the identification of the fault is more speculative. It should be noted that almost all of the well logs in Wise County demonstrate a low density zone slightly above the middle of the Olentangy shale. Because of the uniform location of this thin marker, it is felt that this zone is related to a sedimentary characteristic.

Section E-E' (Plate 23), a generally west-to-east straight line section, was drawn from the structure maps to further illustrate the relationship of the structure of the area to the Pine Mountain fault. The exaggerated scale section (lower) strongly suggests that some sort of duplex structure underlies the Corniferous, creating folds in the Pine Mountain thrust sheet, but there is no clue as to where or how deep in the stratigraphic section they may exist. Such additional fault blocks could account for the domal uplift in the western part of the county as well as the uplift of the Corniferous toward the undrilled part of the county in the vicinity of the Dorchester syncline. Section D-D' also depicts the location of four lateral ramps along the Pine Mountain fault. From west to east along the fault, the plane of movement ramps from the Olentangy to the lower Huron in the high domal area in the western part of the county, rides in the lower Huron for some distance, cuts down on a ramp into the Olentangy on the western side of the syncline, and again ramps up into the lower Huron on the
eastern flank of the syncline. A fourth lateral ramp is indicated at a location under the Coeburn fault, where the Pine Mountain fault at depth again ramps across the lower Huron-Olentangy boundary.

It is interesting to note that on the true scale section, the dip of a line connecting the Pine Mountain fault in the subsurface from its subsurface control to the Glamorgan fault at the surface is fourteen degrees. This approximates the angle measured on lateral ramps by Mitra (1988) and Pohn (Oral Communication, 1988). On the surface, however, the Glamorgan fault appears to be mostly vertical and has folding associated with it that indicates movement is up on the east. Thus, the connection as shown on the true scale section (E-E') is probably not valid. The Glamorgan fault may be connected to the Pine Mountain fault; the more likely possibility exists that it will be found to connect with some shallower decollement that lies within the Pennsylvanian.

The north-south subsurface structures in the Devonian shales and overlying Mississippian rocks are caused by differential movements in parts of the Pine Mountain (Cumberland) thrust sheet in conjunction with lateral ramping of the Pine Mountain fault. Although some surface structures also may be related to this movement, others, such as the Glamorgan fault, are probably only indirectly related to this movement. The Glamorgan fault is probably directly related to the movement of a decollement in the Pennsylvanian rocks and only indirectly related to structures in the deeper rocks.

GAS PRODUCTION

Gas is reported to have been recovered from all of the formations within the interval studied in Buchanan, Dickenson, and Wise Counties (Plate 24). Operators routinely stimulate several units and then co-mingle the production. Because detailed production data from individual beds are not reported, it is difficult or impossible to ascertain how much gas is produced from each individual unit. Detailed completion and production data are not available on most wells completed in the area. About thirteen (13) percent of the wells drilled have been reported initially as dry holes. In many cases, this failure has been because of mechanical difficulties, or because the well was not drilled deep enough to test all potential objectives.

All of the productive intervals studied exhibit low primary interstitial porosity. Fractures, although abundant, are also generally tight, apparently with poor intercommunication. Most wells are "fraced" to establish commercial flow rates. Structure mapping shows that structural position is not a significant factor in determining whether a well is a significant gas producer. Also, contouring of the reported initial potential of the wells does not show any relationship between initial productive rates and the location of the well with regard to the lineations (fractures?) mapped by Gathright (unpublished). Thus, it is concluded that there is no reason for undrilled portions of these three counties not to be productive at about the same rate as the area already drilled.

Completions from units within the Mississippian appear to occur in discontinuous pods. In almost every well, however, completion is reported in two or more zones. This is probably true, also, in the Devonian shales, but it is masked as the whole section between the Corniferous and the Berea Sandstone (and sometimes including the Berea) usually is completed in two units, upper and lower. Production appears to be pervasive from the shales in these counties. If the overlying Mississippian section was completed in a similar manner, Mississippian production would appear to have the same characteristic as that of the Devonian shales. Table 2 is a tabulation of information from the records of the Division of Gas and Oil and the Division of Mineral Resources. The data include production from all completed intervals

. A map showing the productive areas was prepared (Plate 24) and used to estimate undiscovered reserves in undrilled areas. To construct the map on which the productive areas are outlined, it was assumed that the maximum area that could possibly be drained by one well would be enclosed in a circle with a radius of 1/2 mile (503 acres). Because many wells fall on the circumference of the circle which surrounds the adjacent well, it is evident that many operators consider this one mile spacing too wide for maximum efficient recovery. Although wells might ultimately drain the area using the one mile spacing, many wells have been drilled on a one-half mile spacing. This results in

Table 2. Well Completions in Buchanan, Dickenson, and Wise Counties.

	BUCHANAN		DICKENSON		WISE	
FORMATION	COM-PLETIONS	FORMATION AT T.D. (PERCENT)	COM-PLETIONS	FORMATION AT T.D. (PERCENT)	COM-PLETIONS	FORMATION AT T.D. (PERCENT)
Norton	0		0		2	1
Ravencliff	9	4	0		0	
Maxon (Maxton)	2	1	2	0.5	0	
Big Lime	8	3	4	1	5	2
Injun (Keener)	39	15	0		8	4
Weir	0		0		0	
Sunbury	0		0		0	
Berea	19	7	29	7	2	1
Devonian Shale	150	58	302	82.9	40	19
Corniferous	27	10	28	8	155	71
Silurian	6	2	4	0.1	2	1
Ordovician	0		1	0.5	3	1
Total Number of Zones Completed (more than one zone may be completed in any individual well)	207		320		323	
Total Number of Wells Used for Table	162		240		118	
Average Number of Zones Completed per well	1.4		1.3		2.7	

Table 3. Summary of the results of drilling activity to January 1987. This table shows production by county by years and an estimate of proven reserves remaining in current wells.

DATE	BUCHANAN	DICKENSON	WISE
1952-1980	58,408,514 Mcf	34,052,698 Mcf	312,088 Mcf
1981	3,636,885	3,842,898	740,387
1982	2,234,007	3,578,969	554,801
1983	1,000,178	2,572,718	390,084
1984	3,696,416	3,703,484	607,233
1985	2,718,497	4,367,561	6,536,516
1986	3,033,544	4,955,264	6,313,461
Sub-total	74,728,041 Mcf	57,073,592 Mcf	15,454,570 Mcf
Reported Remaining Proven Reserves	41,253,641	118,559,582	93,468,395
TOTAL original producible gas in place	115,981,682 Mcf	175,633,174 Mcf	108,922,965 Mcf

* Data from the files of Virginia Department of Mines, Minerals and Energy, Division of Gas & Oil, Abingdon, Virginia.

overlapping circles on this map and the measured productive area is less than that which would be calculated by multiplying the number of productive wells by 503 acres. In drawing this map, however, the one-half mile circle extends the field outline used a maximum of one location wider than currently drilled if no dry hole limits the extension.

Recovery of gas has been reported from Berea Sandstone and Devonian shale in Wise County south of the Powell and Guest rivers. This area is considered to be in the Valley and Ridge province and not part of the Cumberland thrust sheet, therefore, this 70,000 acres of Wise County is excluded from the potential reserve estimation. It should be noted that a substantial amount of gas could be present in formations under this area. Potential production from this part of Wise County is not included in this study because the productive capacity of the wells that have already been drilled there is unknown. Table IV is a summary of information derived from the Production Map (Plate 25). Some data from Table 2 and 3 were used to arrive at the estimated ultimate average recovery per completed well.

Table 4. Estimated ultimate gas recovery per completed well in Buchanan, Dickenson, and Wise Counties.

COUNTY	BUCHANAN	DICKENSON	WISE
Total Area - Square Miles	508	335	435
Total Area - Acres	325,120	214,400	278,400
Valley and Ridge Acres	0	0	70,000
Total Area less Valley & Ridge	325,120	214,400	208,400
Total Wells Drilled	268	385	236
Wells Reported Productive	209	349	223
Dry	59	36	13
Success Rate	78%	90%	94%
Productive Acres	64,298	82,025	49,791
Acres/Productive Well	239	235	233
Produced 1952-1986	74,768,035 Mcf	57,073,592 Mcf	15,454,670 Mcf
Reserves Remaining in Completed Wells, Dec.1986	41,253,641 Mcf	118,559,582 Mcf	93,468,395 Mcf
Total	116,021,676 Mcf	175,633,174 Mcf	108,923,065 Mcf
Estimated Average Ultimate Recovery/Completed Well	555,128 Mcf	503,247 Mcf	488,444 Mcf

It is assumed that the average future well drilled in Wise, Dickenson, and Buchanan counties will find producible reserves at least equivalent to those found by past drilling and that the undrilled areas of the counties will be productive on the same basis as those already drilled. Table 5 below uses data compiled or derived from the previous tables to establish these reserves.

Table 5. Estimated undiscovered producible reserves in Buchanan, Dickenson, and Wise Counties.

	BUCHANAN	DICKENSON	WISE
(1) Area to be drilled	267,822 AC.	132,375 AC.	158,603 AC.
(2) Multiply by success rate	78%	90%	94%
(3) Equals - future productive area	203,441 AC.	119,138 AC.	149,087
(4) Divide by acres/ productive well	239	235	223
(5) Equals future productive wells	851	507	668
(6) Multiply by Av/rec/Well Table IV	555,000 Mcf	503,000 Mcf	488,000 Mcf
(7) Equals potential undiscovered producible reserves	472,305,000 Mcf	255,021,000 Mcf	325,984,000 Mcf
(8) Estimated Number of Dry Holes to be Drilled =	240	56	43

Table 5, item (7) shows a cumulative potential of undrilled producible reserves of 1,053 billion cubic feet of gas. At 1986 production rates this is a 73 year supply of gas from these three counties. Completion data is available on 60 percent of the wells drilled through 1987. Twenty-five percent of the wells in Buchanan County, thirteen percent of the wells in Dickenson County, and thirty percent of the wells in Wise County obtain some production from beds above the Greenbrier limestone or from the Devonian shales. The upper Mississippian Ravencliff and Maxton (Maxon) sandstones are productive in Buchanan and Dickenson Counties. In all three counties, gas is recovered from the Devonian shales, but development has been extensive only in Wise County. For the purpose of reserve estimation in this report, it is considered that these formations will continue to add reserves through new drilling in a similar proportion to that provided from wells already completed. Thus, production from these units is included in the undiscovered reserve estimate.

Because of the widespread development of production from the black shales throughout the Appalachians in recent years, more details are available on production from these beds than on production from the overlying Mississippian beds.

Gas shows from the Devonian shale in Wise County were recorded as early as 1955, but few wells were completed as producers from the shales until 1984. Those completed prior to 1984 were completed from selected discrete zones, mostly in the lower Huron or Olentangy shales. In 1984, with the advent of hydrofracturing, operators began to perforate and treat the whole shale interval. The shales were and still are completed in two parts. The upper unit that is perforated and artificially fractured in places includes the Berea and generally extends down into the middle Huron. The lower zone commonly extends downward from the middle Huron and includes the lower Huron and most of the Olentangy.

Shortly after drilling, temperature logs on most wells indicate only insignificant gas inflows to the well bore. The indication that gas is entering is often very minor irregularities on the log. These variations are due to the cooling effect of the gas expanding at the small gas entries. The gas reservoirs appear to be the bedding surfaces, fracture zones, and siltstones. The combined reservoir yields gas in at least two phases. The bedding surfaces and fractures provide primary gas storage and production. As pressure is reduced by production, a secondary flow is established at a slower, steady rate from the minute interstices of the rocks into the bedding interfaces and fractures. A third phase may also be present and contribute gas to the long term, low pressure, low volume flow. Gas adsorbed to the surfaces of the shales and the fractures may be released slowly in a late phase of production. This would add to the cumulative flow during the

well's long stabilized period of production.

Enough data are not available in the records of the Division of Gas and Oil or the Division of Mineral Resources to establish a decline curve for gas production from the Devonian shales. As the formations appear to be similar to those in Pike County, Kentucky to the north, it is presumed that a decline curve in Virginia will be similar (Figure 3). Production shows an initial rapid decline in the first years after completion of the well, then after a period of 14 to 15 years, the curve appears to be almost flat. Wells are expected to produce at this low rate for 50 to 100 years and ultimately to produce 200 to 500 MCF from the Devonian shale section.

Bagnall and Ryan (1976) estimated average reserves of 342,360 Mcf per well from the Devonian shales in Lincoln, Mingo, and Wayne Counties in western West Virginia. Devonian shale wells in Big Sandy field average 100 to 200 Mcf per day from the shales upon completion. They become stable after 14 - 15 years at the rate of 27 to 28 Mcf per day. It is noted that forty percent (40%) of the wells in this field did not have a measurable show of gas before treatment. The average ultimate cumulative production per well from the Devonian shale in Big Sandy field is expected to be 300 to 400 million cubic feet of gas.

In 1986, 44 development wells and two exploratory wells were drilled in the Devonian shales in Wise county. They were all successfully completed from the shales and had an average initial potential of 764 Mcf (Gas Research Institute, 1987).

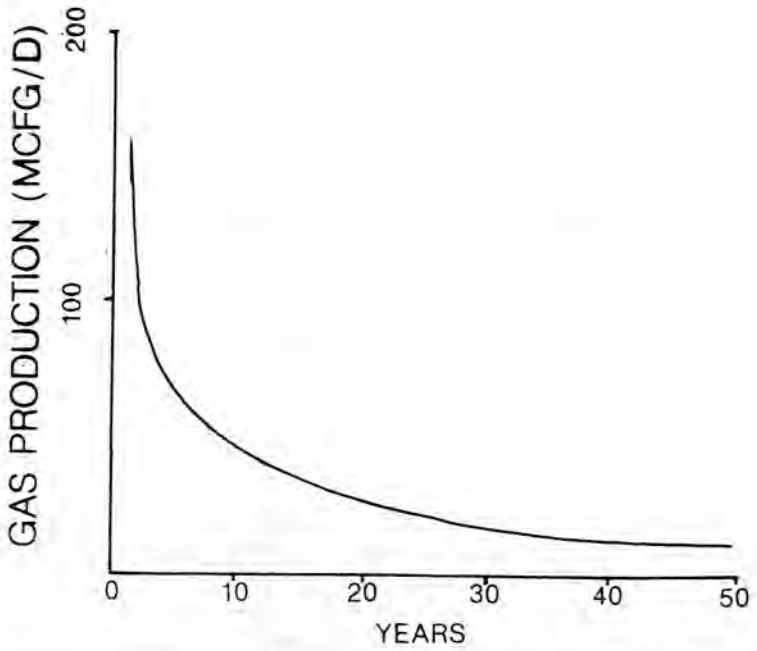


Figure 3. Generalized Production Decline Curve of Devonian Shale gas wells

SUMMARY AND CONCLUSIONS

Only about 25 percent of the land area of Buchanan, Dickenson, and Wise Counties, Virginia has been tested by drilling for hydrocarbons. Isopach maps, structure maps, and cross sections based on over 500 petrophysical logs indicate that local structure is not an important factor controlling production from within the interval between the base of the Devonian shale and the top of the Greenbrier limestone.

Based on interpretation of data from the wells that have been drilled, it is concluded that the remaining undrilled parts of these three counties should be as productive as the areas already drilled. Cumulative production will vary from well to well but, based on past successes, the average future well can be expected to produce over 500 million cubic feet of gas in its lifetime. Again, based on statistics, it is estimated that 2026 producing wells and 339 dry holes will be drilled to fully develop these counties. It is anticipated that these wells will find a producible cumulative reserve of 1,053 billion cubic feet of gas.

Numerous investigators have mapped this area of the Cumberland overthrust, and the area continues to be of interest. Currently, detailed surface mapping is being accomplished by the Virginia Division of Mineral Resources and the United States Geological Survey. This work may supply answers to some of the questions remaining and resolve some of the apparent existing differences of interpretation as the work is integrated with that of previous authors.

Future studies of environments of deposition based on outcrops and information from rock samples obtained from gas wells, both those that have been drilled and those to be drilled, if done, could provide clues to the productivity of

the rocks, delineate the better trends in advance of drilling and provide information as how better to complete and produce the wells.

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COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

PLATE 1
OPEN-FILE REPORT 92-2

MAP SHOWING STRUCTURAL ELEMENTS OF BUCHANAN, DICKENSON, AND WISE COUNTIES

(modified from T. F. McLoughlin, 1986)

FRANK H. JACOBEEN, JR.

1992

5 0 5
MILES

KENTUCKY
VIRGINIA
WEST VIRGINIA
KENTUCKY
VIRGINIA
LANDSAT LINEAMENT
CANEBRAKE FAULT
MOUNTAIN
PINE
SYNCLINE
MIDDLESBORO
SYNCLINE
FAULT
JESS FORK FAULT
LITTLE PAWPAW FAULT
RUSSELL FAULT
FORK FAULT
DRY FORK FAULT
KEEN MOUNTAIN FAULT
ANTICLINE
BUCHANAN CO
TAZEWELL CO
DICKENSON CO
RUSSELL CO
SQUIRREL KNOB ANTICLINE
BUCHANAN CO
DICKENSON CO
DICKENSON CO
WISE CO
BUCK KNOB ANTICLINE
DORCHESTER SYNCLINE
GLAMORGAN FAULT
COBURN FAULT
MONOCLINE
POWELL VALLEY ANTICLINE
SCOTT CO
WISE CO
LEE CO

BU-206
BU-213
BU-211
BU-165
BU-209
BU-163
BU-169
BU-155
BU-170
DI-198
DI-221
DI-253
DI-225
DI-241
DI-188
DI-254
DI-140
WS-179
WS-180
WS-34
WS-58
WS-77
WS-121
WS-61
WS-82
WS-54
WS-167
WS-53
WS-68
WS-47
WS-67

A A′
B B′
C C′
D D′
E E′

KEY

FOLDS

- Monocline
- Anticline
- Coal-bed anticline (after R. L. Miller, 1974)
- Syncline
- Coal-bed syncline (after R. L. Miller, 1974)

FAULTS

- Thrust fault, tick in direction of dip, T on upper plate, arrows indicate direction of movement, U on up side, D on down side.
- LANDSAT LINEAMENT

LINE OF STRATIGRAPHIC SECTION

- Wells in line of section

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DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

PLATE 2
OPEN-FILE REPORT 92-2

LOCATION OF WELL CONTROL

FRANK H. JACOBEEN, JR.

1992

5 0 5
MILES

KENTUCKY
VIRGINIA
WEST VIRGINIA
BUCHANAN CO.
DICKENSON CO.
BUCHANAN CO.
TAZEWELL CO.
KENTUCKY
VIRGINIA
DICKENSON CO.
WISE CO.
RUSSELL CO.
SCOTT CO.
WISE CO.
LEE CO.

KEY

- DRY HOLE WITH LOG
- DRY HOLE
- GAS WELL
- GAS WELL WITH LOG

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DIVISION OF MINERAL RESOURCES

PLATE 3
OPEN-FILE REPORT 92-2

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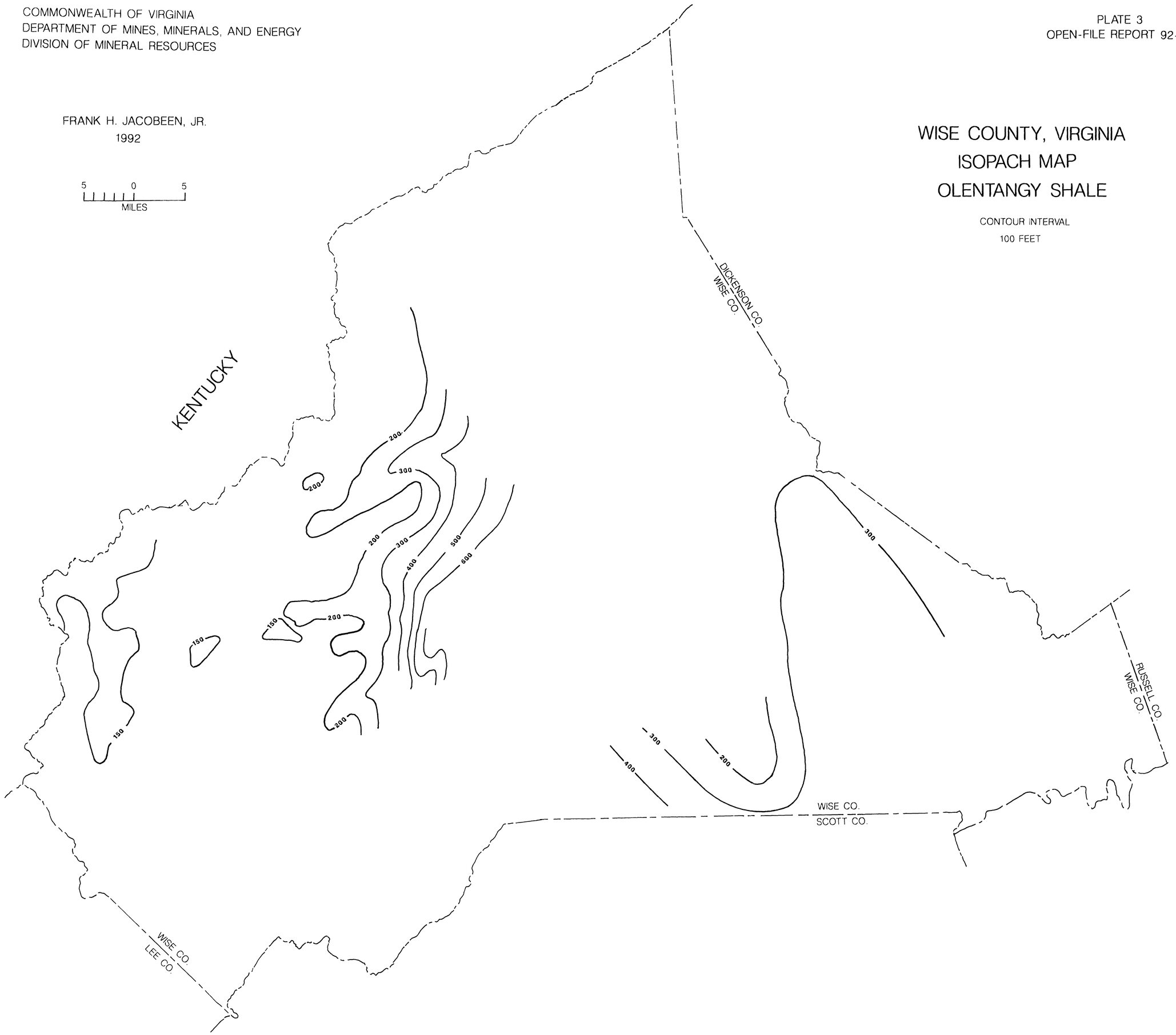
WISE COUNTY, VIRGINIA
ISOPACH MAP
OLENTANGY SHALE

CONTOUR INTERVAL
100 FEET

5 0 5
MILES



COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

PLATE 4
OPEN-FILE REPORT 92-2

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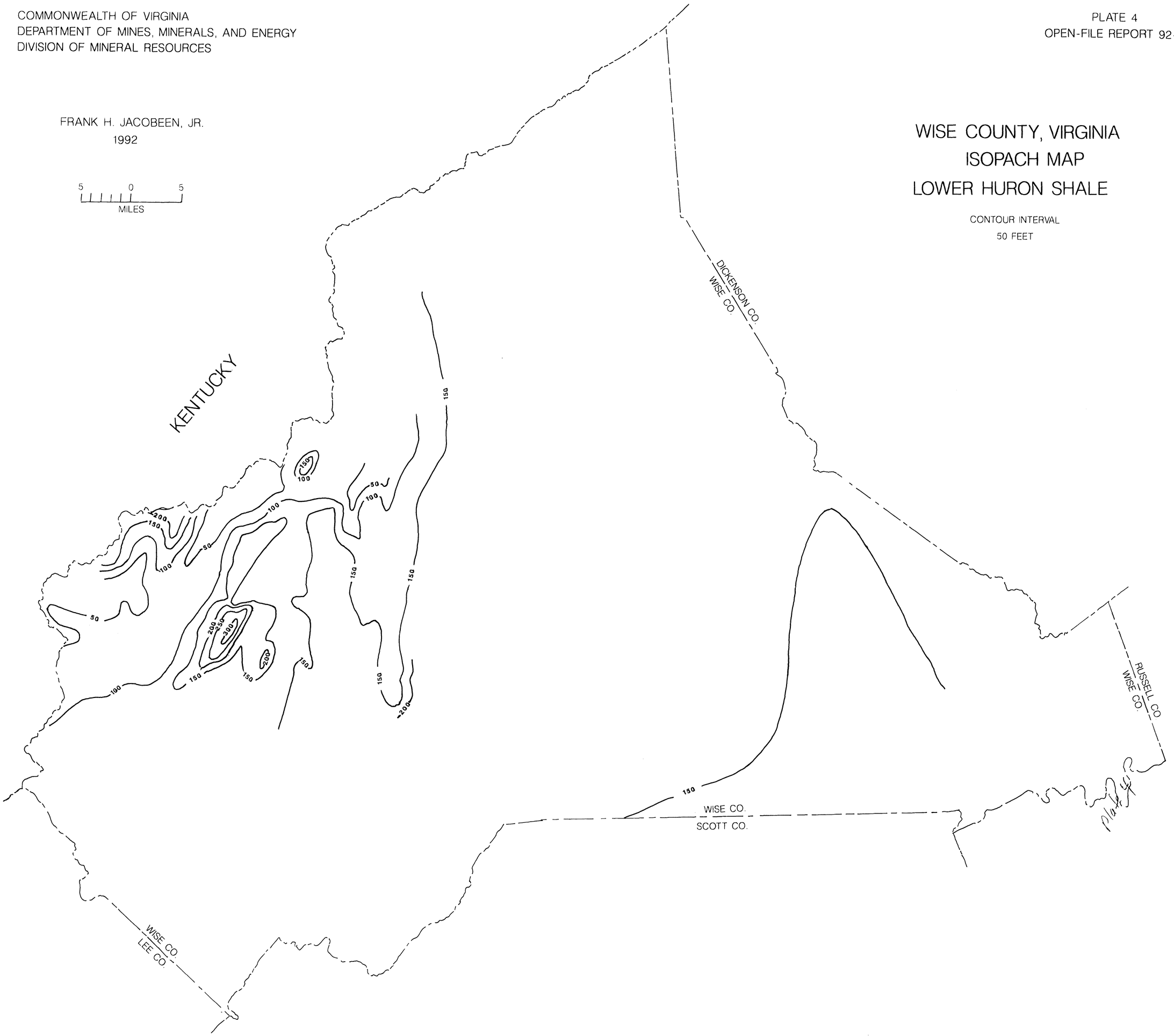
WISE COUNTY, VIRGINIA
ISOPACH MAP
LOWER HURON SHALE

CONTOUR INTERVAL
50 FEET

5 0 5
MILES



COMMONWEALTH OF VIRGINIA
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DIVISION OF MINERAL RESOURCES

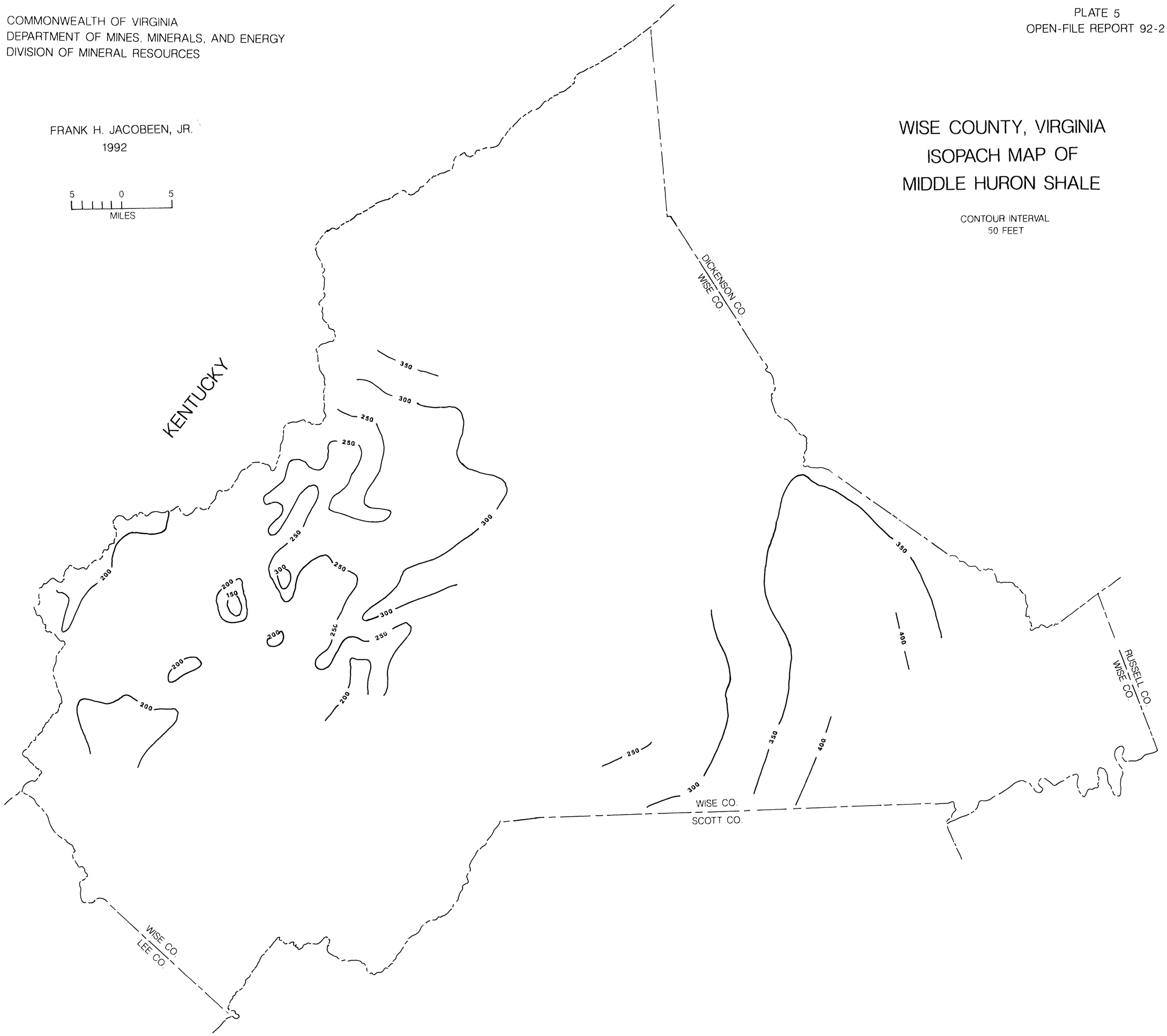
PLATE 5
OPEN-FILE REPORT 92-2

FRANK H. JACOBEEN, JR.
1992

WISE COUNTY, VIRGINIA
ISOPACH MAP OF
MIDDLE HURON SHALE

CONTOUR INTERVAL
50 FEET

5 0 5
MILES



COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

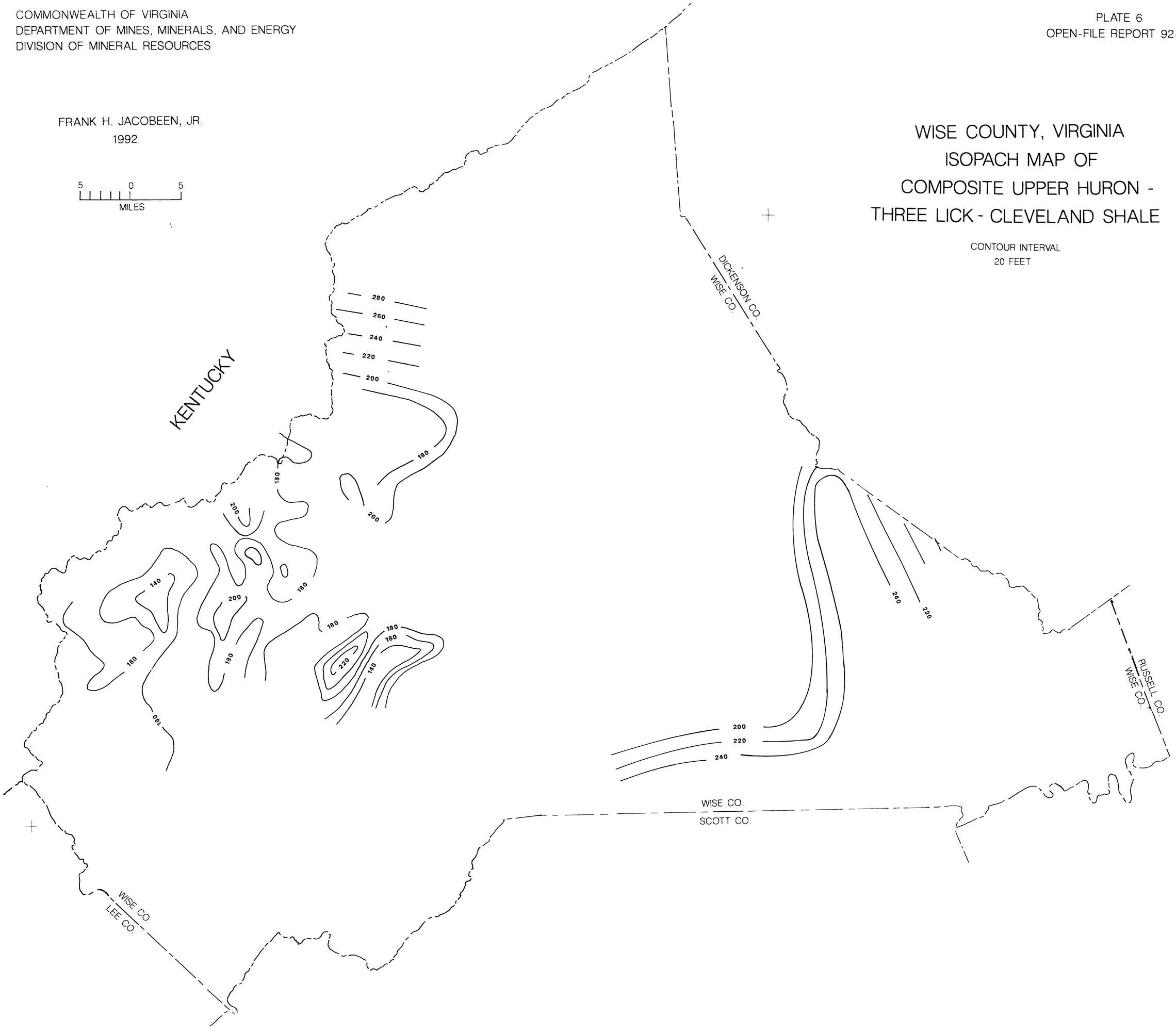
PLATE 6
OPEN-FILE REPORT 92-2

FRANK H. JACOBEEN, JR.
1992

WISE COUNTY, VIRGINIA
ISOPACH MAP OF
COMPOSITE UPPER HURON - THREE LICK - CLEVELAND SHALE

CONTOUR INTERVAL
20 FEET

5 0 5
MILES



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DIVISION OF MINERAL RESOURCES

PLATE 7
OPEN-FILE REPORT 92-2

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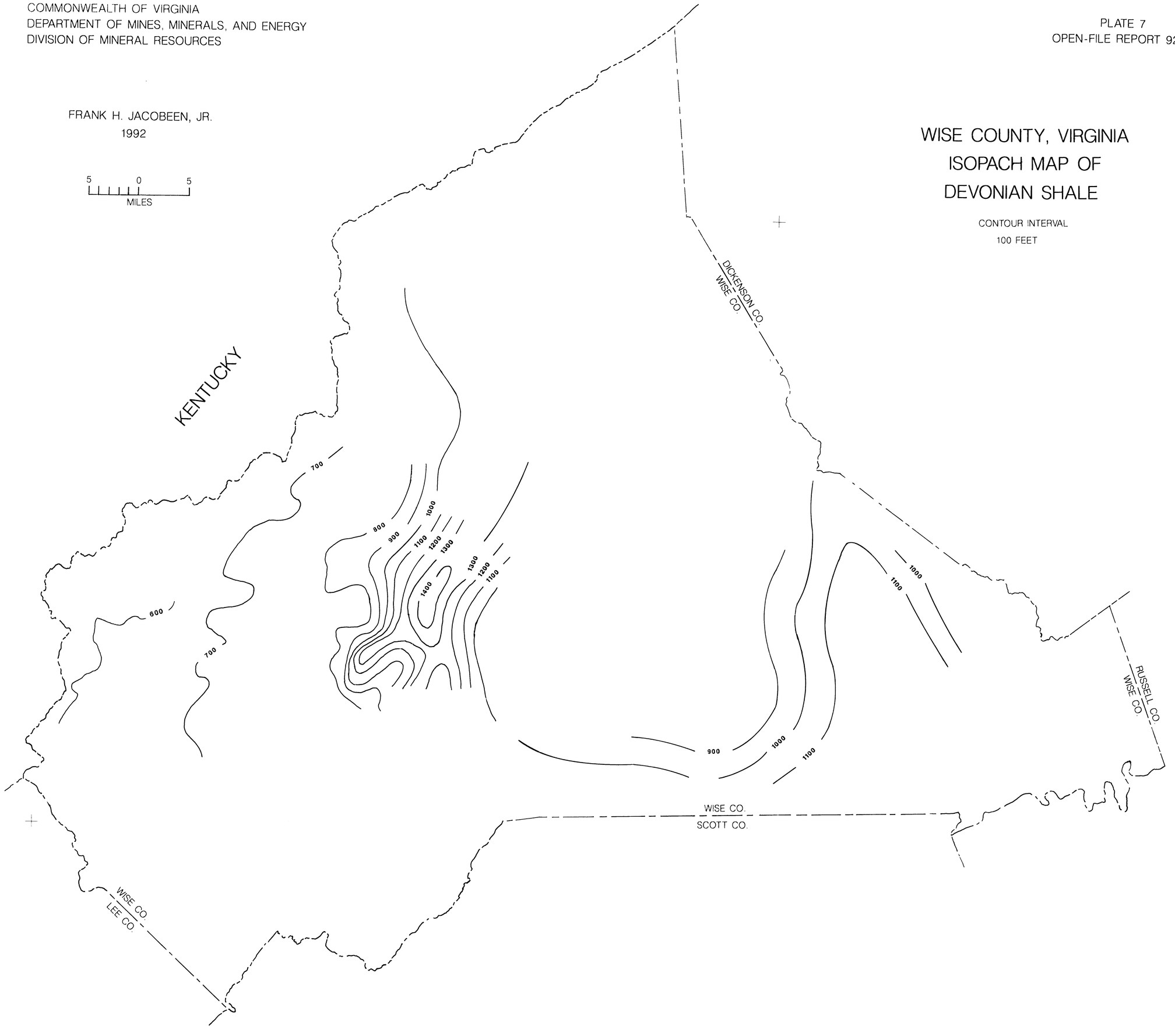
1992

5 0 5
MILES

WISE COUNTY, VIRGINIA
ISOPACH MAP OF
DEVONIAN SHALE

CONTOUR INTERVAL
100 FEET



COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

PLATE 8
OPEN-FILE REPORT 92-2

ISOPACH MAP - BEREA SANDSTONE

FRANK H. JACOBEEN, JR.

1992

5 0 5
MILES

CONTOUR INTERVAL
25 FEET

KENTUCKY
VIRGINIA
WEST VIRGINIA
BUCHANAN CO.
DICKENSON CO.
TAZEWELL CO.
DICKENSON CO.
WISE CO.
RUSSELL CO.
KENTUCKY
VIRGINIA
SCOTT CO.
WISE CO.
LEE CO.

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

PLATE 9
OPEN-FILE REPORT 92-2

ISOPACH MAP - SUNBURY SHALE INTERVAL

FRANK H. JACOBEEN, JR.

1992

5 0 5
MILES

CONTOUR INTERVAL
25 FEET

KENTUCKY
VIRGINIA

WEST VIRGINIA

BUCHANAN CO.
DICKENSON CO.
TAZEWELL CO.
RUSSELL CO.
SCOTT CO.
WISE CO.
LEE CO.

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

PLATE 10
OPEN-FILE REPORT 92-2

ISOPACH MAP - GREENBRIER - PRICE INTERVAL

FRANK H. JACOBEEN, JR.

1992

5 0 5
MILES

CONTOUR INTERVAL
50 FEET

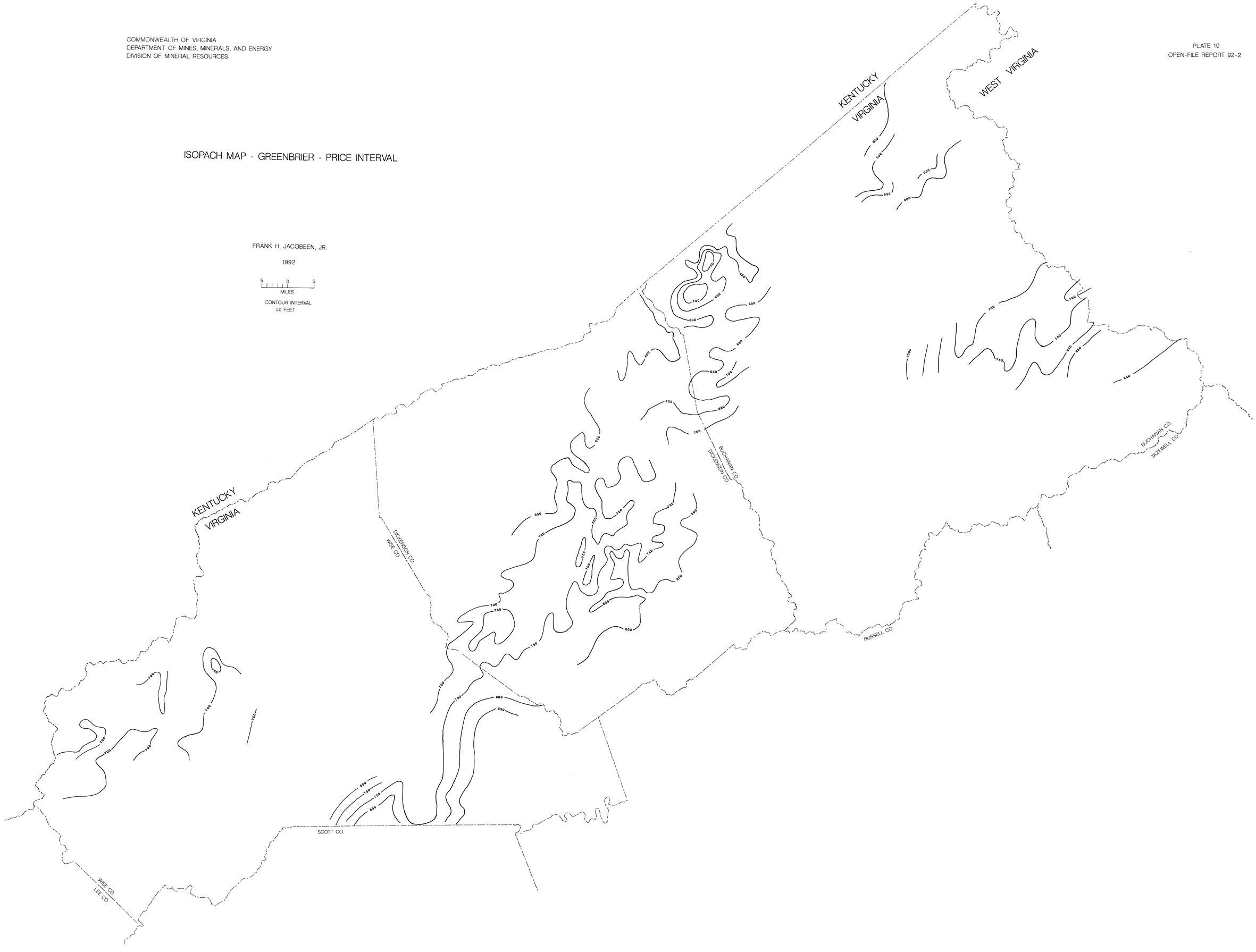


PLATE 11
OPEN-FILE REPORT 92-2

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

ISOPACH MAP - GREENBRIER LIMESTONE

FRANK H. JACOBEEN, JR.

1992

5 0 5
MILES

CONTOUR INTERVAL
50 FEET

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

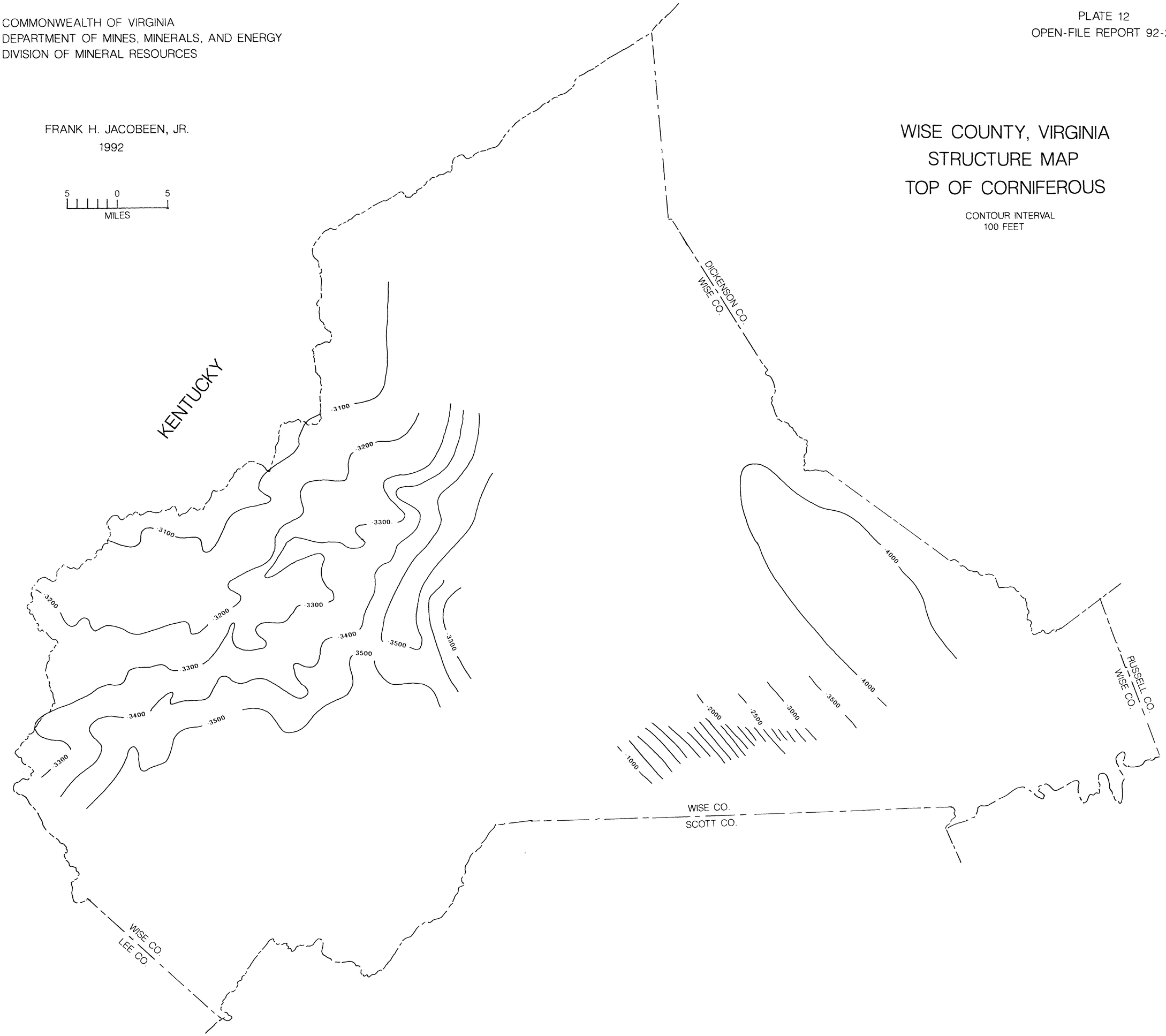
PLATE 12
OPEN-FILE REPORT 92-2

FRANK H. JACOBEEN, JR.
1992

WISE COUNTY, VIRGINIA
STRUCTURE MAP
TOP OF CORNIFEROUS

CONTOUR INTERVAL
100 FEET

5 0 5
MILES



COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

PLATE 13
OPEN-FILE REPORT 92-2

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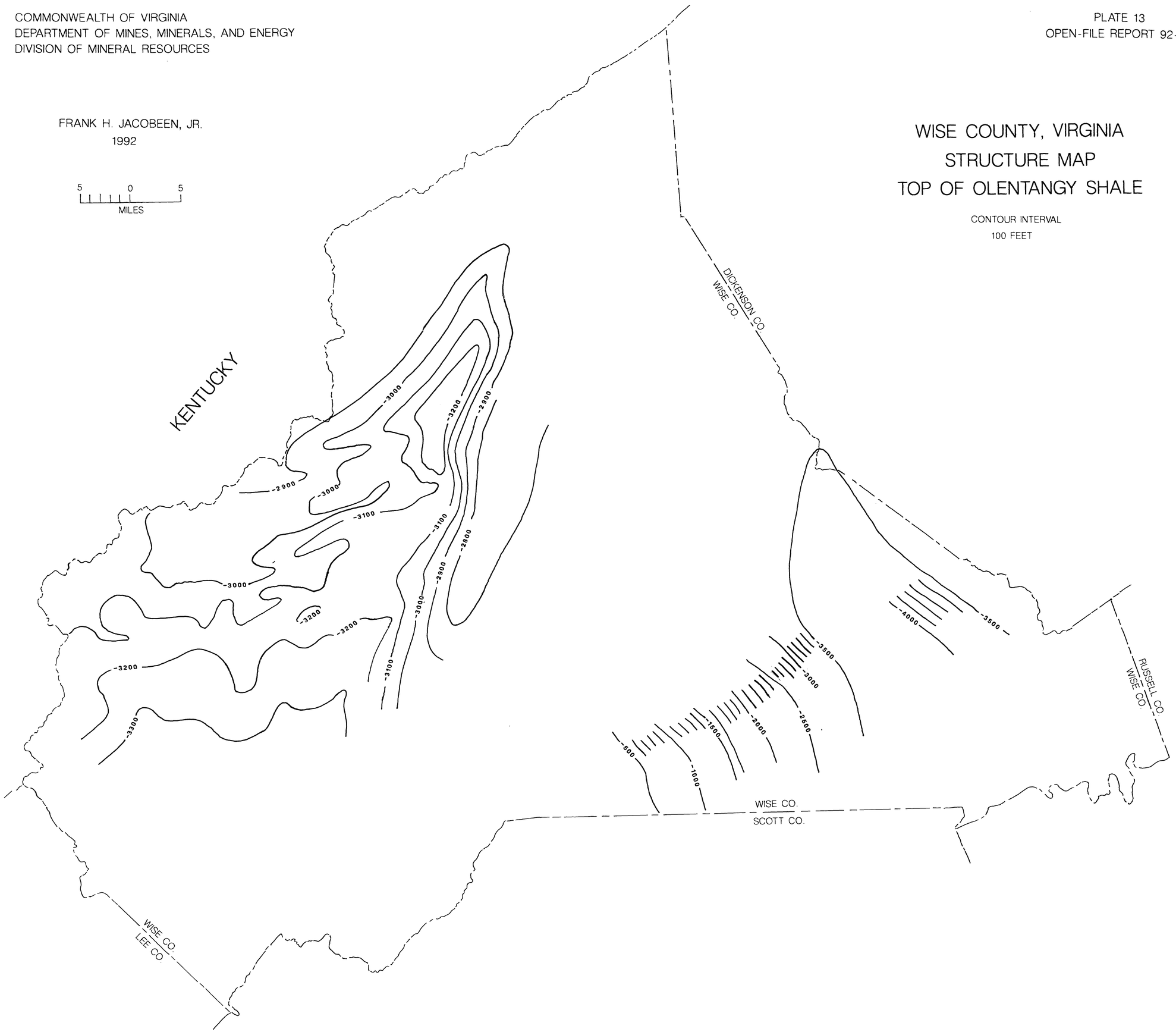
1992

WISE COUNTY, VIRGINIA
STRUCTURE MAP
TOP OF OLENTANGY SHALE

CONTOUR INTERVAL
100 FEET

5 0 5
MILES



COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

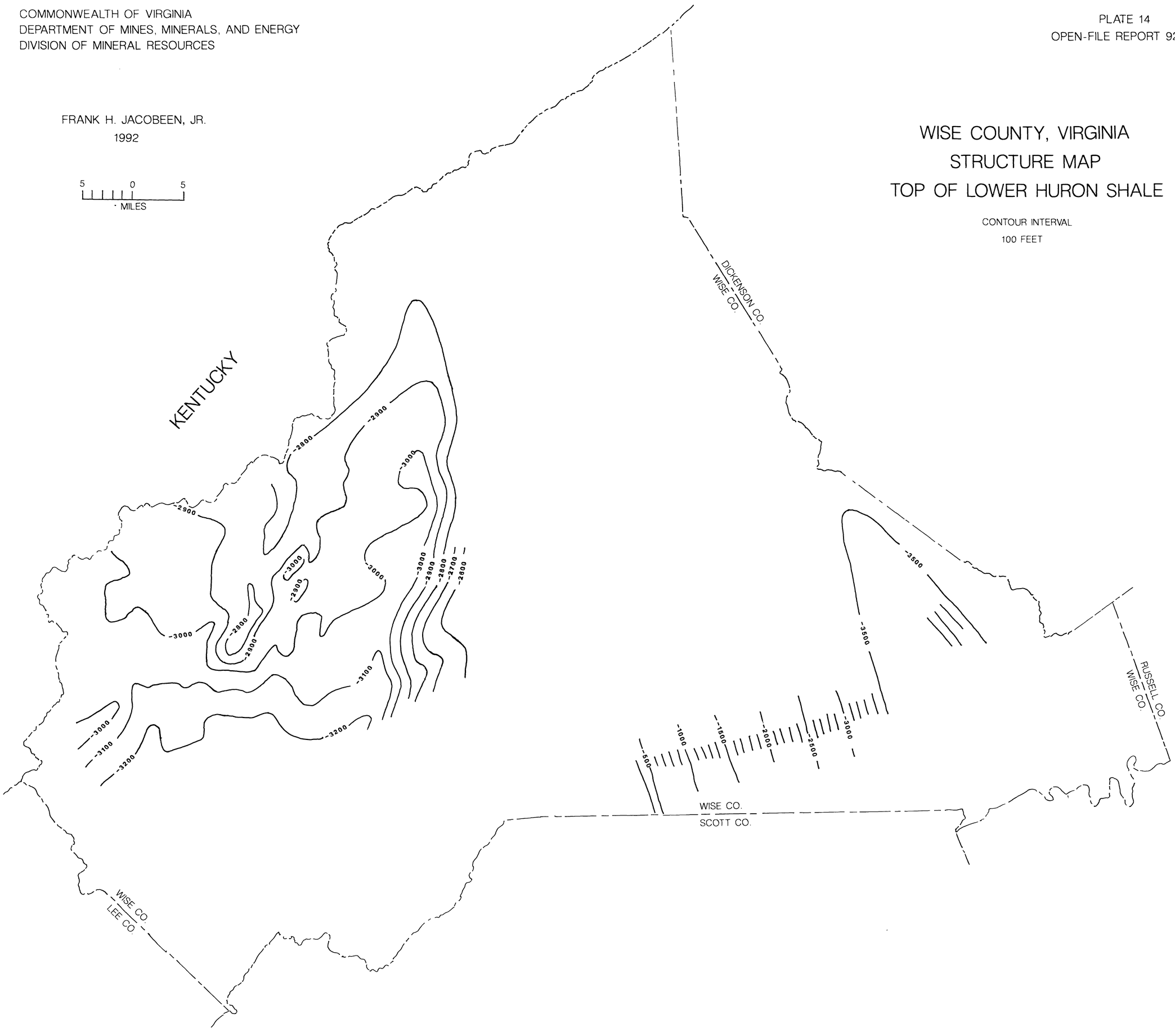
PLATE 14
OPEN-FILE REPORT 92-2

FRANK H. JACOBEEN, JR.
1992

WISE COUNTY, VIRGINIA
STRUCTURE MAP
TOP OF LOWER HURON SHALE

CONTOUR INTERVAL
100 FEET

5 0 5
MILES



COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

PLATE 15
OPEN-FILE REPORT 92-2

FRANK H. JACOBEEN, JR.
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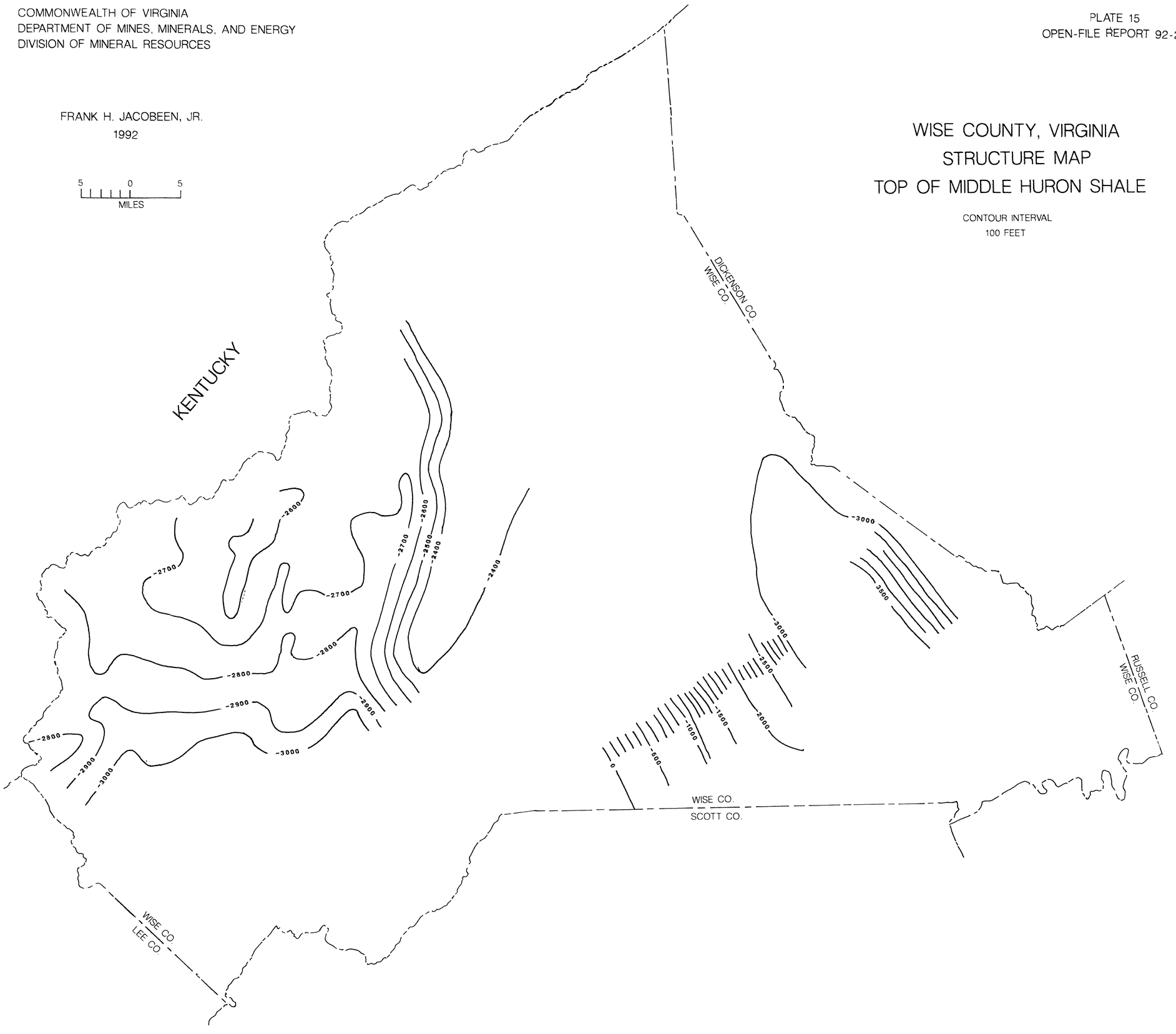
WISE COUNTY, VIRGINIA
STRUCTURE MAP
TOP OF MIDDLE HURON SHALE

CONTOUR INTERVAL
100 FEET

5 0 5
MILES



COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

PLATE 16
OPEN-FILE REPORT 92-2

STRUCTURE MAP - TOP OF BEREA SANDSTONE

FRANK H. JACOBEEN, JR.

1992

5 0 5
MILES

CONTOUR INTERVAL
100 FEET

KENTUCKY
VIRGINIA

WEST VIRGINIA

KENTUCKY
VIRGINIA

BUCHANAN CO.
DICKENSON CO.

DICKENSON CO.
WISE CO.

BUCHANAN CO.
TAZEWELL CO.

RUSSELL CO.

SCOTT CO.

WISE CO.
LEE CO.

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

PLATE 17
OPEN-FILE REPORT 92-2

STRUCTURE MAP - TOP OF SUNBURY SHALE

FRANK H. JACOBEEN, JR.

1992

5 0 5
MILES

CONTOUR INTERVAL
100 FEET

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

PLATE 18
OPEN-FILE REPORT 92-2

STRUCTURE MAP - BASE OF GREENBRIER

FRANK H. JACOBEEN, JR.

1992

5 0 5
MILES

CONTOUR INTERVAL
100 FEET

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

PLATE 19
OPEN-FILE REPORT 92-2

STRUCTURE MAP - TOP OF GREENBRIER LIMESTONE

FRANK H. JACOBEEN, JR.

1992

5 0 5
MILES

CONTOUR INTERVAL
100 FEET

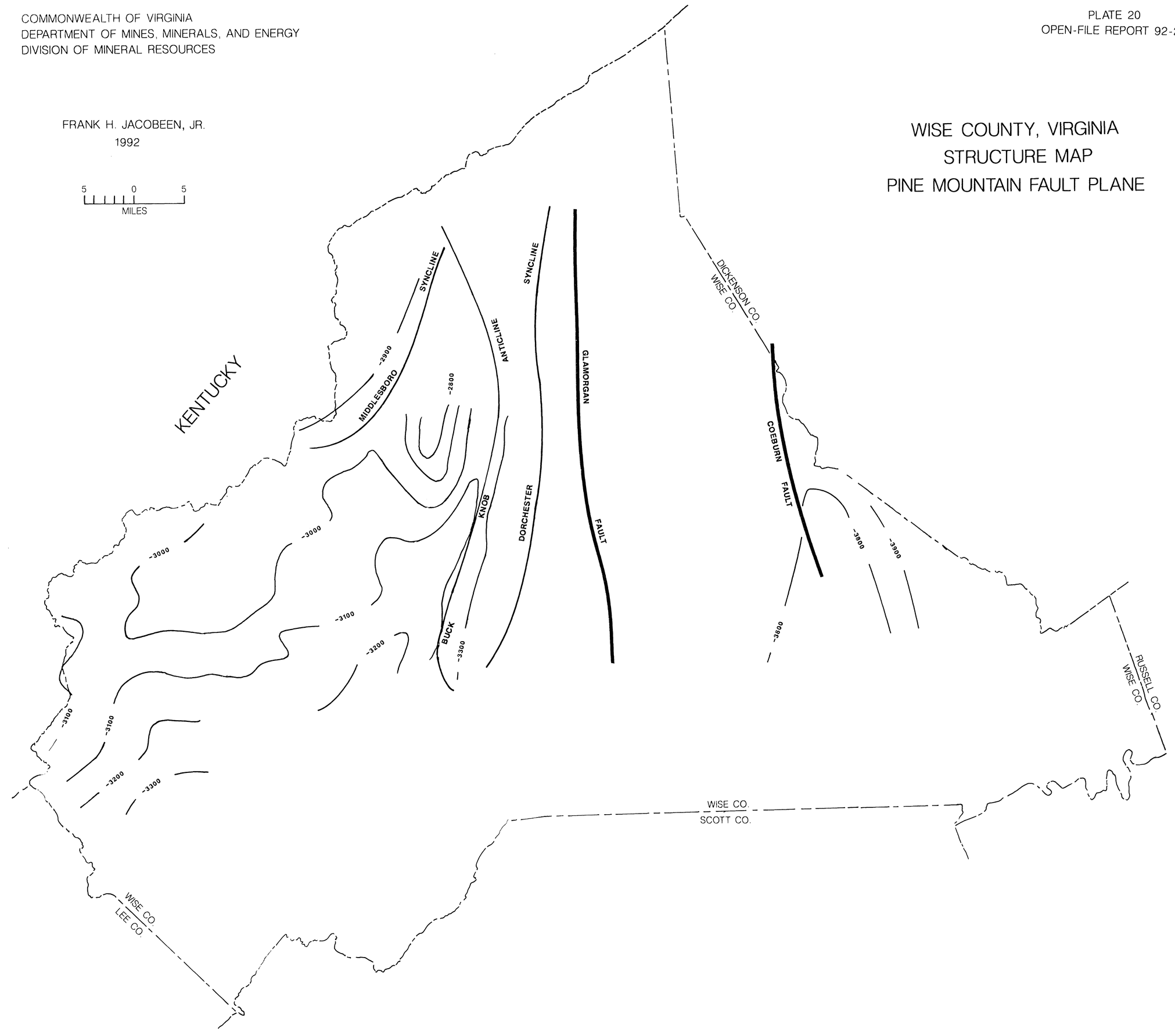
COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

PLATE 20
OPEN-FILE REPORT 92-2

FRANK H. JACOBEEN, JR.
1992

WISE COUNTY, VIRGINIA
STRUCTURE MAP
PINE MOUNTAIN FAULT PLANE

5 0 5
MILES



COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

CROSS SECTION A - A´

PLATE 21
OPEN-FILE REPORT 92-2

A

A´

WS - 53	WS - 17	WS - 58	WS - 34	WS - 121	WS - 61	WS - 47	WS - 180	WS - 179	DK - 140	DK - 188	DK - 254	DK - 241	DK - 225	DK - 253	DK - 198	DK - 221	BU - 173	BU - 213	BU - 206	BU - 165	BU - 211	BU - 209	BU - 169	BU - 155	BU - 163
N46°E 3.7 mi	N69°E 2.3 mi	N40°E 3.6 mi	S11°E 4.0 mi	N74°E 1.3 mi	S61°E 6.0 mi	N34°E 5.6 mi	N5°W 2.6 mi	N85°E 2.4 mi	N40°E 3.4 mi	S52°E 1.5 mi	N54°E 4.4 mi	N40°E 2.6 mi	N50°W 3.2 mi	N13°W 5.6 mi	S56°E 4.9 mi	N47°E 3.5 mi	N8°E 6.2 mi	N7.6°E 5.4 mi	S37°E 7.0 mi	N81°E 4.9 mi	S23°E 2.2 mi	S31°W 3.4 mi	S65°W 3.2 mi	N58°W 5.6 mi	

PENNSYLVANIAN

MISSISSIPPIAN

DEVONIAN

Wise Formation

Gladeville Sandstone

Norton Formation

Lee Formation

Bluestone Formation

Hinton Formation

Stony Gap Sandstone Member (Maxton Sand)

Bluefield Formation (Little Lime)

Greenbrier Limestone

Maccrady Formation

Grainger Formation

Datum

Sunbury Shale

Coffee Shale

Berea beds

Devonian Shale

LOWER HURON SHALE

OLENTANGY FORMATION

Kanawha Formation

New River Formation

Pocahontas Formation

Bluestone Formation

Little Stone Gap

Hinton Formation

Stony Gap Sandstone Member (Maxton Sand)

Bluefield Formation

(Little Lime)

Greenbrier Limestone

Maccrady Formation

Price Formation

Datum

Sunbury Shale

Coffee Shale

Berea beds (Bedford Shale) ?

Devonian Shale

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

STRATIGRAPHIC CROSS SECTION B - B´

PLATE 22
OPEN-FILE REPORT 92-2

B WEST — **B´** EAST

WS-67 El. 1920 — 2.9 miles — WS-68 El. 2216 — 2.8 miles — WS-54 El. 2073 — .7 mile — WS-167 El. 2076 — 1.1 miles — WS-82 El. 2172 — 2.8 miles — WS-121 El. 2187 — 1.3 miles — WS-61 El. 2463 — 10.7 miles — WS-179 El. 2549

SURFACE EQUIVALENT NAMES: BIG STONE GAP SHALE / MIDDLE GREY SILTSTONE / LOWER BLACK SHALE

BEREA SANDSTONE
CLEVELAND MEMBER
THREE LICK BED
UPPER HURON SHALE
MIDDLE HURON SHALE
LOWER HURON SHALE
OLENTANGY SHALE
CORNIFEROUS

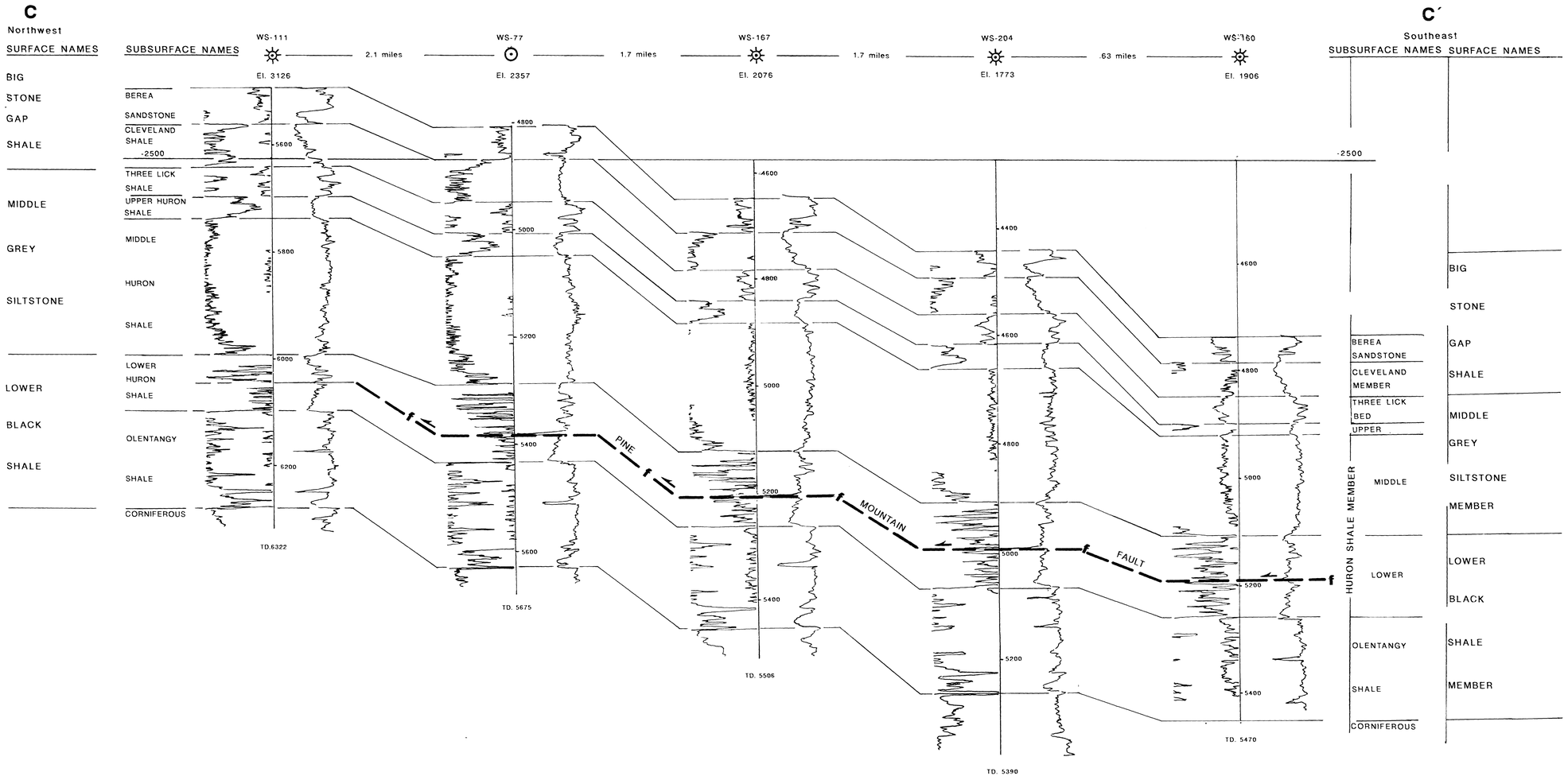
PINE MTN. FAULT
(Movement above fault into section)

TD. 5395 — TD. 5700 — TD. 5526 — TD. 5506 — TD. 5787 — TD. 6548 — TD. 6219

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

CROSS SECTION C-C´

PLATE 23
OPEN-FILE REPORT 92-2



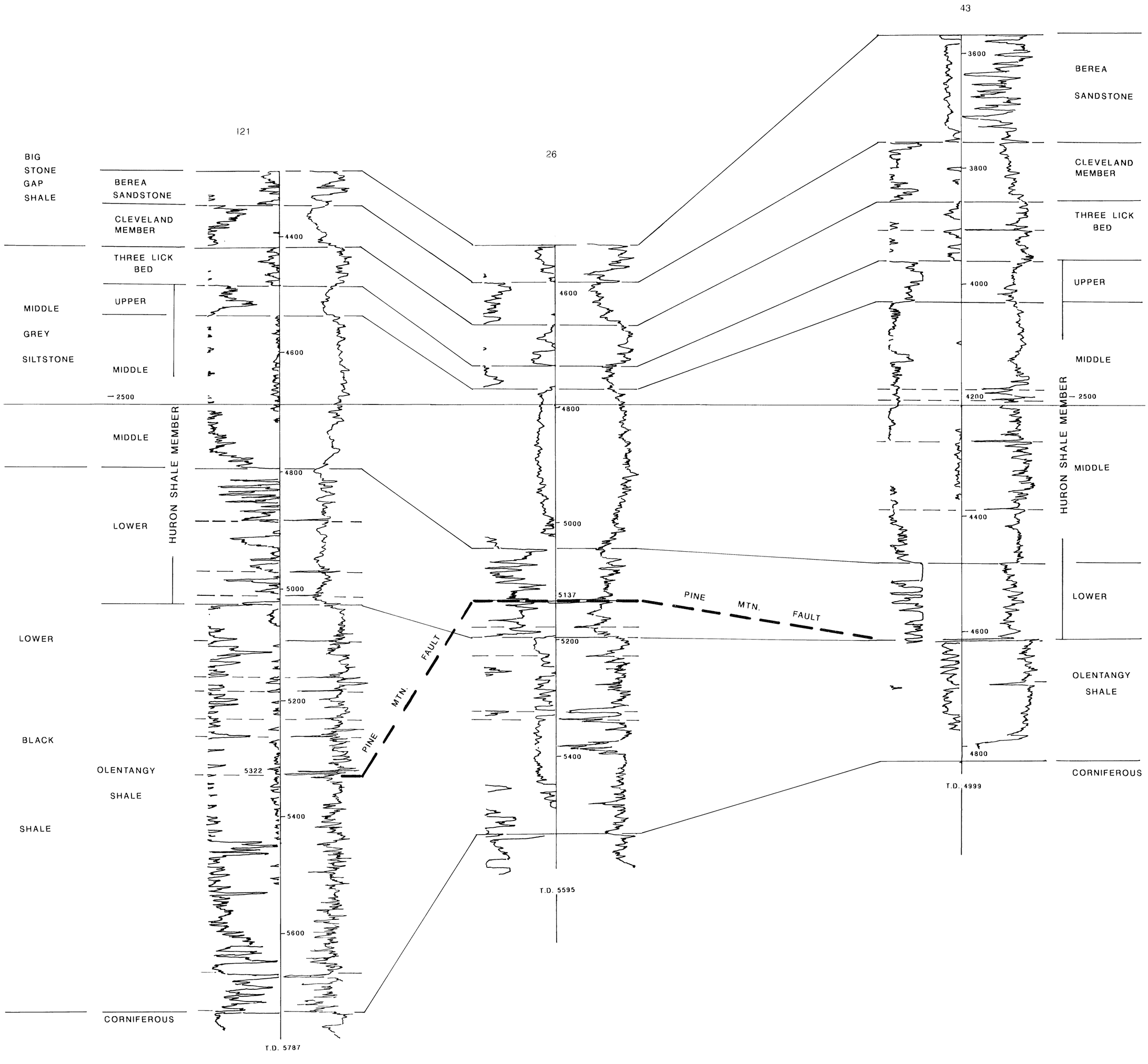
COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

CROSS SECTION D - D´

PLATE 24
OPEN-FILE REPORT 92-2

D — **D´**

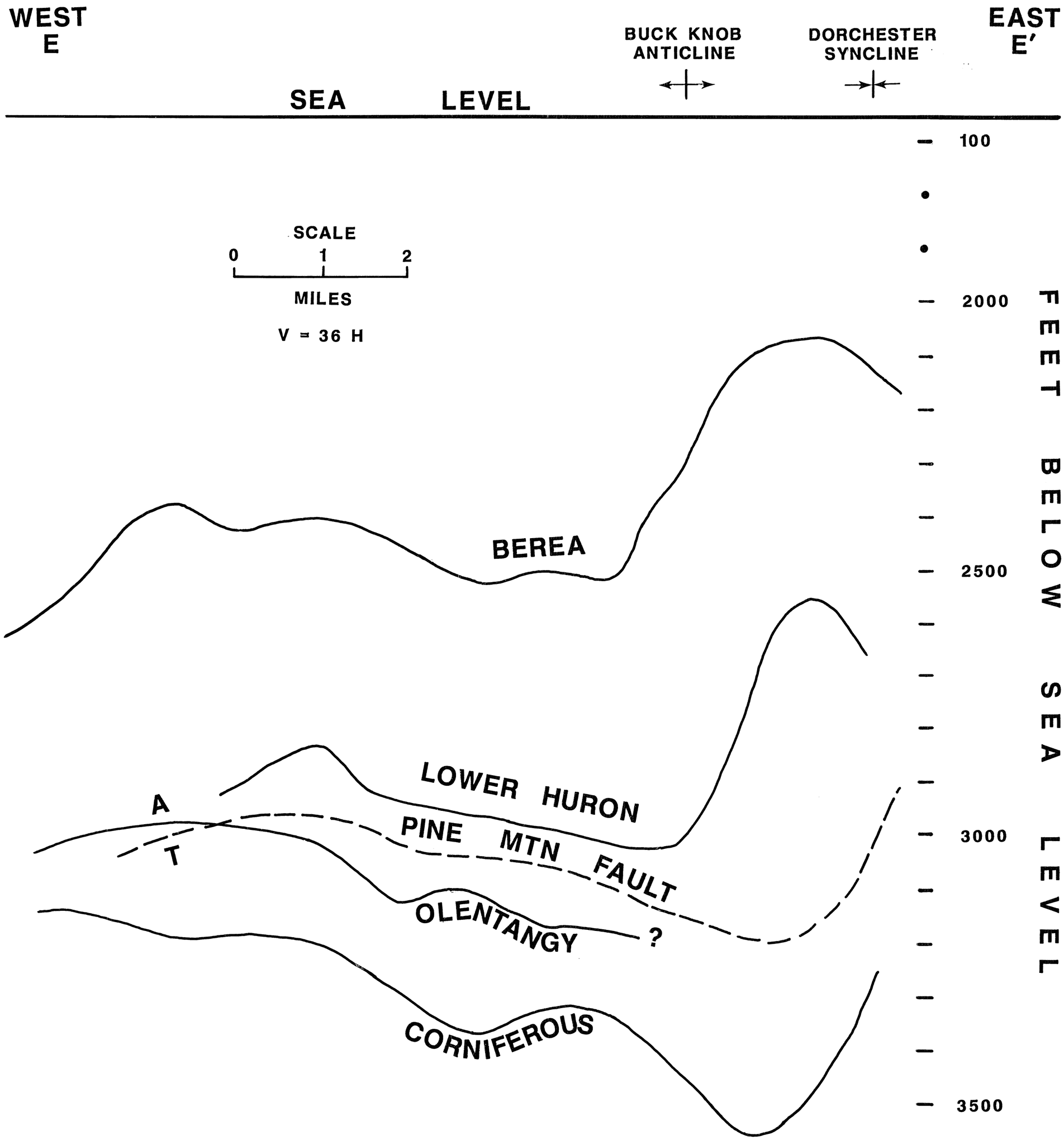
SOUTH — WS-121 El.2187 — 3.8 miles — WS-26 El. 2296 — 5.6 miles — WS-43 El. 1708 — NORTH



COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

CROSS SECTION E - E´

PLATE 25
OPEN-FILE REPORT 92-2



COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS, AND ENERGY
DIVISION OF MINERAL RESOURCES

PLATE 26
OPEN-FILE REPORT 92-2

PRODUCTION MAP

FRANK H. JACOBEEN, JR.

1992

5 0 5
MILES

KENTUCKY
VIRGINIA

WEST VIRGINIA

KENTUCKY
VIRGINIA

BUCHANAN CO.
DICKENSON CO.

BUCHANAN CO.
TAZEWELL CO.

DICKENSON CO.
WISE CO.

RUSSELL CO.

SCOTT CO.

WISE CO.
LEE CO.