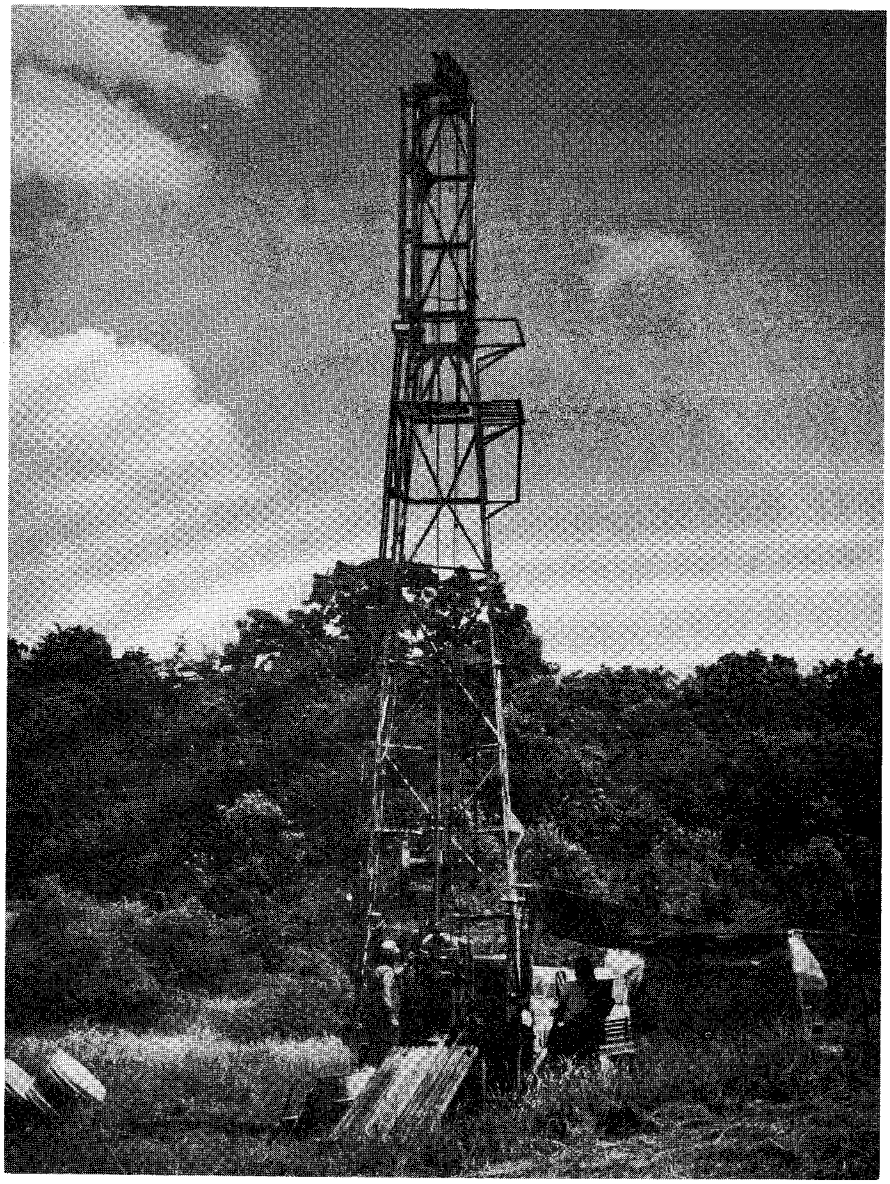
VIRGINIA DIVISION OF MINERAL RESOURCES PUBLICATION 46

COAL-BED METHANE RESOURCE EVALUATION MONTGOMERY COUNTY, VIRGINIA

C. B. Stanley and A. P. Schultz



COMMONWEALTH OF VIRGINIA

DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
Robert C. Milici, Commissioner of Mineral Resources and State Geologist

CHARLOTTESVILLE, VIRGINIA
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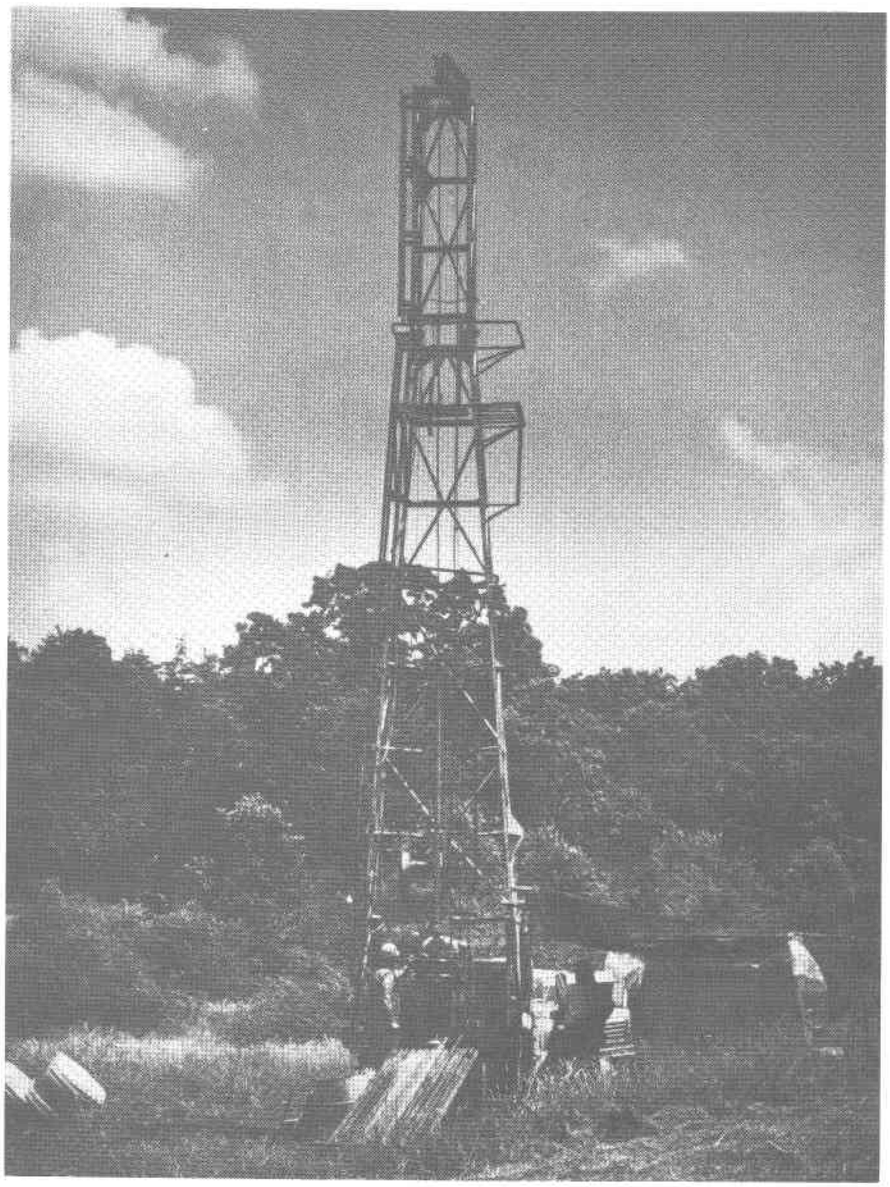

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FRONT COVER: Drill rig utilized at site number three near Merrimac, Montgomery County, Virginia on acreage owned by VPI & SU.

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C. B. Stanley and A. P. Schultz
Virginia Division of Mineral Resources
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Richmond, Virginia

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COAL-BED METHANE RESOURCE EVALUATION MONTGOMERY COUNTY, VIRGINIA

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ABSTRACT

Three diamond core holes have been drilled by the Virginia Division of Mineral Resources under DOE grant DE-FG44-81R410431 to assess the coal-bed methane resource of Mississippian coals in a portion of the Valley coal fields near Blacksburg, Virginia. Coals of the upper member of the Mississippian Price Formation were encountered in two holes at depths ranging from 1110 to 1462 feet below the surface. The cored coal samples were immediately sealed in metal canisters, and tests were made to determine the volume of gas present within each sample. This preliminary report provides details on the regional and local geology of the area under study, the thicknesses, elevations, and gas contents of the coals encountered, and a preliminary economic feasibility analysis.

That analysis was performed for the Division of Mineral Resources by Gruy Petroleum Technology, Incorporated, Arlington, Virginia. Their evaluation of the coal-bed methane data suggests that a resource potential exists for future development if one or more of the following criteria are met:

(1) Thicker coal-bearing intervals with similar gas contents are discovered in other parts of the Valley coal fields;
(2) Higher coal-bed methane contents are found;
(3) The profit margin is significantly increased because of reduction of development costs and/or increases in gas prices.

Because of the complex geologic setting of the Valley fields, the extreme variability of coal thicknesses, and the paucity of subsurface data, further drilling is necessary in order to accurately assess the economic potential of coal-bed methane outside the study area.

INTRODUCTION

The Valley coal fields of southwestern Virginia (Campbell, 1925) contain the geologically oldest commercially mined coals in North America (Kreisa and Bambach, 1973). The coals are gassy, and during mining there were many reported instances of methane-related explosions (Stevens, 1959). Located in the Valley and Ridge province of the Southern Appalachians, the coals of the Valley fields have been more deeply buried and intensely deformed than the coal beds of the Pocahontas basin of the Appalachian Plateau (Campbell, 1925; Bartholomew and Lowry, 1979; Schultz, 1979). As a result of this burial, coals of the Middle Mississippian Price Formation are of a low volatile bituminous to semianthracite rank (Campbell, 1925; see Appendix II). Coals metamorphosed to this rank may generate significant amounts of methane, and fracture porosity, permeability, and reservoir capacity of the coal beds may be significantly increased by tectonic deformation (Kindley, 1982).

Stevens (1959) reported from conversations with miners that large quantities of methane were commonly liberated during mining, especially when faults were encountered. Methane related explosions occurred in the Parrott, Great Valley, Hard Coal, and Merrimac mines in Montgomery and Pulaski counties, Virginia (Stevens, 1959).

Reports of high gas content in the coals of the Valley fields have led the Virginia Division of Mineral Resources to initiate an evaluation of the coal-bed methane resource near Blacksburg, Virginia, under DOE Contract No. DE-FG44-81R410431. This project was designed to obtain reliable data on the subsurface elevations, thicknesses, quality, and gas content of the Mississippian coals.

Location of Drill Holes

In order to assess the methane resource of part of the Valley coal fields near Blacksburg, Virginia, three exploratory diamond core holes were sited at various positions with respect to regional geologic structures: near Prices Fork, Sunnyside, and Merrimac (Figures 1 and 2). Several criteria were established for the selection of these sites:

(1) Sites were chosen where geological mapping indicated that there is at least one thousand feet of strata above the coal. This amount of overburden provides a sufficient barrier to the migration of gas from the coal bed, increasing the probability of obtaining a more accurate gas estimate for the area underlain by coal.

(2) The drill holes were located well away from abandoned underground mines, where the coal bed may have been partially degassed. Since there are no accurate maps of the underground mines, there is a possibility of unexpectedly encountering old workings when drill-

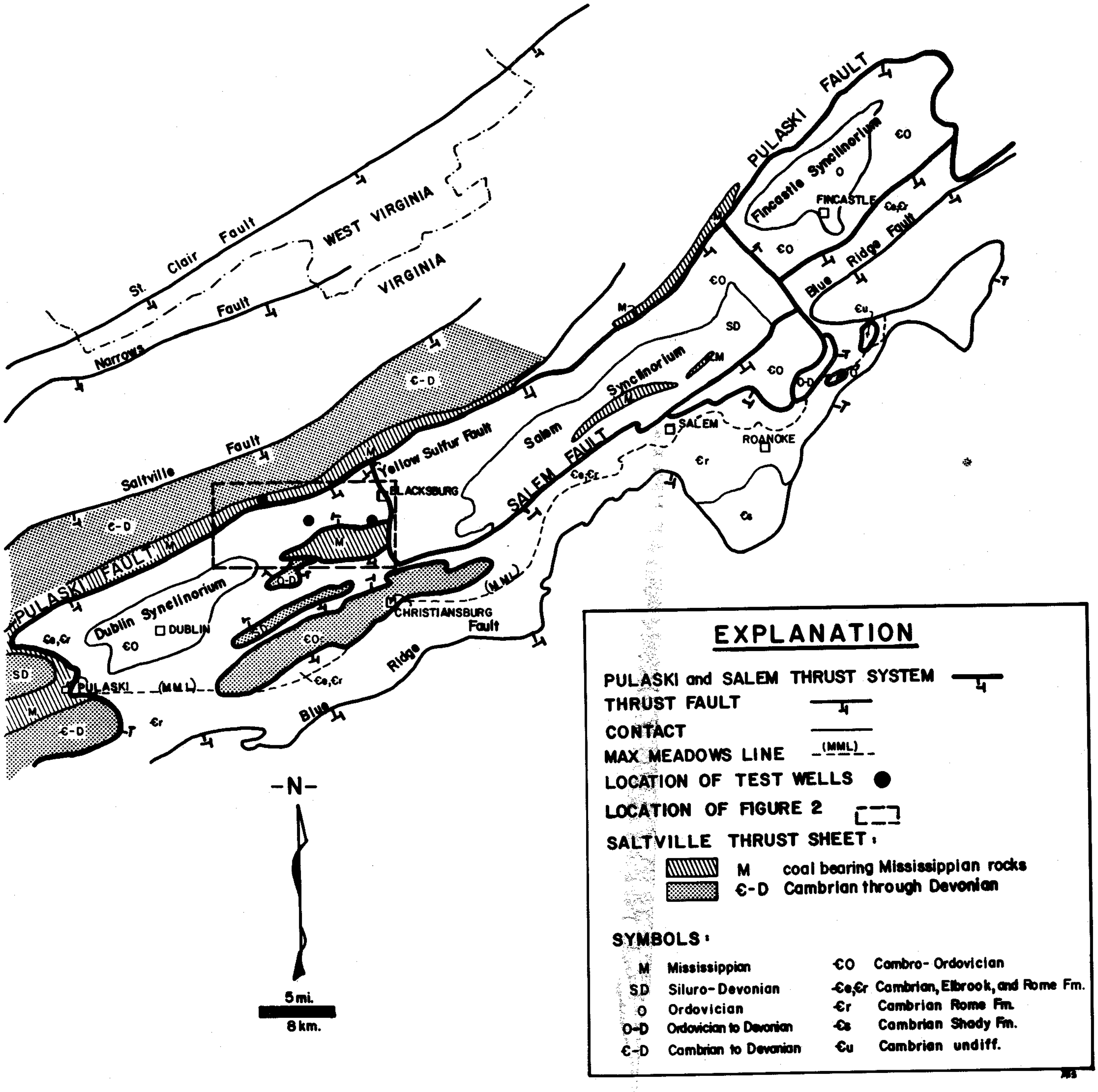


Figure 1. Tectonic index map of a portion of the Southern Appalachian Valley and Ridge and Blue Ridge provinces showing major regional structures and location of drill holes (modified from Bartholomew, Milici and Schultz, 1980).

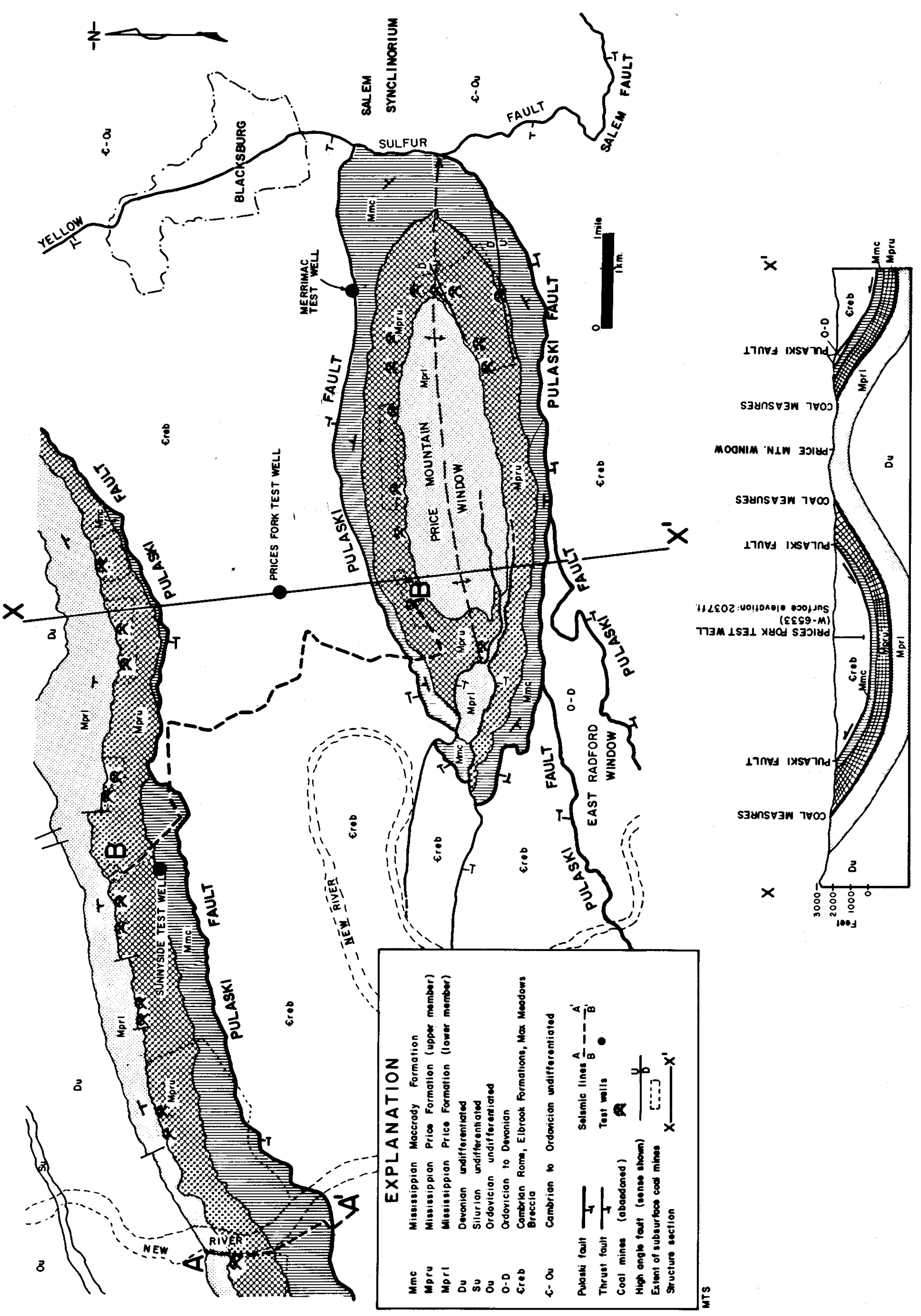


Figure 2. Generalized geologic map of the study area showing distribution of Mississippian coal-bearing strata, major structural features, location of seismic lines, and test wells. Map adapted from the geological maps of the Blacksburg 7.5-minute quadrangle (Bartholomew and Lowry, 1979) and the Radford North 7.5-minute quadrangle (Schultz and Bartholomew, in press).

ing near the outcrop of the coal bed (Figure 2).

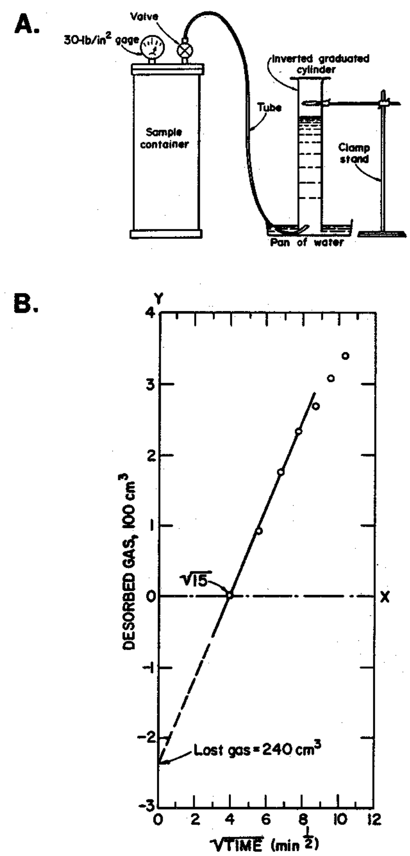
(3) The holes were located in several structural settings to determine if there is any relationship between gas content, volume of gas desorbed, and geologic structure.

Joy Manufacturing Company of La Porte, Indiana, was contracted to drill the holes with a truck-mounted 22HD drill rig. Geologists from the Virginia Division of Mineral Resources were on site continuously during drilling, where they measured, described, and boxed the core, recorded drilling progress, and sampled the coals encountered for methane testing. The core was later re-examined and described in greater detail before being shipped to the Division's sample repository in Charlottesville. Core recovery on the Sunnyside and Merrimac test wells was one hundred percent. Recovery on the Prices Fork test well was, as would be expected when drilling into extremely folded and broken strata, much poorer, with some zones represented only by cuttings in the core barrel.

Determination of Gas Content

The direct method of determining the gas content of coals, which was developed by the United States Bureau of Mines, was used in this study (Diamond and Levine, 1981). This procedure involves sealing the cored coal sample in a metal canister from which the desorbed gas is periodically bled into an inverted, water-filled graduated cylinder. The gas volume is determined by downward displacement of the water column (Figure 3A). The desorbed gas is measured every fifteen minutes for the first two hours after the sample is sealed in the canister, and thereafter either daily, or twice daily, depending on the volume of gas that the sample desorbs. This may continue for weeks or even months, depending on the gas content of the sample.

Theoretically, the coal begins to desorb gas the moment it is encountered by the drill bit. After coring is completed, the core barrel must be retrieved and emptied and the core described before the sample can be sealed in the canister. During this period, a significant amount of gas may be desorbed. The volume of this "lost gas" cannot be measured directly, but may be determined graphically. Diamond and Levine (1981) have developed a method of estimating the volume of lost gas based on the assumption that, for the first several hours of emission, the volume of gas desorbed by a given sample is proportional to the square root of the desorption time. A plot of the cumulative emission after each reading versus the square root of the time the sample has been desorbing should yield a straight line (Figure 3B). The intercept line with the X axis is the



Data for lost gas graph

Reading	Time a.m.	Time since placed in can, min.	√(Time in can + 15), min. ½	Gas released, cm³	Total gas, cm³
1	12:50	0	3.37	0	0
2	1:05	15	5.48	92	92
3	1:20	30	6.71	84	176
4	1:35	45	7.75	55	231
5	1:50	60	8.66	36	267
6	2:05	75	9.49	40	307
7	2:20	90	10.25	33	340

Figure 3. (A) Apparatus used in measuring desorbed gas (from Diamond and Levine, 1981), and (B) Table and plot, depicting method of determining lost gas.

square root of the elapsed time, in minutes, from the time gas desorption begins until the sample is sealed in the canister. The negative Y intercept is the estimated volume, in cubic centimeters, of the lost gas. In diamond core drilling, if water is used as a drilling fluid, it is assumed that the sample begins to desorb gas one-half the distance to the surface, where the pressure of the gas in the coal begins to exceed the hydrostatic pressure of the column of water occupying the drill hole.

In addition to the estimated volume of the lost gas and the measured volume of gas desorbed, there is a certain amount of gas that remains trapped in the coal sample after natural desorption has ceased. The volume of this residual gas can be measured directly by crushing the desorbed coal sample in a ball mill and then measuring the volume of gas then released by the water displacement method.

Although the total gas content of the sample, excluding the lost gas, could be rapidly determined by placing the sample directly in a ball mill and grinding it to a fine powder, Diamond and Levine (1981) point out that it is important to determine both the actual volumes of naturally desorbed and residual gas for each sample. This is important because the residual gas represesnts a portion of the total gas volume that would not naturally flow into a degassification well. The amount of residual gas in a coal seam appears to be directly related to the seam's condition. Coals that are hard and blocky tend to desorb gas less readily, thus retaining higher amounts of residual gas within their structure. Coals that have been faulted and sheared have an increase in surface area and naturally desorb gas in much greater volumes. Therefore, ares where coal seams are faulted and severely sheared but still sealed, may be desirable locations to attempt coal degassification projects.

Acknowledgements

The writers wish to thank the following individuals of the Virginia Division of Mineral Resources for their help in the completion of this project: S. S. Johnson, Project Manager, for coordination of all project activities; M. J. Bartholomew for his assistance with core description and daily well supervision; J. A. Henderson, G. P. Wilkes, M. Gwinn, B. Miller for their assistance on the well sites, and J. Francescon for typing the initial drafts and J. L. Hensley for typing the final. The authors would also like to express their appreciation to T. M. Gathright, II for the photographs and M. Stroh and L. E. Valente for their drafting.

GENERAL GEOLOGIC SETTING

Coal-bearing Mississippian strata are located on the Saltville thrust sheet, one of several southeast dipping regional-scale imbricate thrusts that comprise the Appalachian Valley and Ridge province in the Blacksburg-Radford area. Near the study area (Figure 2) clastic and carbonate rocks of the Saltville thrust sheet range in age from Middle Cambrian to Middle Mississippian, and form an approximately 13,000 foot-thick southeast dipping succession, bounded on the northwest by the Saltville fault and overridden on the southeast by Lower to Middle Cambrian carbonates and phyllitic mudstones of the Pulaski thrust sheet (see Table 1). Regional conodont color alteration indexes (CAI) of Ordovician strata range from 3 to 4 for rocks of the Saltville thrust sheet and from 4 to 5 for rocks of the

Table 1. Generalized stratigraphic column showing approximate thicknesses of the rocks of the Saltville-Pulaski thrust sheets.

PERIOD	FORMATION	THICKNESS: Feet (meters)		
		New River (Saltville thrust sheet)	Price Mtn. (Kipps Well)	Pulaski thrust sheet
Mississippian	Maccrady	1605 (490)		
	Price	975 (297)	730 (222)	
Devonian	"Chemung"	698 (212)	710 (216)	
	Brailier	2699 (792)	1759 (536)	
	Millboro	850 (259)	2415 (736)	
	Needmore	30 (9)	50 (15)	
	Huntersville	30 (9)	124 (38)	
	Rocky Gap	40 (12)		
Silurian	Keefer	140 (43)	130 (40)	
	Rose Hill	127 (39)	185 (56)	
	Tuscarora	100 (30)	163 (50)	
Ordovician	Juniata	165 (50)	187 (57)	
	Martinsburg	980 (299)	2743 (836)	
	Eggleston		158 (48)	
	Moccasin	55 (17)	37 (11)	
	Middle Ordovician fms.	529 (161)		Conococheague 1800 (600)
Cambrian	Knox Group	2563 (781)		Elbrook 1800 (600)
	Nolichucky	56 (17)		Rome 600+ (200)
	Honaker	826 (278)		

Pulaski thrust sheet (Harris and Milici, 1977). The thermal cutoff for the accumulation of natural gas may correspond to a CAI value of 4.5 (Epstein, Epstein and Harris, 1977). Hence, even the older and more deeply buried strata of the Saltville block are well within the limit of organic thermal maturity.

Stratigraphy

Coal-bearing Mississippian rocks in the study area consist of sandstones, siltstones, and mudstones of the Maccrady and Price formations, with the Price containing a prominent coal-bearing horizon. Rocks of Maccrady Formation are the youngest known to have been deposited prior to Pulaski thrusting and can be subdivided into two members (Bartholomew and Lowry, 1979). The lower member is about 1150 feet thick and consists of interbedded mottled grayish-red and greenish-gray mudstones, medium-grained massive sandstones, medium- to coarse-grained cross-bedded sandstones and minor dark gray to black mudstones. The upper member is about 180 feet thick and consists of interbedded siltstones, mudstones, quartz-pebble conglomerates and coarse-grained conglomeratic sandstones.

In the study area, the Mississippian Price Formation has been divided into a basal conglomeratic member, the Cloyd Conglomerate Member, a lower marine member, and an upper nonmarine member (Bartlett, 1974; Kreisa and Bambach, 1973; Bartholomew and Lowry, 1979). The coal seams encountered in the Sunnyside and Merrimac test wells occur near the transition from the nonmarine upper member to the marine lower member.

The nonmarine upper member, approximately 900 feet thick, is characterized by mottled grayish-red and greenish-gray mudstone that grades downward into dark gray to black mudstones, quartzose sandstones, and coal. Two coal seams, the Merrimac and Langhorne, are areally extensive and have been mined for many years in this area. The Merrimac is stratigraphically above the Langhorne and ranges from 5 to 12 feet thick (Campbell, 1925). The Langhorne seam is thinner (1 to 3 feet) and is usually between 10 to 20 feet below the Merrimac. The marine lower member of the Price Formation is approximately 1500 feet thick and consists of interbedded micaceous lithic sandstones, thick quartz-pebble conglomerates, quartz arenites, siltstones, and shales.

Rocks of the Pulaski thrust sheet consist of calcareous, phyllitic mudstones, argillaceous dolomites, and limestones of the Lower Cambrian Rome Formation and the Middle Cambrian Elbrook Formation. Max Meadows tectonic breccia occurs near the Rome-Elbrook contact (Cooper, 1961).

The Rome Formation is very poorly exposed in the study area and is dominantly interbedded and interlaminated, mottled grayish-red and greenish-gray, thinly bedded to thinly laminated, dark and light gray phyllitic mudstones. Fine-grained dolomite with argillaceous partings is also present in the Rome Formation. The total stratigraphic thickness of the Rome Formation has not been determined in the study area because of both poor exposure and complex folding and faulting. Approximately 400 feet of Rome was drilled in the Prices Fork test well.

Rocks of the Elbrook Formation and associated Max Meadows tectonic breccias are extensively exposed in the study area. The Elbrook Formation is approximately 1900-2300 feet thick and is divided into three distinct sections. The upper and middle parts of the Elbrook Formation (1500 feet thick) are dominantly limestones, argillaceous dolomites, chert-berting dolomites, stromatolitic limestones, massively bedded thrombolitic dolomites, and minor ribbon-banded limestones. Limestone content increases up-section while argillaceous dolomites decrease.

The lower part of the Elbrook Formation (400 feet thick) consists of argillaceous to very argillaceous, thin bedded to thinly laminated dolomites, massive dark gray dolomites and algal laminated dolomitic limestones. Near the base of the formation, olive green and light pink argillaceous dolomites are interbedded with gray, very argillaceous to phyllitic thin bedded dolomites with thick, stylolitic shale partings.

Max Meadows tectonic breccias are abundant in the lower part of the Elbrook Formation and upper part of the Rome Formation. Two general types of breccia are present; one characterized by gray dolomite clasts in a crushed dolomite matrix, the other by green phyllitic mudstone and dolomite clasts in a sheared phyllitic matrix.

Structure

Near Blacksburg, rocks of the Maccrady Formation (and locally those of the upper Price Formation) occur along the decollement surface of the Pulaski thrust sheet (Figure 2). Erosion of regional-scale folds of the Pulaski and Saltville thrust sheets has resulted in exposures of Mississippian rocks in the Price Mountain window and of Devonian through Ordovician rocks in the East Radford window. Northwest of the present leading edge of the Pulaski thrust sheet, Mississippian coal bearing rocks are relatively undeformed and dip 30-35 degrees to the southeast. Steeper dips (50-60 degrees) occur near relatively small scale thrust faults. Mesoscopic NE-SW trending folds and associated cleavage are rare and limited to shaly parts of the Mississippian section.

By comparison, Mississippian rocks in the Price Mountain window are folded and faulted (Figure 2). The overall structure of the window is a fault-modified NE-SW plunging anticline. Mesocopic folds are locally abundant on and near the hinge of the anticline and along major fault zones. Along the southwest side of the Price Mountain anticline, two southeast-dipping thrust faults rise from decollements in the Mississippian coals and truncate the anticlinal axis. Locally, these thrusts place the Price Formation over the Maccrady Formation and the Maccrady Formation over dolomites and breccias of the Pulaski thrust sheet. Coal exposed in the fault zones is complexly folded, sheared, and tectonically thickened and thinned (Schultz, 1979). Abundant smaller scale normal and reverse faults occur in the rocks of the window as well as larger high angle oblique-slip faults, such as the Merrimac and Slate Branch faults (Bartholomew and Lowry, 1979). Rocks of the Pulaski thrust sheet are highly deformed and consist of irregularly shaped, internally folded and faulted masses of the Rome Formation and Max Meadows breccias in a complexly folded and faulted terrain of the Elbrook Formation. Folds and faults are abundant and have highly variable styles and orientations.

CORE DRILLING

The Prices Fork Test Well

The first core hole, the Prices Fork test well (W-6533), was begun on January 14, 1982. Located on the Blacksburg 7.5-minute quadrangle at 37° 12′44″N latitude, 80°29′19″W longitude, 2037 feet elevation, the hole was collared in dolomites of the Middle Cambrian Elbrook Formation (Figure 2). Drilling in this hole was difficult, due to complexly folded, faulted, and brecciated rocks of the Pulaski thrust sheet (see discussion on structure). The Prices Fork well, located approximately midway between the Price Mountain window and the leading edge of the Pulaski thrust sheet, was designed to test an anticlinal structure indicated by reports of the depth to the coal-bearing portion of the Price Formation (Stevens, 1959). The four-inch-diameter hole was continuously cored using NCD wireline tools. Drilling became increasingly difficult with depth and, on March 23, 1982, the decision was made to abandon the hole both because of very poor hole conditions (caving and squeezing, which would have required the permanent installation of 1773 feet of four-inch steel casing) and the unexpected thickness of the Pulaski thrust sheet.

The Sunnyside Test Well

The Sunnyside test well (W-6534), located in the Radford North 7.5-minute quadrangle at 37°13′48″N latitude, 80°32′30″W longitude, 2015 feet elevation, was spudded in on April 1, 1982. The well began in the Middle Mississippian Maccrady Formation (Figure 2). The first 321 feet were continuously cored using NCD wireline tools. Four-inch steel casing was installed and continuous coring was resumed with NX wireline tools. The Maccrady-Price formational contact was encountered at 290 feet. The first coal of the upper member of the Price Formation was encountered at 1110.05 feet, where 0.6 feet of coal was cored and sampled for testing. All coals were sealed in metal canisters and tested for methane gas on the drill site by the geologists present, and subsequently in the laboratories of the United States Bureau of Mines in Pittsburgh, Pennsylvania.

The lower member of the Price Formation was encountered at a depth of 1213.1 feet. Due to lack of stratigraphic control, drilling was continued to 1672.0 feet to ensure that the entire coal-bearing sequence had been penetrated. The hole was complete on May 13, 1982. A full suite of wireline geophysical well logs, including 16″-64″ normal resistivity, spontaneous potential, natural gamma, gamma-gamma density, neutron, caliper, acoustic velocity, acoustic televiewer, and pulse temperature was run on the well by the United States Geological Survey (Figure 4).

The Merrimac Test Well

Drilling of the Merrimac test well (W-6535), located at 37°12′08″N latitude, 80°25′47″W longitude, 2090 feet elevation, on the Blacksburg 7.5 -minute quadrangle (Figure 2), was begun on May 20, 1982. Sited slightly north of the Price Mountain window in the Pulaski thrust sheet, the well was spudded into dolomite of the Middle Cambrian Elbrook Formation.

Because of the difficulties encountered in coring the Elbrook Formation in the Prices Fork test well, a four-and-one-half inch tricone rock bit was used initially. The extreme hardness, fine grain size, and complete lack of breccia within the Elbrook Formation in this well made the performance of the tricone rock poorer than that of a conventional diamond bit. Coring was initiated on May 26 at a depth of 45.0 feet using four-inch NCD wireline tools. The Pulaski fault was encountered at a depth of 104.6 feet, where water began to flow with good artesian recharge. This artesian flow continued to the completion of the well. The well passed through the Pulaski fault into mudstones, siltstones and sandstones of the middle Mississippian Maccrady Formation.

On June 6, 1982, the upper member of the Middle Mississippian Price Formation was encountered at a depth of 604.19 feet. The first major coal of the Price Formation was cored at a depth of 1403.5 feet. All coals were sealed in canisters and tested. The lower member of the Price Formation was encountered at a depth of 1481 feet. The well was continued to a total depth of 1674.0 feet to ensure that the entire coal-bearing interval had been penetrated. Drilling was completed on June 28, 1982. Geophysical well logs, including 16″-64″ normal resistivity, spontaneous potential, natural gama, gamma-gamma density, neutron and temperature, were run on the well by the United States Geological Survey (Figure 5).

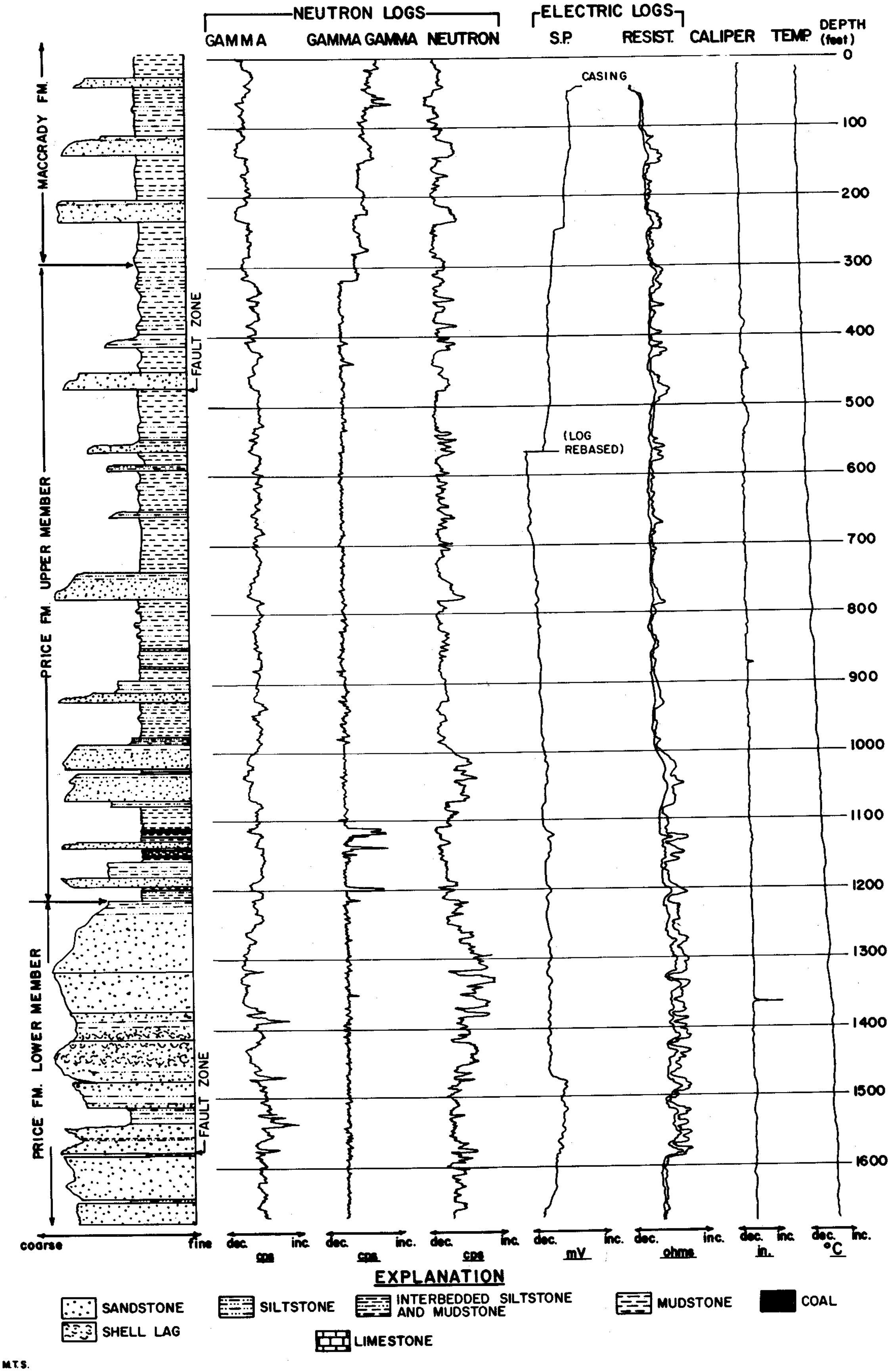


Figure 4. Lithologic and geophysical well logs of the Sunnyside test well, W-6534.

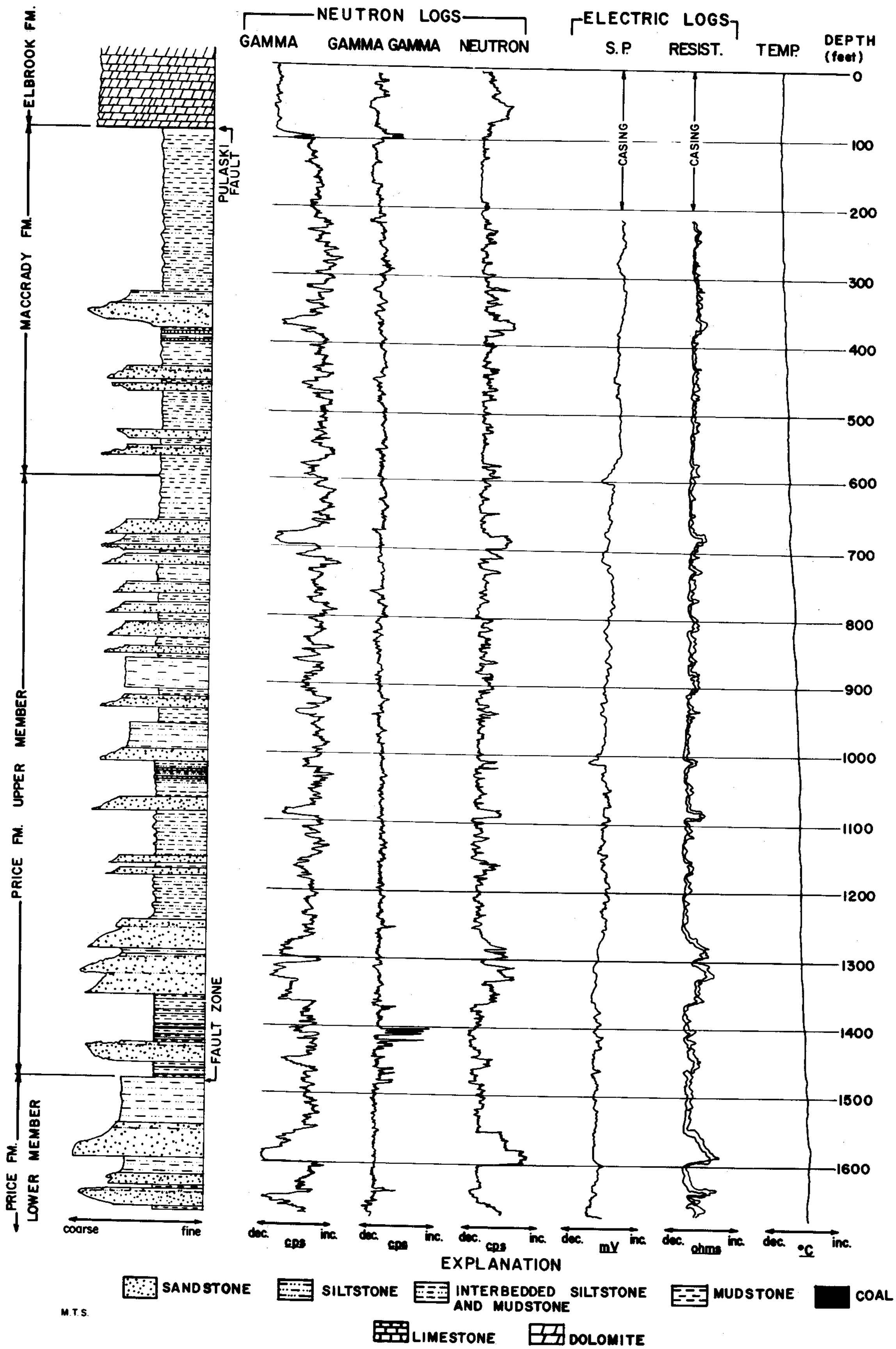


Figure 5. Lithologic and geophysical well logs of the Merrimac test well, W-6535.

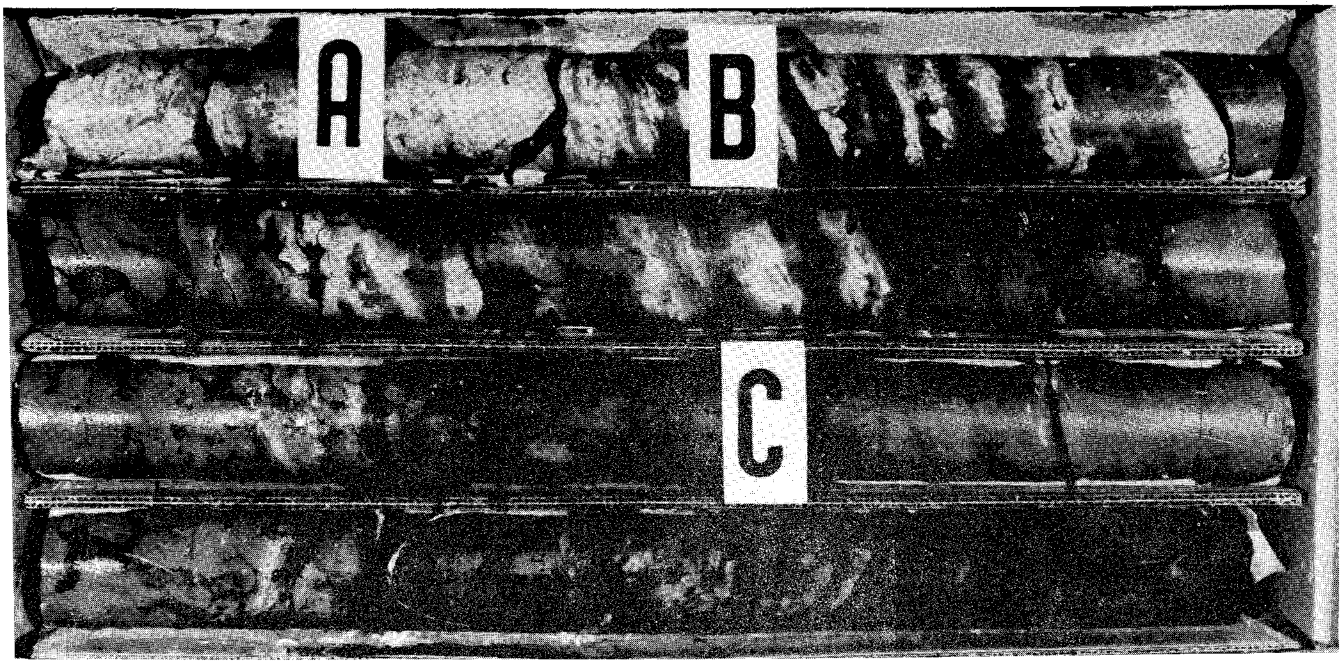


Figure 6. Typical Maccrady Formation lithologies. A. yellowish-gray carbonte bed; B. carbonate nodules in a dark red siltstone; C. dark red siltstone.

GEOLOGY OF THE PRICE AND MACCRADY FORMATIONS OF THE SUNNYSIDE AND MERRIMAC TEST WELLS

Stratigraphy

Rocks of the lower member of the Mississippian Maccrady Formation were the youngest rocks encountered during drilling. The lower Maccrady is dominantly mottled grayish-red and greenish-gray mudstones and siltstones with minor grayish-red and gray sandstones. Mudstones of the Maccrady Formation typically contain irregularly shaped yellowish-gray carbonate nodules and rarely, thin carbonate beds (Figure 6).

Near Blacksburg, the Price-Maccrady contact has been placed at the stratigraphically lowest occurrence of grayish-red siltstones (Bartholomew and Lowry, 1979). The contact in both the Sunnyside and Merrimac wells was placed on the basis of:

1. a change from dominantly grayish-red siltstones of the Maccrady Formation to dominantly gray siltstones and sandstones of the Price Formation, and
2. a change from relatively thick mudstones and minor discrete sandstone lenses of the Maccrady Formation to cyclic, fining-upward sandstone dominated packages of the Price Formation.

The contact is gradational over 100-150 feet.

Cycles characteristic of the upper member of the Price Formation consist of medium-to coarse-grained gray sandstones, with rare basal lithic conglomerates (Figure 7) that fine upward into gray siltstones with interbedded and interlaminated dark gray to black mudstones (Figure 8). The cycles are usually capped by grayish-red or gray mudstones which may contain carbonate nodules and rare carbonate beds similar to those of the overlying Maccrady Formation. The mudstone caps are sometimes interrupted by thin coarsening-upward sandstone lenses (Figures 4 and 5). Down section, the cycles increase in thickness from less than 30 feet to greater than 200 feet and the mudstone intervals become richer in organic material and coal.

The coal-bearing intervals in both test wells are located below an 80 to 100 foot thick medium-grained sandstone. In the Sunnyside test well, this coal-bearing interval is approximtely 90 feet thick and is dominantly siltstone with minor mudstone and sandstone (Figures 9 and 10).

The "Merrimac" coal-bearing interval was encountered in the Sunnyside test well at 110.05 feet and is 10.75 feet thick. The interval consists of six separate coal seams, totaling 6.7 feet in thickness, that are separated by bony mudstone and siltstone (Figure 11). Coal seams of the "Merrimac" interval range from 0.3 to 2.0 feet thick. The interval is bounded above and below by thick black mudstones, an important factor in preventing migration of methane out of the seams.

Below the "Merrimac" coal-bearing interval, two additional coal zones are present. The first, possibly the "Langhorne" (Campbell, 1925) interval, was

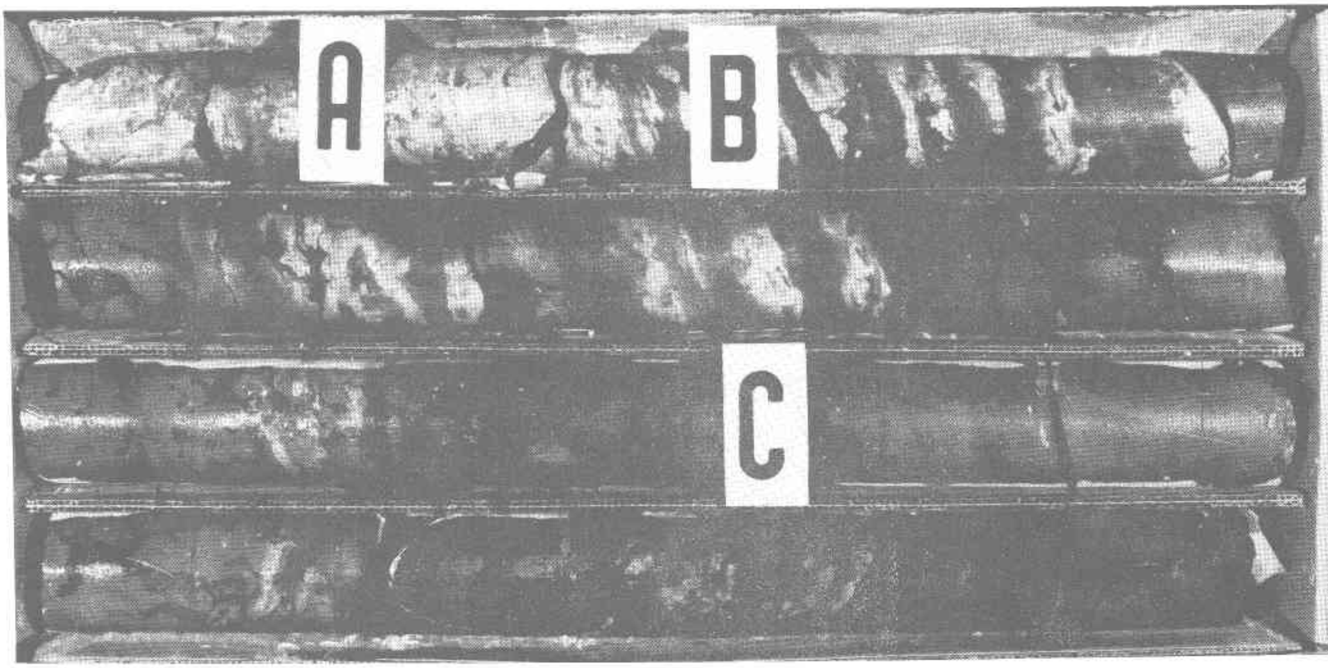


Figure 6. Typical Maccrady Formation lithologies. A. yellowish-gray carbonte bed; B. carbonate nodules in a dark red siltstone; C. dark red siltstone.

GEOLOGY OF THE PRICE AND MACCRADY FORMATIONS OF THE SUNNYSIDE AND MERRIMAC TEST WELLS

Stratigraphy

Rocks of the lower member of the Mississippian Maccrady Formation were the youngest rocks encountered during drilling. The lower Maccrady is dominantly mottled grayish-red and greenish-gray mudstones and siltstones with minor grayish-red and gray sandstones. Mudstones of the Maccrady Formation typically contain irregularly shaped yellowish-gray carbonate nodules and rarely, thin carbonate beds (Figure 6).

Near Blacksburg, the Price-Maccrady contact has been placed at the stratigraphically lowest occurrence of grayish-red siltstones (Bartholomew and Lowry, 1979). The contact in both the Sunnyside and Merrimac wells was placed on the basis of:

1. a change from dominantly grayish-red siltstones of the Maccrady Formation to dominantly gray siltstones and sandstones of the Price Formation, and
2. a change from relatively thick mudstones and minor discrete sandstone lenses of the Maccrady Formation to cyclic, fining-upward sandstone dominated packages of the Price Formation.

The contact is gradational over 100-150 feet.

Cycles characteristic of the upper member of the Price Formation consist of medium-to coarse-grained gray sandstones, with rare basal lithic conglomerates (Figure 7) that fine upward into gray siltstones with interbedded and interlaminated dark gray to black mudstones (Figure 8). The cycles are usually capped by grayish-red or gray mudstones which may contain carbonate nodules and rare carbonate beds similar to those of the overlying Maccrady Formation. The mudstone caps are sometimes interrupted by thin coarsening-upward sandstone lenses (Figures 4 and 5). Down section, the cycles increase in thickness from less than 30 feet to greater than 200 feet and the mudstone intervals become richer in organic material and coal.

The coal-bearing intervals in both test wells are located below an 80 to 100 foot thick medium-grained sandstone. In the Sunnyside test well, this coal-bearing interval is approximtely 90 feet thick and is dominantly siltstone with minor mudstone and sandstone (Figures 9 and 10).

The "Merrimac" coal-bearing interval was encountered in the Sunnyside test well at 110.05 feet and is 10.75 feet thick. The interval consists of six separate coal seams, totaling 6.7 feet in thickness, that are separated by bony mudstone and siltstone (Figure 11). Coal seams of the "Merrimac" interval range from 0.3 to 2.0 feet thick. The interval is bounded above and below by thick black mudstones, an important factor in preventing migration of methane out of the seams.

Below the "Merrimac" coal-bearing interval, two additional coal zones are present. The first, possibly the "Langhorne" (Campbell, 1925) interval, was encountered at 1136.4 feet. The seam is 1.8 feet thick and has mudstone above and below. The second coal interval at 1195.7 feet consists of two seams, 1.2 and 0.75 feet thick, separated by a 0.9 foot thick black mudstone and has a mudstone roof and a sandstone floor.

The coal-bearing interval of the Merrimac test well is approximately 75 feet thick and is dominantly black carbonaceous mudstone with subordinate siltstone and sandstone. Two major coal intervals and several minor seams are present (Figures 12 and 13).

The "Merrimac" interval was drilled at 1403.5 feet and consists of three seams totaling 4.1 feet. The coal seams are separated by carbonaceous mudstones with siltstone lenses, making the total thickness of the "Merrimac" interval 8.4 feet. Relatively thick mudstone occurs above and below the coal interval.

The "Langhorne" coal interval was encountered at 1420.0 feet and is composed of four relatively thin seams totaling 1.9 feet of coal separated by coaly mudstones. Below the "Langhorne" interval, several thin, widely spaced seams ranging from 0.2-0.8 feet thick are present in a mudstone dominated sequence.

Below the coal-bearing intervals in both holes are gray, medium- to coarse-grained sandstones of the lower member of the Price Formation. The contact between the upper and lower members is placed at the top of the first sandstone below the mudstone-coal intervals (Figures 4 and 5). The sandstones of the lower member of the Price Formation have many recognizable marine features, such as polymodal ripple cross-laminations, sandy quartz pebble conglomerates (Figure 14), and marine brachiopod fossil lags (Figure 15).

Structure

The Prices Fork test well, spudded into dolomites of the Elbrook Formation, encountered the first zone of folds, faults, and Max Meadows breccia at approximately 130 feet below the surface (Figure 16). These highly deformed zones increased in frequency and thickness downward. Dips range from horizontal to vertical, changing frequently. A 70-foot-thick zone of intensely folded and fractured dolomite and Max Meadows tectonic breccia occurs at the Elbrook-Rome contact from 840-910 feet. A major fault at approximately 1301 feet separated relatively undeformed phyllitic mudstones of the Rome Formation (dipping 35-40 degrees) from vertically bedded dolomite of the Elbrook Formation. From this fault to the bottom of the hole (1773.5 feet) no further Rome occurs and there is a repeated section of Elbrook.

The Sunnyside test well was sited just north of the present trace of the Pulaski fault, near the Price-Maccrady contact (Figure 2). Outcrops in the vicin-

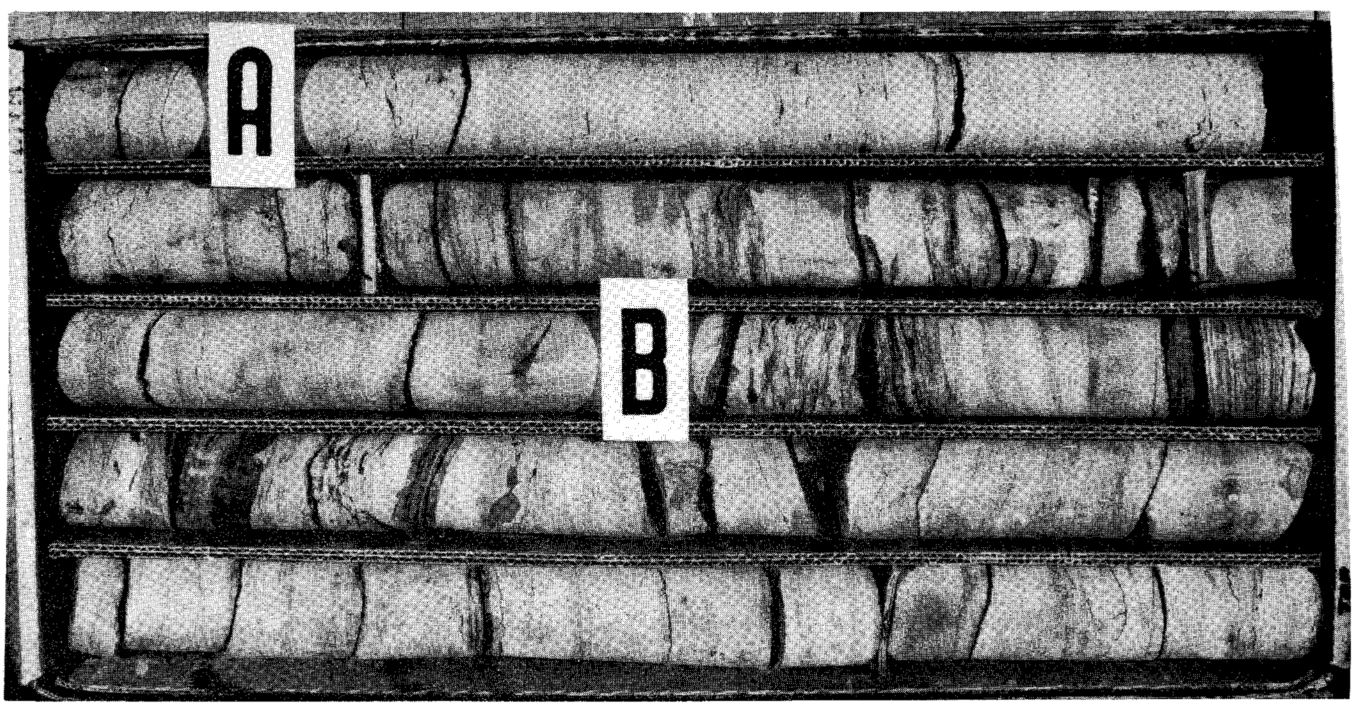


Figure 7. Base of typical cycle in the upper member of the Price Formation. A. coarse-grained, light gray sandstone with rare lithic fragments B. interbedded coarse-to medium-grained sandstone with gray shale lamellae and rare lithic clasts.

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The coal-bearing interval of the Merrimac test well is approximately 75 feet thick and is dominantly black carbonaceous mudstone with subordinate siltstone and sandstone. Two major coal intervals and several minor seams are present (Figures 12 and 13).

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Below the coal-bearing intervals in both holes are gray, medium- to coarse-grained sandstones of the lower member of the Price Formation. The contact between the upper and lower members is placed at the top of the first sandstone below the mudstone-coal intervals (Figures 4 and 5). The sandstones of the lower member of the Price Formation have many recognizable marine features, such as polymodal ripple cross-laminations, sandy quartz pebble conglomerates (Figure 14), and marine brachiopod fossil lags (Figure 15).

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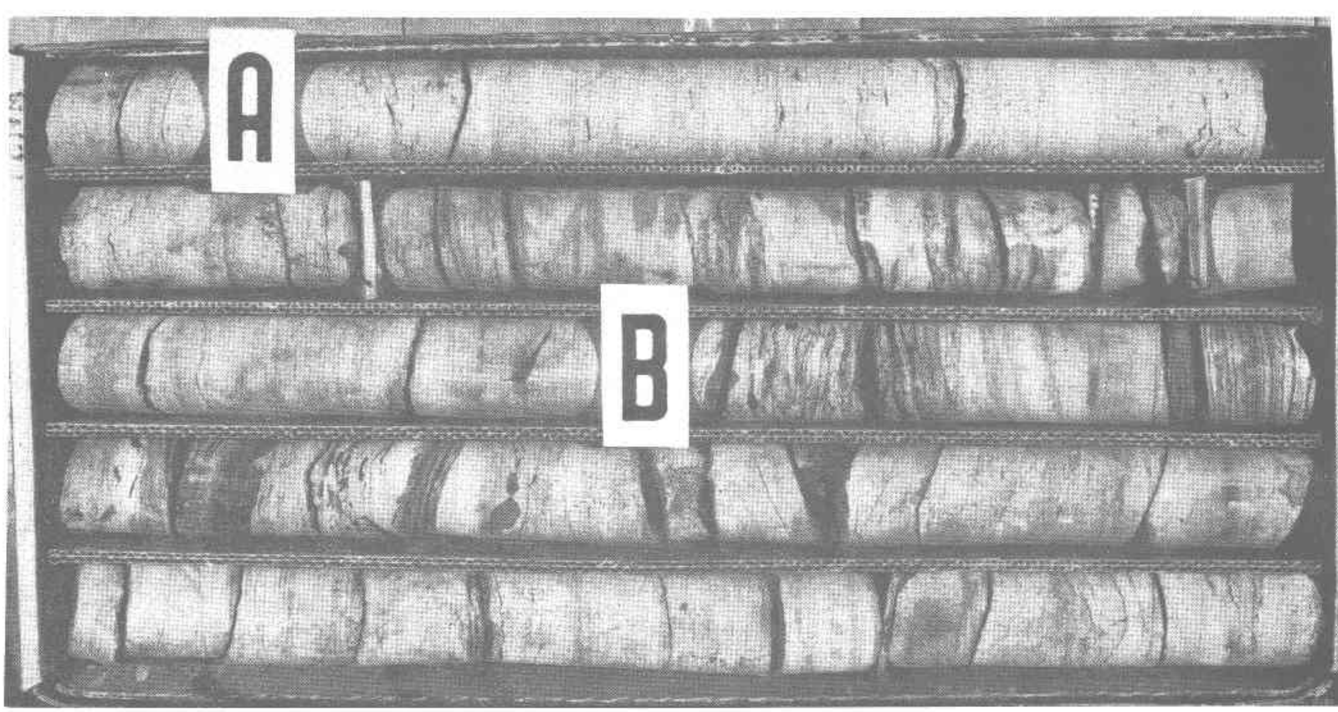


Figure 7. Base of typical cycle in the upper member of the Price Formation. A. coarse-grained, light gray sandstone with rare lithic fragments B. interbedded coarse-to medium-grained sandstone with gray shale lamellae and rare lithic clasts.

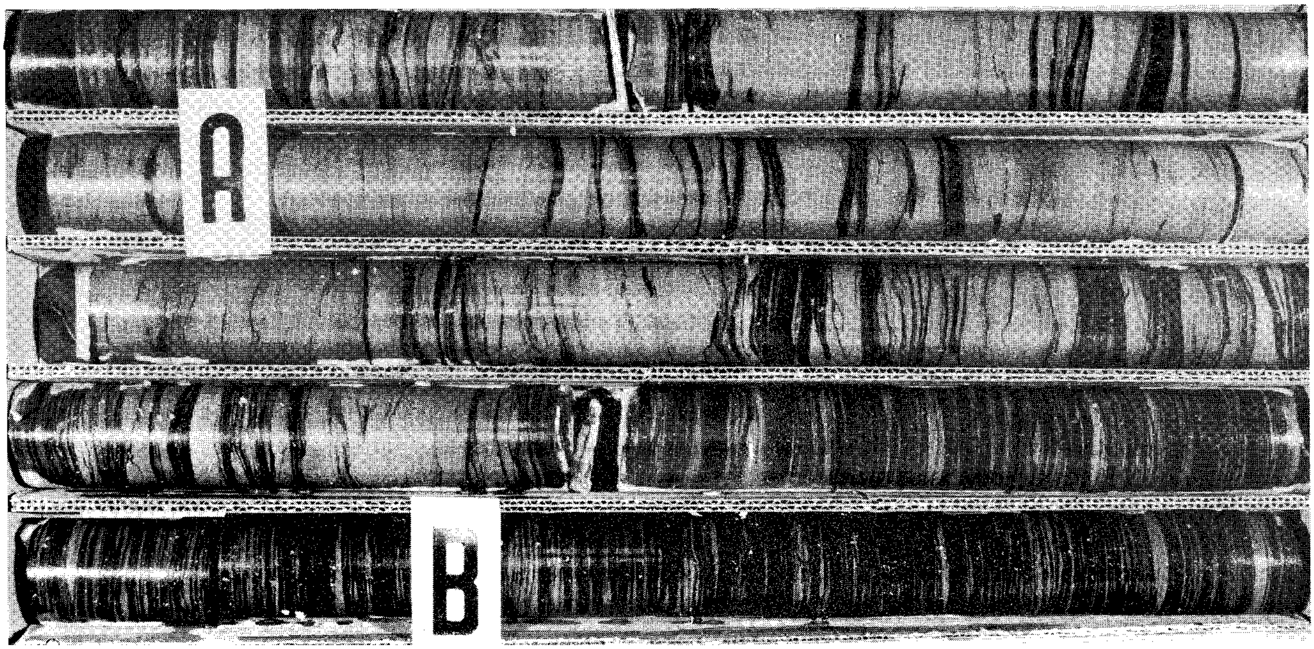


Figure 8. Middle portion of typical cycle in the upper member of the Price Formation. A. medium- to fine-grained light gray sandstones and siltstones with ripple cross-laminated dark gray to black mudstone partings B. interbedded ripple cross-laminated dark gray to black mudstones and medium gray, medium- to fine-grained and siltstones.

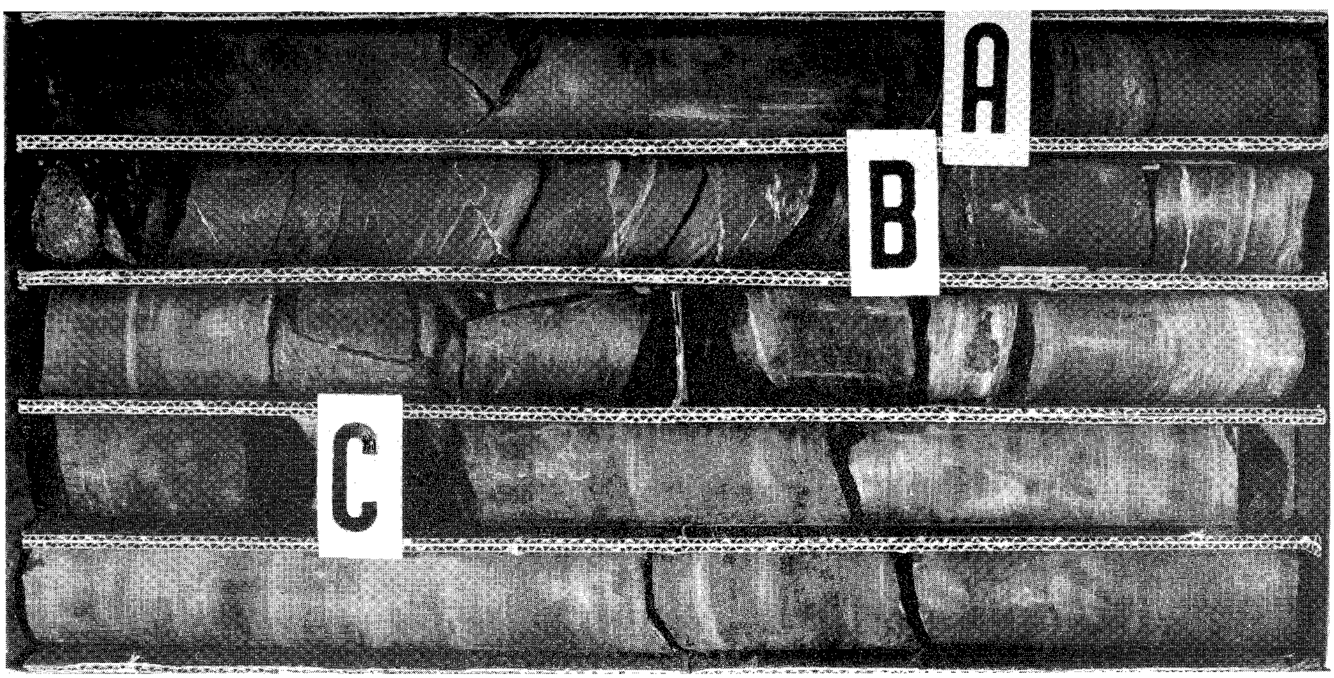


Figure 9. Top of cycle in the upper member of the Price Formation A. B. C. are locations of coal sampled for methane. Coals occur in dark gray mudstones and gray siltstones. Note calcite filled fractures left of B.

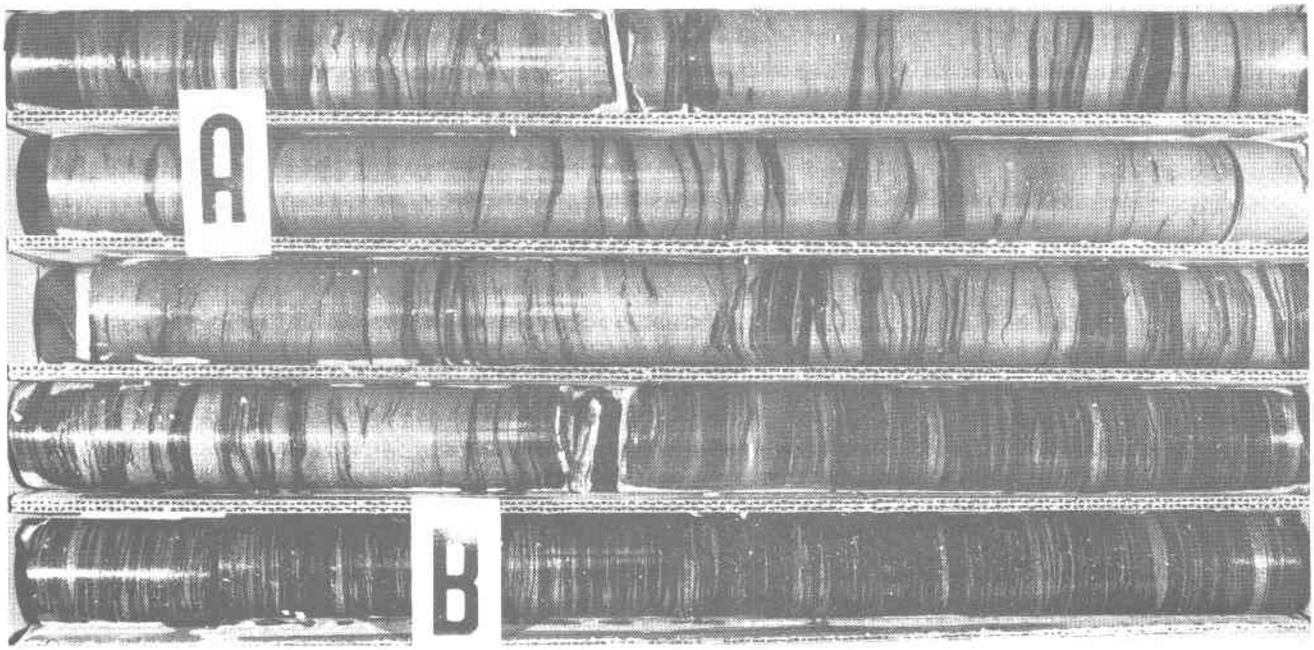


Figure 8. Middle portion of typical cycle in the upper member of the Price Formation. A. medium- to fine-grained light gray sandstones and siltstones with ripple cross-laminated dark gray to black mudstone partings B. interbedded ripple cross-laminated dark gray to black mudstones and medium gray, medium- to fine-grained and siltstones.

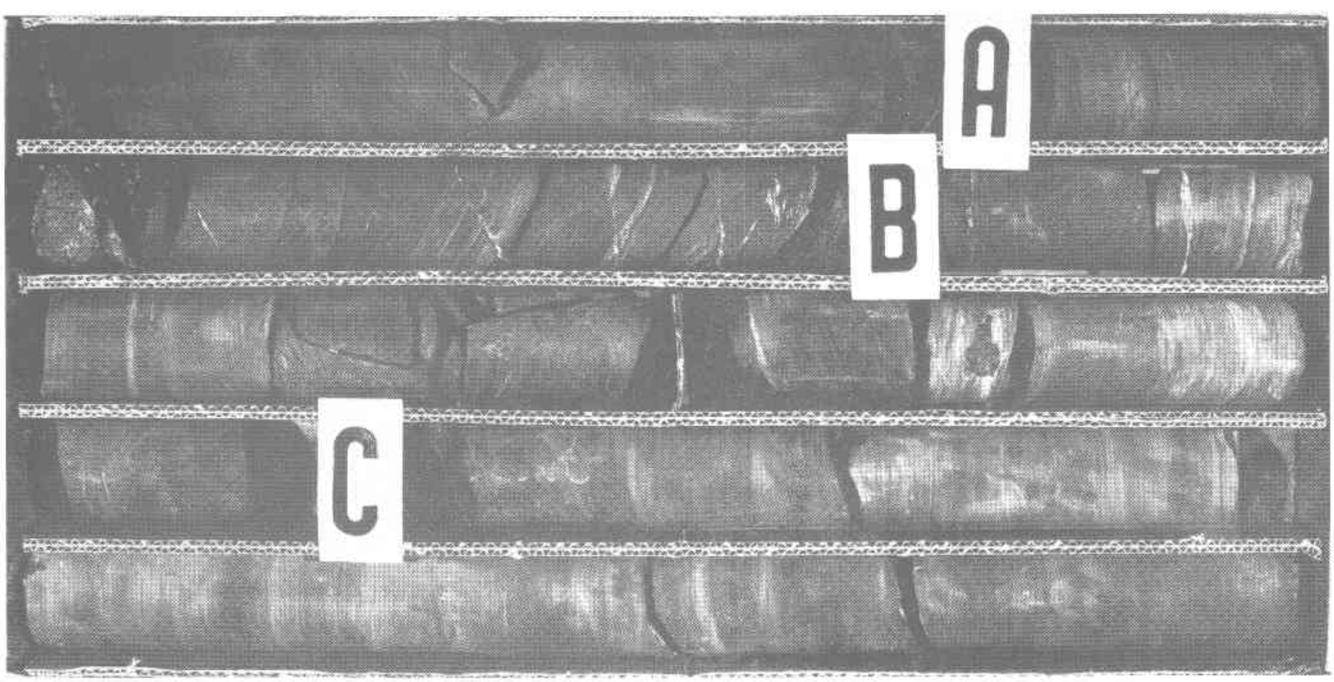


Figure 9. Top of cycle in the upper member of the Price Formation A. B. C. are locations of coal sampled for methane. Coals occur in dark gray mudstones and gray siltstones. Note calcite filled fractures left of B.

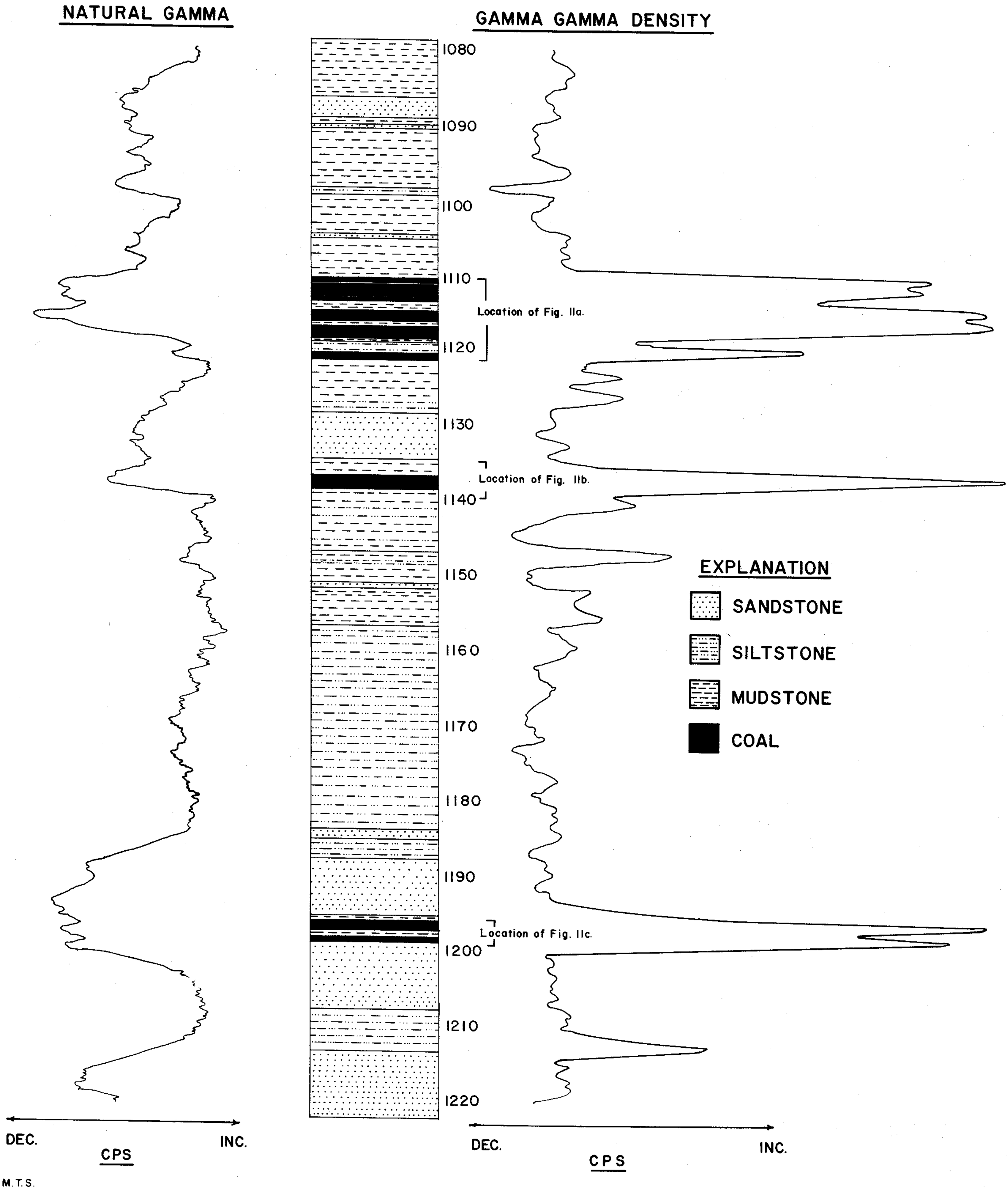


Figure 10. Lithologic, natural gamma, and gamma-gamma density logs of the coal-bearing interval of the Sunnyside test well.

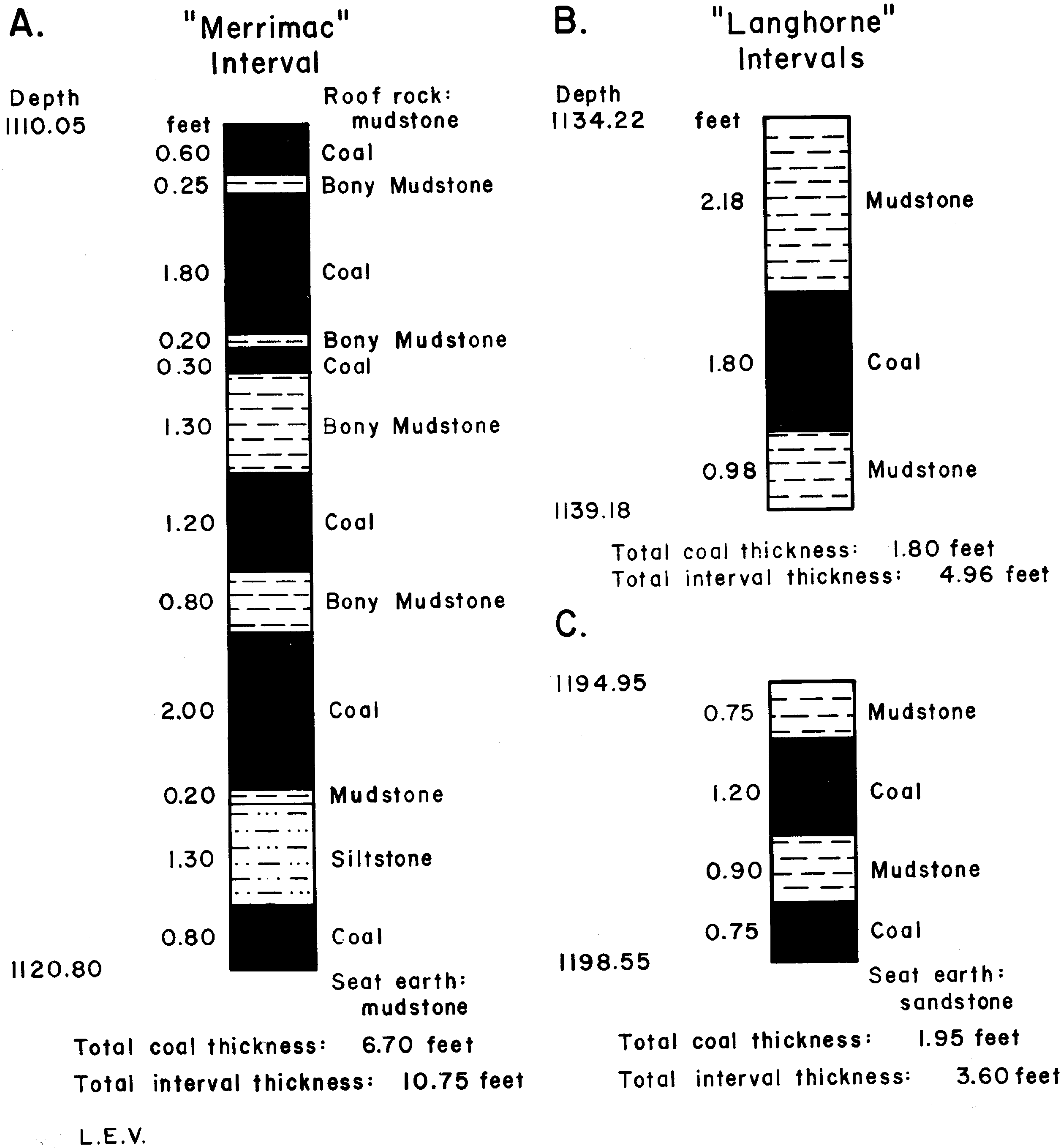


Figure 11. Detailed descriptions and thicknesses of the coal intervals of the Sunnyside test well (see also Figures 4 and 10).

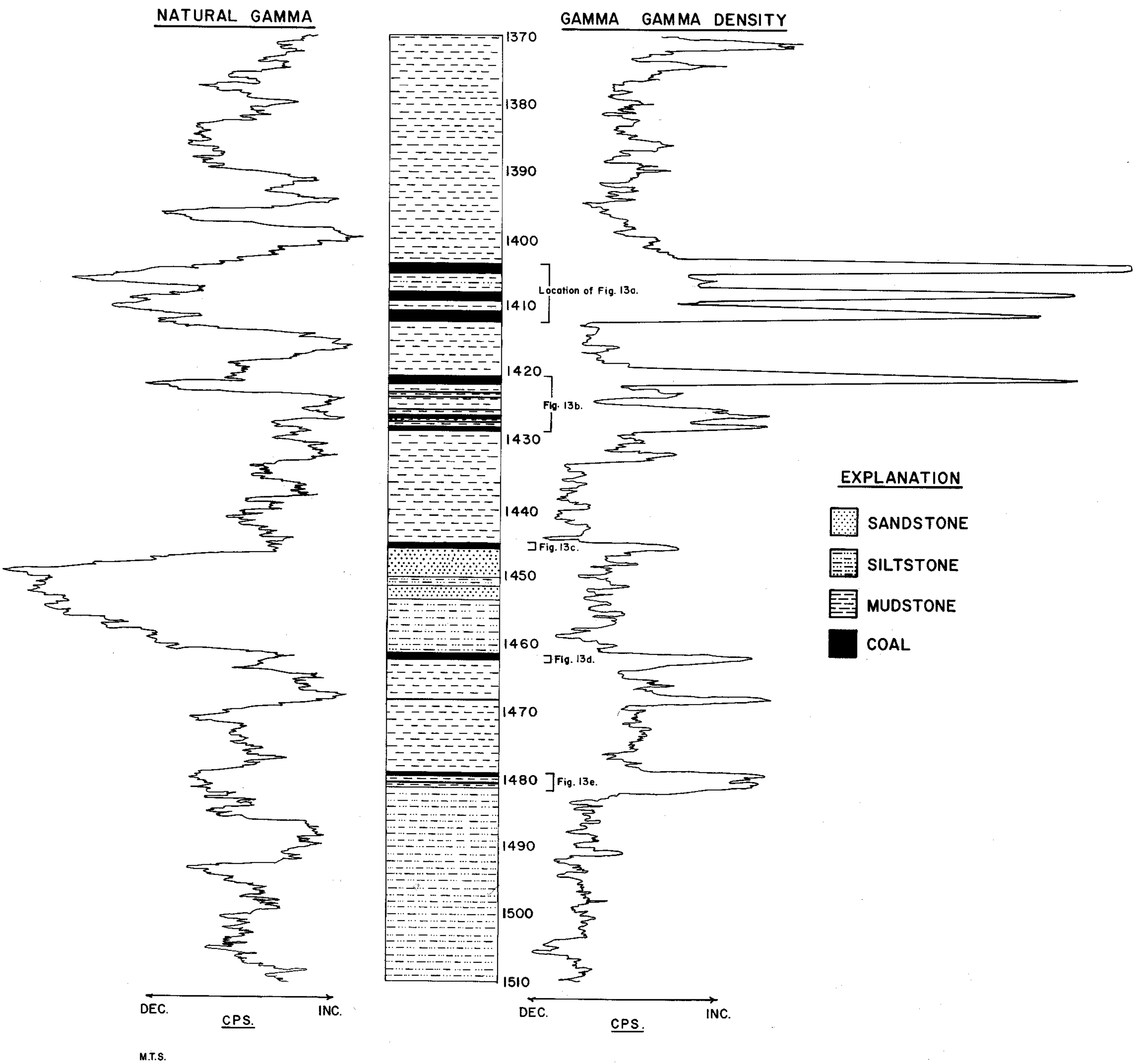


Figure 12. Lithologic, natural gamma, and gamma-gamma density logs of the coal-bearing interval, Merrimac test well.

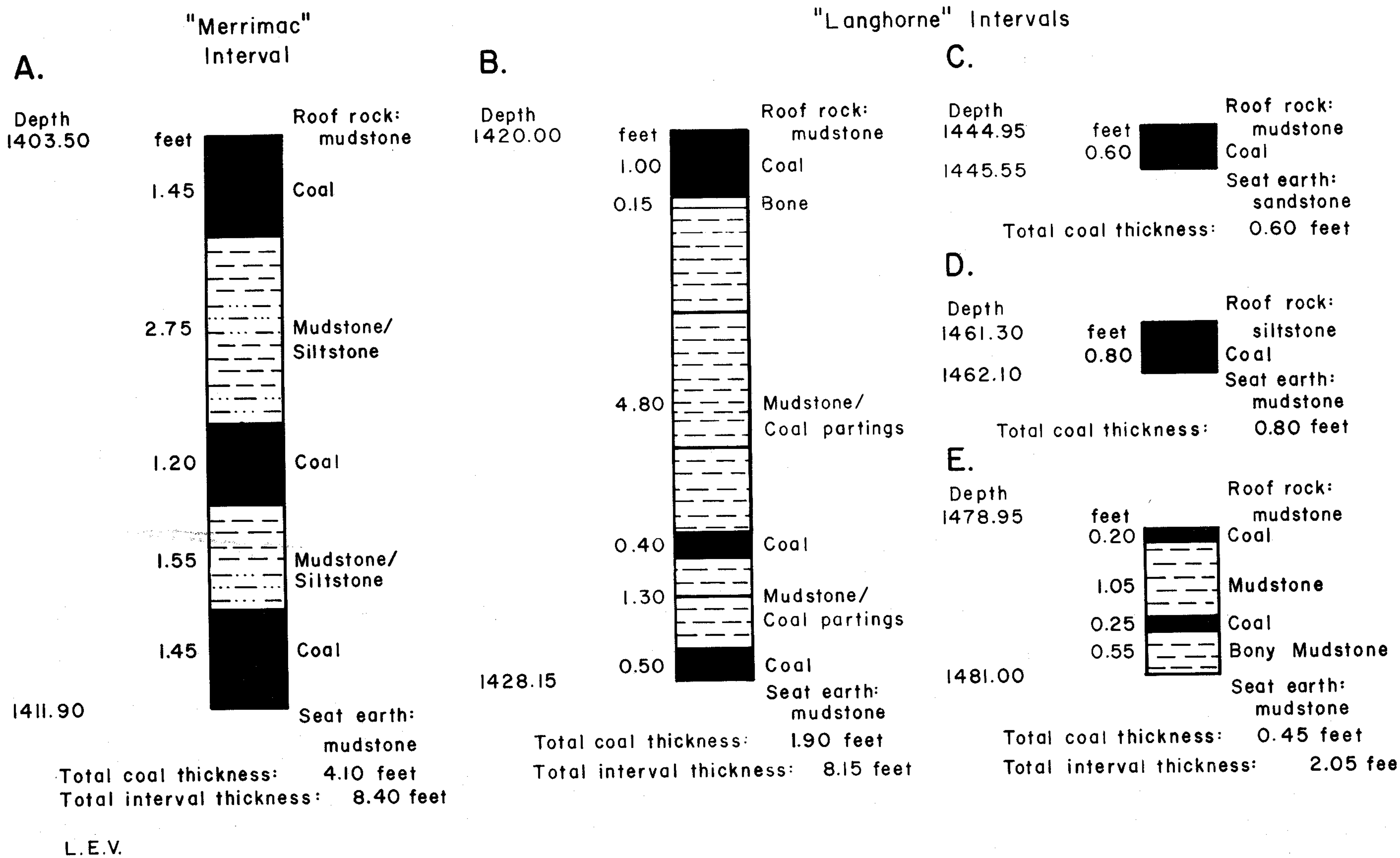


Figure 13. Detailed descriptions and thicknesses of coal intervals, Merrimac test well (see also Figures 5 and 12).

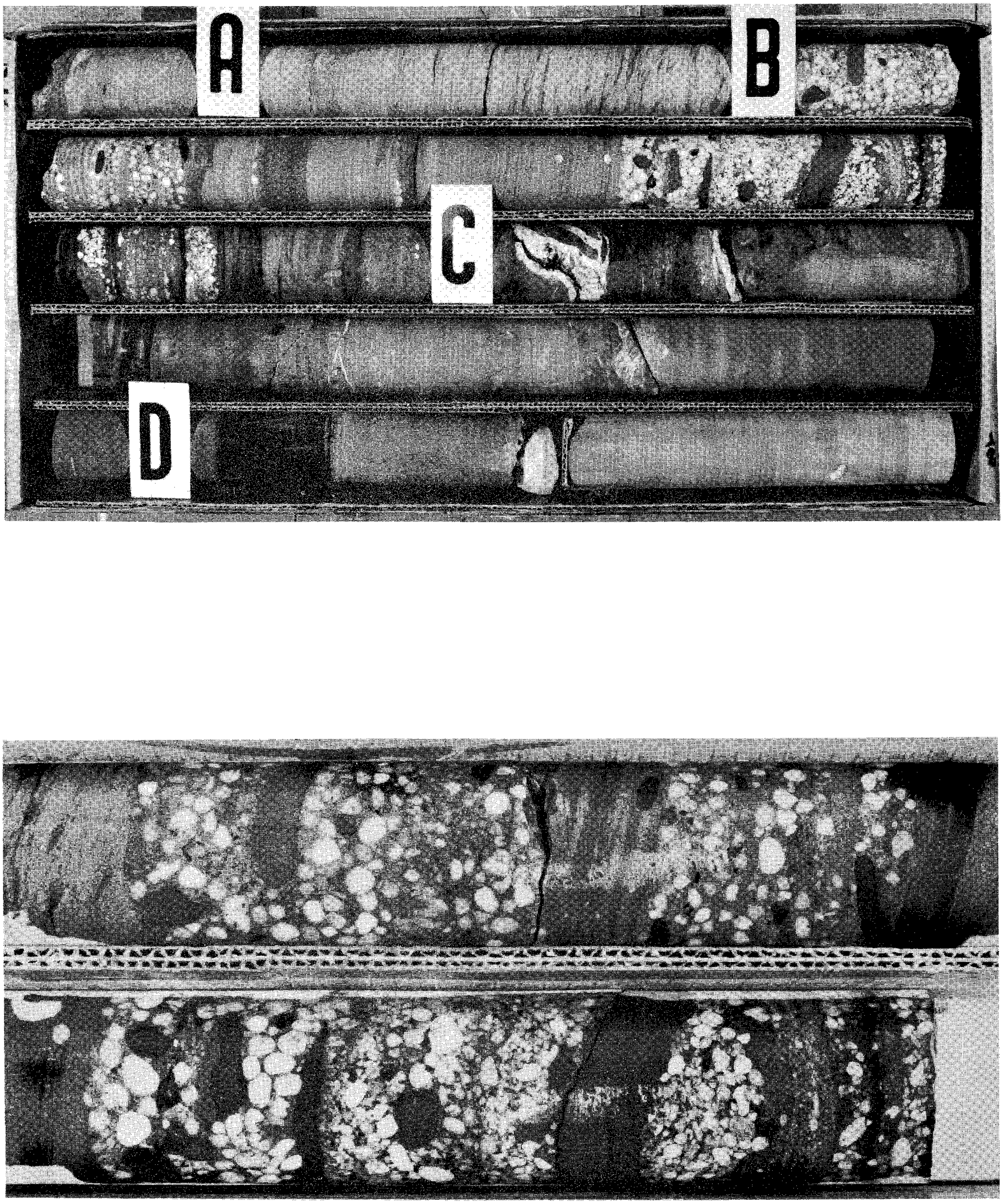


Figure 14. Typical lithologies of the lower member of the Price Formation A. medium-grained sandstone with rippled cross-laminated mudstone streaks. B. sandy quartz pebble conglomerate with rare iron stone and lithic clasts (enlarged at bottom). C. large calcite filled fracture with calcite crystals in vugs. D. thin mudstone bed in medium- to fine-grained sandstone.

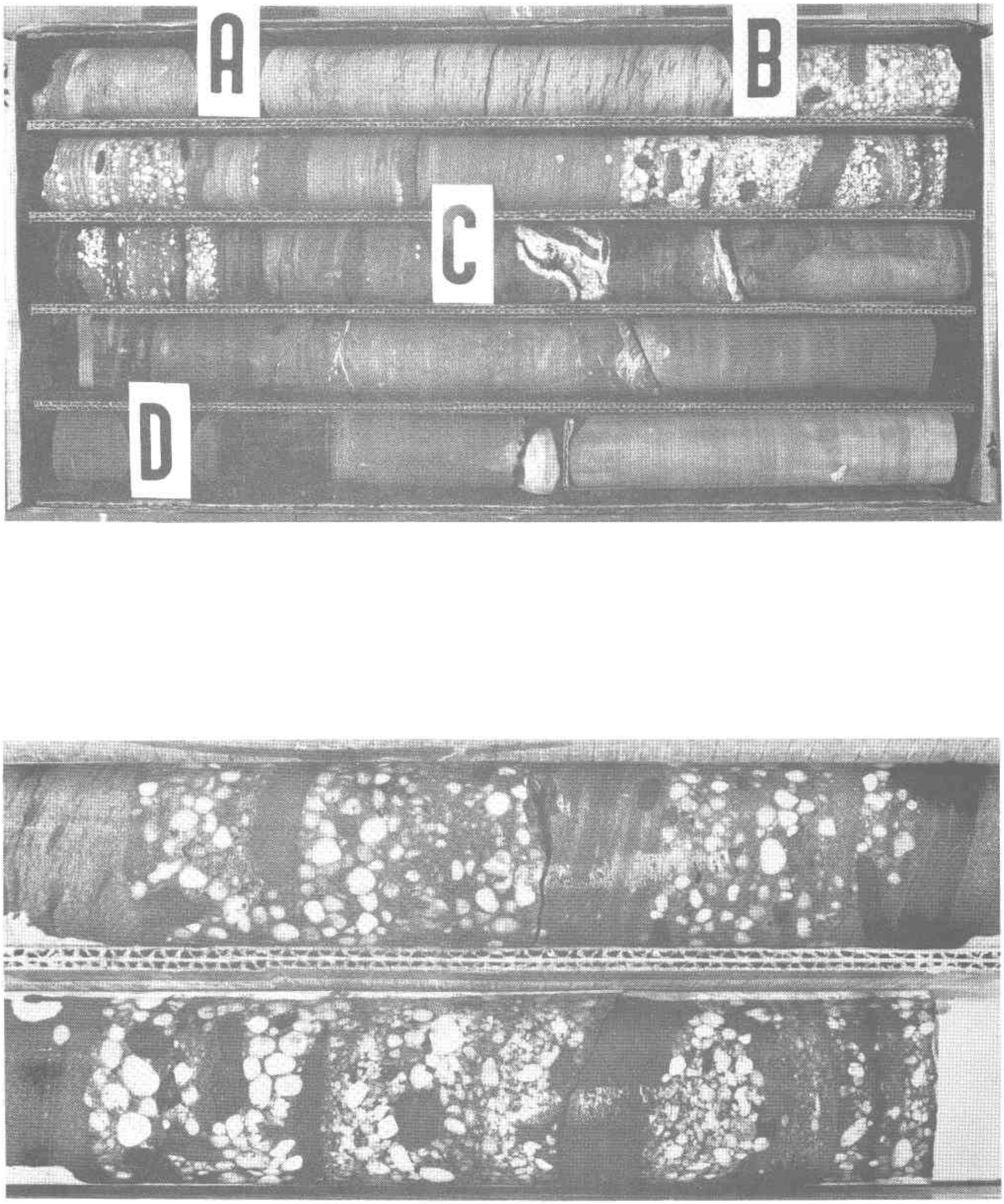


Figure 14. Typical lithologies of the lower member of the Price Formation A. medium-grained sandstone with rippled cross-laminated mudstone streaks. B. sandy quartz pebble conglomerate with rare iron stone and lithic clasts (enlarged at bottom). C. large calcite filled fracture with calcite crystals in vugs. D. thin mudstone bed in medium- to fine-grained sandstone.

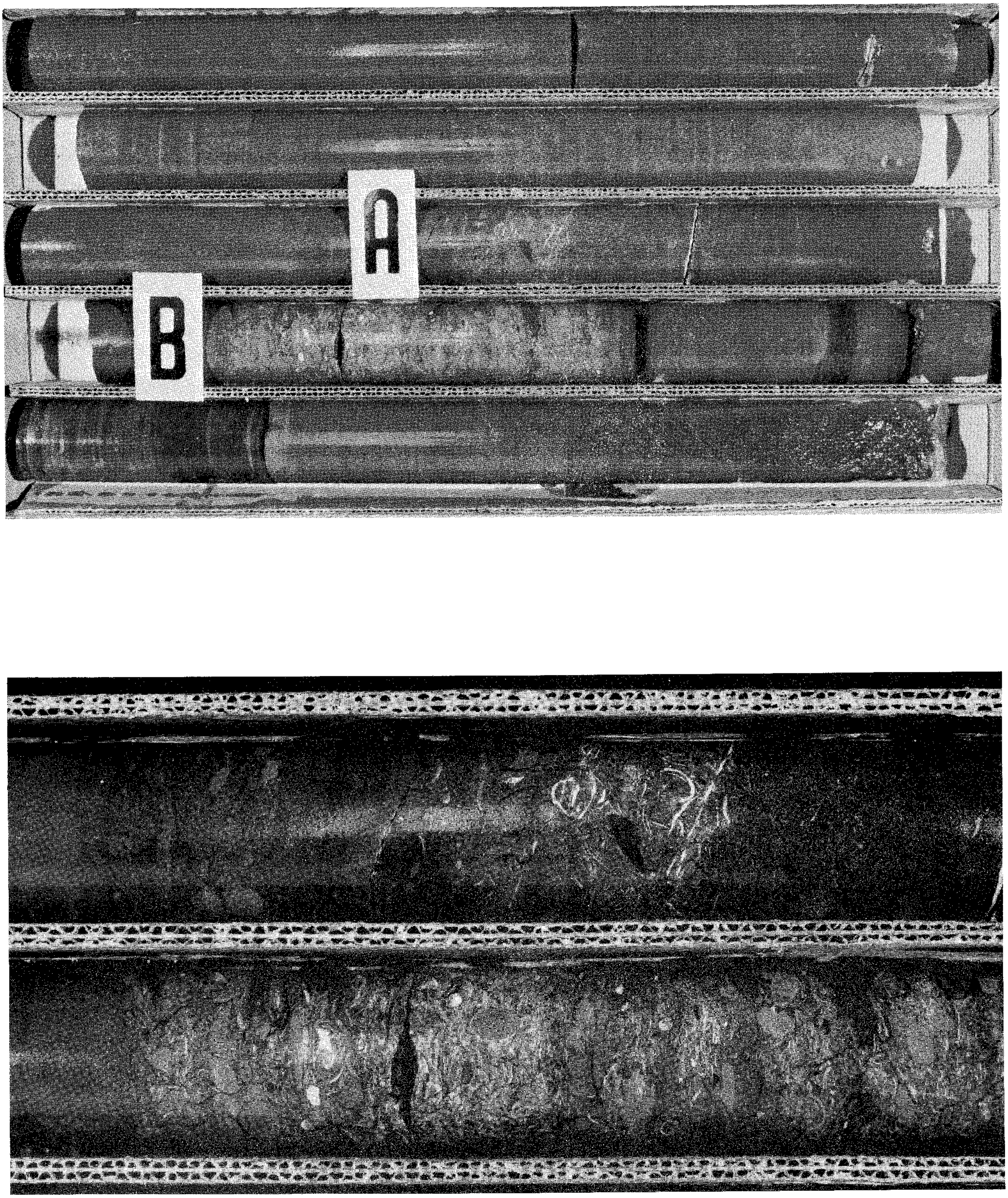
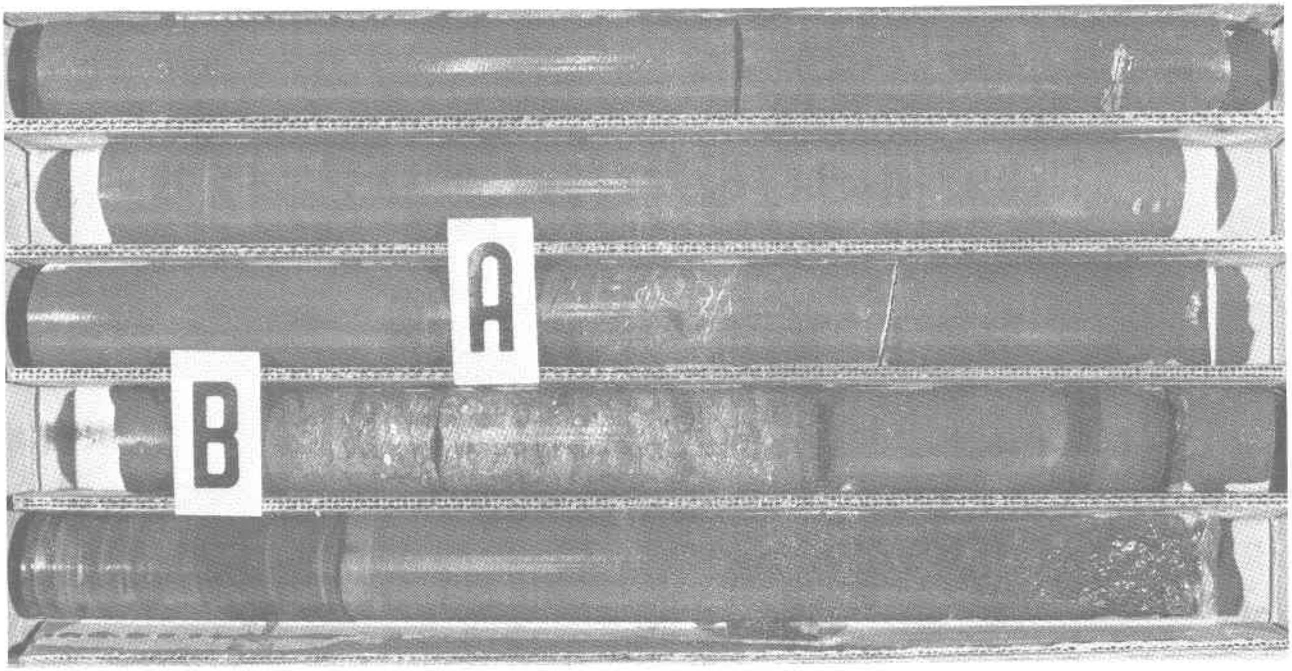


Figure 15. Typical lithologies of the lower member of the Price Formation. Medium- to fine-grained, medium gray, massive to ripple cross-laminated sandstones with: A and B. intensely bioturbated (burrowed) sandy shales containing abundant brachiopod fossils (enlarged at bottom).



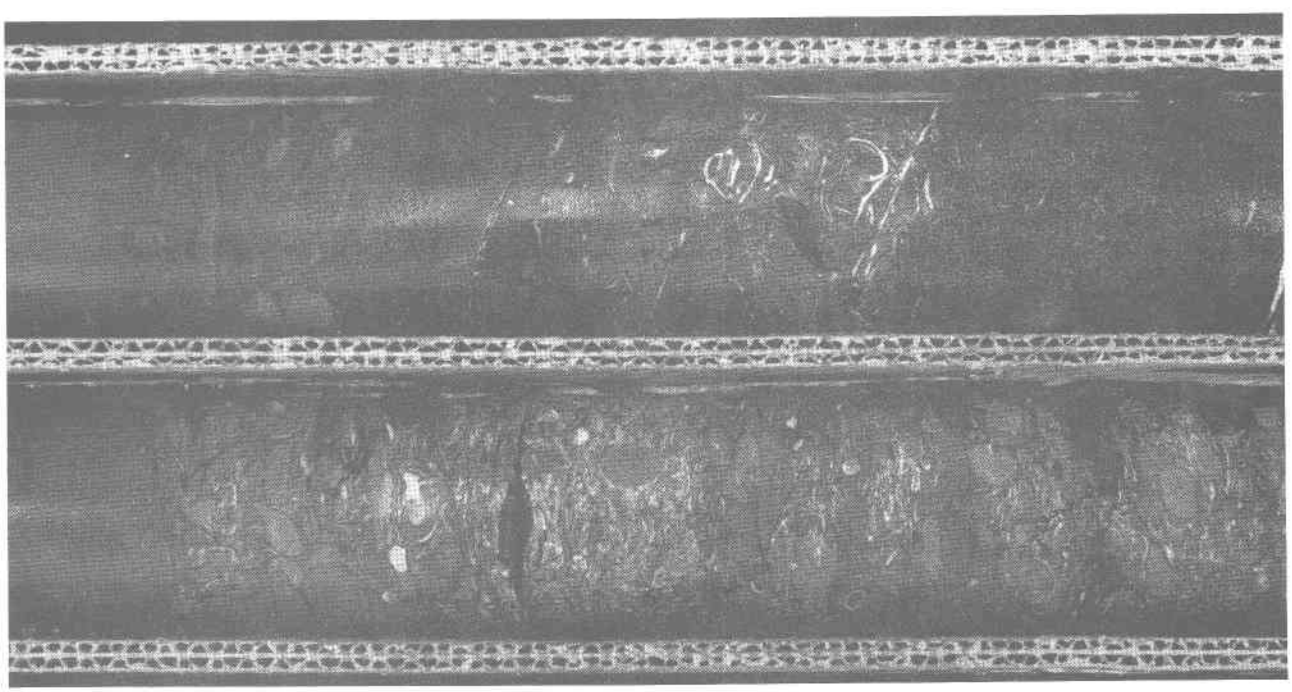


Figure 15. Typical lithologies of the lower member of the Price Formation. Medium- to fine-grained, medium gray, massive to ripple cross-laminated sandstones with: A and B. intensely bioturbated (burrowed) sandy shales containing abundant brachiopod fossils (enlarged at bottom).

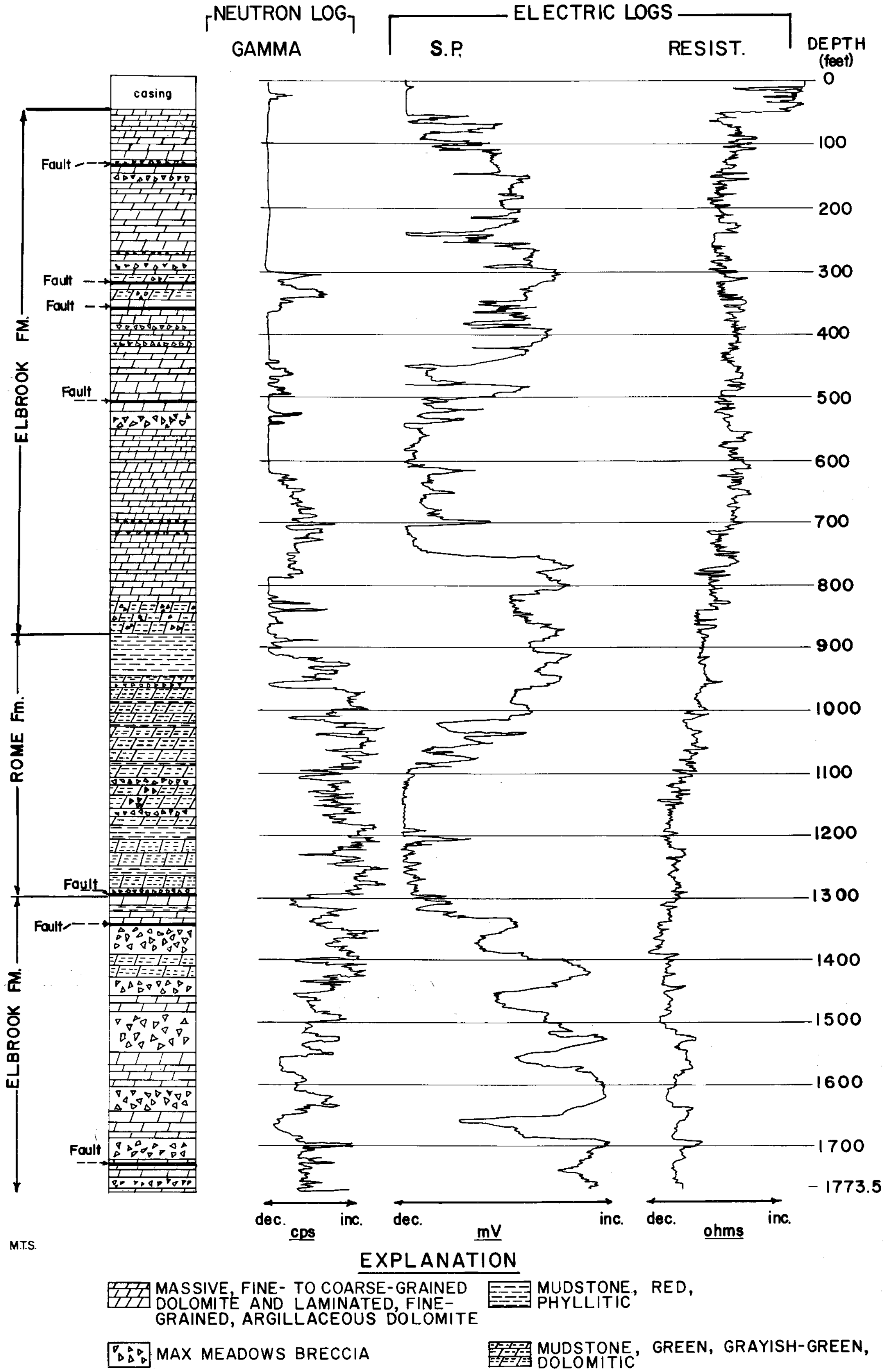


Figure 16. Lithologic and geophysical well logs, Prices Fork test well, W-6533.

ity of the hole expose rocks which are locally folded and faulted. Similar structures are present in the test well. At least four fault zones containing numerous calcite veins, disrupted bedding, and cleavage were encountered in the hole (Figure 4). In general, dips range from 20-40 degrees in the upper part of the hole and gradually flatten to 0-5 degrees near the bottom. Coals encountered in the well were horizontal.

The coal seams drilled in the Sunnyside test well are blocky and undeformed. However, coal exposed in mine workings just north of the well is greatly folded and sheared. Campbell (1925) reported the highly variable condition of coals in mines in this vicinity, ranging from "blocky and undisturbed" to "crushed and distorted."

The Merrimac test well was spudded into dolomite of the Elbrook Formation approximately 300 feet from the northwest edge of the Price Mountain window (Figure 2). The Pulaski fault occurs at 104.6 feet below the surface and the fault dip is 20-25 degrees, presumably to the northwest. Above the thrust contact, Elbrook dolomites are folded, fractured, and brecciated, with abundant vugs and calcite veins. Although there are large pod-like masses of Max Meadows breccias in the vicinity of the Merrimac test well (Bartholomew and Lowry, 1979), no breccia was drilled. Instead, the fault zone consists of highly fractured dolomite above a six-inch-thick, black, clay-rich, foliated gouge overlying highly fractured grayish-red and greeninsh-gray mudstones of the Maccrady Formation.

Below the Pulaski thrust, the Mississippian section is faulted and contains numerous bedding-parallel slickensided surfaces and calcite veins. Bedding dips uniformly from 25 to 35 degrees, probably to the northwest, and flattens from 10 to 0 degrees below about 1000 feet.

Coals drilled in the Merrimac test well are tightly folded, highly sheared, and foliated, consistent with coal outcrops (Schultz, 1979) and published descriptions of coal in mines in Montgomery County, Virginia (Campbell, 1925).

ECONOMIC FEASIBILITY[1]

A preliminary feasibility analysis of production from the coal-bed methane resource was conducted by Gruy Petroleum Technology (formerly Gruy Federal). The analysis, discussed in this section, was of the type that a sophisticated, commercial enterprise would undertake to evaluate the potential of a product or investment in the very early stages of development or evaluation. As a potential project progesses from the idea-stage toward implementation, increasing effort is devoted to refinement of assumptions, specifications, and projections of alternative outcomes, and the likelihood of each. Greater precision also is required as the project progresses through increasingly serious consideration. Ultimately, a final decision is made to proceed, abandon, or defer. The general financial feasibility process is described in Appendix V, which has been extracted from our project proposal.

Since the feasibility study is very preliminary, the primary effort has been devoted to estimating production from the methane-drainage wells. It is comparatively easy to approximate drilling costs, operating costs, tax considerations, capital requirements for surface equipment, and gas prices. Moreover, these data are likely to be different from one project to another. Thus, the usefulness of the feasibility information is maximized by production and eonomic-life information which can be adapted to the specific circumstances and financial considerations of the potential investor.

Well Productivity and Well Life

Well productivity was estimated by assuming production would decline hyperbolically, as is typical for fractured reservoirs. An initial productivity of 20 Mcf/D was assumed, consistent with the National Petroleum Council's opinion that gas recovery rates in methane-drainage wells average 3 Mcf/D per foot of coal-seam thickness (National Petroleum Council, 1980). A production rate of 4.8 Mcf/D was assumed to be the minimum economic rate at which a well could be produced; i.e., when production declined below 4.8 Mcf/D, a well would be shut in because its operating cost would exceed the value of the gas produced.

Well spacings of 10, 20, and 40 acres were considered, with gas recovery for each well-spacing calculated from porous-media flow theory assuming radial, isotropic flow. For all spacings, original gas-in-place was assumed to be 3,220 Mcf/acre, consistent with the gas desorption tests made on the coal samples obtained during drilling.

Gas recovery is a function of well spacing, increasing with well density. Conversely, well life decreases with increasing well density because with less gas to be produced per well, a well's economic limit is encountered sooner. Table 2 lists for each well spacing considered, annual production, and total recovery over the life of an average well.

Financial Projections

Five variables appear to be particularly critical

[1] Written by Gruy Petroleum Technology Incorporated, Arlington, Virginia 22202.

Table 2. Annual production (Mcf[1]) for methane drainage wells.

Year	Well Spacing 10-acre	20-acre	40-acre
1	5,888	6,355	6,729
2	4,071	5,021	5,903
3	2,980	4,068	5,221
4	2,274	3,363	4,651
5	1,209	2,828	4,171
6	—	2,410	3,762
7	—	2,080	3,411
8	—	1,566	3,107
9	—	—	2,842
10	—	—	2,610
11	—	—	2,405
12	—	—	2,224
13	—	—	2,063
14	—	—	1,918
15	—	—	1,789
Total recovery	16,422	27,691	52,806
Gas-in-place	32,220	64,440	128,880
% recovery	50.97	42.97	40.97
Well life, years	4.65	7.86	15.00

[1] 1 Mcf=one thousand cubic feet

in the development of financial projections for coalbed methane production. The five are: well productivity (and assumed back-pressure), economic well-life, well cost (and capital for surface equipment), gas price, and gas quality. Other less important factors include operating and maintenance costs, tax rates (if applicable), severance and production taxes (state and local), royalties, working interest division, depletion allowance considerations, and some estimate of the investor's expected rate of return on investment. The rate of return should approximate the investor's marginal cost of capital plus a provision for the riskiness of the project compared to the investor's normal undertakings.

Incremental profit and loss, balance sheet, and cash flow estimates are developed by year from the data described above. For example, assume 40-acre spacing and a constant gas price at the wellhead of $5.00 per Mcf. Also, assume that the investor owns the land and mineral rights so that there is no royalty. Further, assume that operating and maintenance cost is $4,800/year, the severance tax rate is 0%, depletion allowance is 15%, and the cost of compressing the gas to contract line-pressure is 10% of the gas itself.

This information is converted into profit and loss statements and cash flow estimates as shown in Table 3. The total gas production, less the override or gas production, less the override or royalty to the mineral rights owner, is the net production on which the working interest (investors) receive revenue at a contract price per Mcf. Severance and production taxes are zero in this illustration for Virginia. The operating, maintenance, and compression cost is the assumed $4,800/year plus 10% of the total production times its contract price. The 10% represents the gas consumed in compressing of the remaining production to line pressure. Subtraction yields a variable margin (referred to as net revenue in the petroleum industry). The entire well cost in this example is capitalized and depreciated in proportion to production (unit of production basis). Depletion at 15% of working interest revenue and the depreciation are subtracted to determine taxable income, which we have taxed at a composite federal/state rate of 50% to calculate the after/tax profit. The non-cash charges against revenue (depreciation and depletion are added back to after-tax profit to determine the annual cash flow. We will ignore the month or so lag between production, as well as certain other timing differences. The same assumptions, but with a $10.00/Mcf gas price, are the basis for Table 4.

The result is cash outflow (investment) for the well followed by an operating cash inflow. Note the interest expense is omitted to permit a discounted cash flow rate of return on investment. However, a complete project cash flow would have to take financing costs and repayment into account.

Well costs, which are detailed in Table 5, have been used as estimated by TRW Energy Systems Group (1981) in a study for the U.S. Department of Energy. Gathering and distribution system costs have been omitted because the user, the distance from the well, and the gas quality specifications are not known.

The financial projections for 10-, 20- and 40-acre spacing and various constant gas prices are summarized in Table 6. The 10-, and 20-acre spacing does not produce nearly enough gas to generate incremental variable margin equal to the initial investment outlay, given the gas content and coal thickness identified for the two test wells. Even 40-acre spacing, seven feet of individual coal seams, and a price of $5.00/Mcf generates barely enough incremental margin to cover the investment outlay. If the price doubled to $10.00 or if the total coal thickness were 14 feet (and the price were $5.00/-Mcf), the incremental margin would be about 2.6 times the investment, making possible a return on investment around 20%. However, an override or royalty of one-eighth would significantly reduce the attractiveness because it is a proportionate reduction of revenue without affecting costs.

Discussion and Interpretation

The financial data for the specific test-well data

Table 3. Profit and loss statements and cash flow estimates at $5.00/Mcf for coal-bed methane of the Price Formation, Montgomery, County, Virginia (dollars in thousands).

Price = $5.00/Mcf
Spacing = 40 acres
Operating/Maintenance = $4,800/yr.
Override = 0
Depletion = 15%
Severance tax = 0%
Compression cost = 10% of gas

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Total production (MMcf)	6.73	5.91	5.22	4.65	4.17	3.76	3.41	3.11	2.84	2.61	2.41	2.22	2.06	1.92	1.79	52.81
Less: Override	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net production (MMcf)	6.73	5.91	5.22	4.65	4.17	3.76	3.41	3.11	2.84	2.61	2.41	2.22	2.06	1.92	1.79	52.81
Revenue	33.6	29.5	26.1	23.3	20.9	18.8	17.1	15.5	14.2	13.0	12.0	11.1	10.3	9.6	9.0	264.0
Severance Tax	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Operating, Compresion and Maintenance Cost	8.2	7.8	7.4	7.1	6.9	6.7	6.5	6.4	6.2	6.1	6.0	5.9	5.8	5.7	5.7	98.4
Variable margin	25.4	21.7	18.7	16.2	14.0	12.1	10.6	9.1	8.0	6.9	6.0	5.2	4.5	3.9	3.3	165.6
Less:																
Depreciation	17.2	15.1	13.3	11.9	10.6	9.6	8.7	7.9	7.3	6.7	6.2	5.7	5.3	4.9	4.6	135.0
Depletion @15%	4.1	3.3	2.7	2.2	1.7	1.2	1.0	.6	.3	.1	-	-	-	-	-	17.2
Taxable income	4.1	3.3	2.7	2.1	1.7	1.3	.9	.6	.4	.1	(.2)	(.5)	(.8)	(1.0)	(1.3)	13.4
Income tax @50%	2.0	1.7	1.3	1.1	.8	.7	.4	.3	.2	.1	(.1)	(.2)	(.4)	(.5)	(.7)	6.7
PAT	2.1	1.6	1.4	1.0	.9	.6	.5	.3	.2	.0	(.1)	(.3)	(.4)	(.5)	(.6)	6.7
Non-cash items	21.3	18.4	16.0	14.1	12.3	10.8	9.7	8.5	7.6	6.8	6.2	5.7	5.3	4.9	4.6	152.2
Cash flow	23.4	20.0	17.4	15.1	13.2	11.4	10.2	8.8	7.8	6.8	6.1	5.4	4.9	4.4	4.0	158.9

Table 4. Profit and loss statements and cash flow estimates at $10.00/Mcf for coal-bed methane of the Price Formation, Montgomery County, Virginia (dollars in thousands).

Price = $10.00/Mcf
Spacing = 40 acres
Operating/Maintenance = $4,800/yr.
Override=0
Depletion = 15%
Severance tax = 0%
Compression cost = 10% of gas

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Total production (MMcf)	6.73	5.91	5.22	4.65	4.17	3.76	3.41	3.11	2.84	2.61	2.41	2.22	2.06	1.92	1.79	52.81
Less: Override	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net production (MMcf)	6.73	5.91	5.22	4.65	4.17	3.76	3.41	3.11	2.84	2.61	2.41	2.22	2.06	1.92	1.79	52.81
Revenue	67.3	59.1	52.2	46.5	41.7	37.6	34.1	31.1	28.4	26.1	24.1	22.2	20.6	19.2	17.9	528.1
Operating, Compresion and Maintenance Cost	11.5	10.7	10.0	9.5	9.0	8.6	8.2	7.9	7.6	7.4	7.2	7.0	6.9	6.7	6.6	124.8
Variable margin	55.8	48.4	42.2	37.0	32.7	29.0	25.9	23.2	20.8	18.7	16.9	15.2	13.7	12.5	11.3	403.3
Less:																
Depreciation	20.2	29.7	28.4	28.3	28.3	-	-	-	-	-	-	-	-	-	-	135.0
Depletion @15%	10.1	8.9	6.9	4.4	2.1	13.3	5.1	4.7	4.2	3.9	3.6	3.3	3.1	2.9		2.7
Taxable income	25.5	9.8	6.9	4.3	2.2	15.7	20.8	18.5	16.6	14.8	13.3)	11.9	10.6	9.6	8.6	189.1
Income tax @50%	12.7	4.9	3.5	2.1	1.1	7.9	10.4	9.2	8.3	7.4	6.7	5.9	5.3	4.8	4.3	94.5
PAT	12.8	4.9	3.4	2.2	1.1	7.8	10.4	9.3	8.3	7.4	6.6	6.0	5.3	4.8	4.3	94.6
Non-cash items	30.3	38.6	35.3	32.7	30.5	13.3	5.1	4.7	4.2	3.9	3.6	3.3	3.1	2.9	2.7	214.2
Cash flow	43.1	43.5	38.7	34.9	31.6	21.1	15.5	14.0	12.5	11.3	10.2	9.3	8.4	7.7	7.0	308.8

Table 5. Methane drainage well costs.

Drilling: 1,275 ft. @ $40/ft.	$ 51,000
Mobilization	20,000
Site preparation and cleanup	18,000
Water pump	21,000
Wellhead equipment	15,000
Stimulation and perforation	17,000
Logging	8,000
Coring	6,000
Total	$156,000

suggest that the potential investment would not be justified by either a commercial enterprise or a federal, state, or local governmental entity (the difference, of course, is the taxes payable). The payback and return on investment at a $5.00 gas price are inadequate. It is unlikely that a price of $10.00 would be appropriate even under the gas-substitution assumption that the gas would be valued at the price of available gas replaced.

Thus, the better target seems to be thicker coal seams (individual seams totalling 15 to 20 feet or more), preferably closer to the surface (reducing drilling costs). However, even then the economics may not be attractive if the 40-acre spacing overstates the achievable drainage area.

It is possible that the Virginia Polytechnic Institute and State University or the Radford Army Ammunition Plant might be interested in considering the coal-bed methane possibilities under certain conditions. However, a total of seven feet of individual coal seams and substitution for gas bought at $5.00/Mcf does not seem sufficiently attractive to warrant the $156,000 well cost with 40-acre spacing. Thicker coal of the same gas quality would be more interesting.

GEOPHYSICAL DATA

Geophysical well logs were run on the core holes by the United States Geological Survey and the Department of Geological Sciences at Virginia Polytechnic Institute and State University. These logs provide an accurate means for determining the true thickness and elevation of coals encountered in both diamond core and rotary holes. In addition, density logs can be used to differentiate between coals, which have densities ranging from 1.725 to 1.925 grams per cubic centimeter, and bone, which has a density of 2.1 to 2.3 grams per cubic centimeter. Natural gamma, neutron, spontaneous potential and resistivity logs show accurately the subtle variations in lithology, such as fining-and coarsening-upward sandstone sequences, sandy and coaly mudstones, and carbonate beds (Figures 4 and 5). Using bore hole televiewer, acoustic velocity, and caliper logs, fracture zones, and faults can also be detected.

Temperature logs were run on two wells. The Sunnyside well had a top-hole temperature of 12.23 degrees Celsius and a bottom-hole temperature of 18.18 degrees Celsius, with a geothermal gradient of approximately 0.0036 degrees Celsius per foot. The Merrimac well had a top-hole temperature of 12.6 degrees Celsius and a bottom-hole temperature of 18.9 degrees Celsius, with a geothermal gradient of 0.0038 degrees Celsius per foot. Ground water influx

Table 6. Hypothetical coal-bed methane wells and economics.

Spacing	40-Acre					20-acre		10-acre	
Coal thickness (ft)	7	14	7	14	7	7	7	7	7
Depth (ft)	1275	1275	1275	1275	1275	1275	1275	1275	1275
Price/Mcf	$10.00	$5.00	$5.00	$5.00	$3.00	$5.00	$3.00	$5.00	$3.00
Override	-	-	-	12.5%	-	-	-	-	-
Annual Operating Cost	$4800	$4800	$4800	$4800	$4800	$4800	$4800	$4800	$4800
Production Taxes	-	-	-	-	-	-	-	-	-
Compression cost (10% of Gas)	10%	10%	10%	10%	10%	10%	10%	10%	10%
Cumulative production (MMcf)	52.8	105.6	52.8	105.6	52.8	27.7	22.7	16.4	16.4
Life (years)	15	15	15	15	15	8	8	5	5
Net production (MMcf)	52.8	105.6	52.8	92.4	52.8	27.7	27.7	16.4	16.4
Incremental revenue ($000)	$528	$528	$264	$462	$158	$138	$ 83	$ 82	$ 49
Incremental operating Margin* ($000)	$403	$403	$166	$337	$ 71	$ 86	$ 36	$ 50	$ 20
Well investment ($000)	$156	$156	$156	$156	$156	$156	$156	$156	$156

*Before overheads, depreciation, depletion, and income taxes.

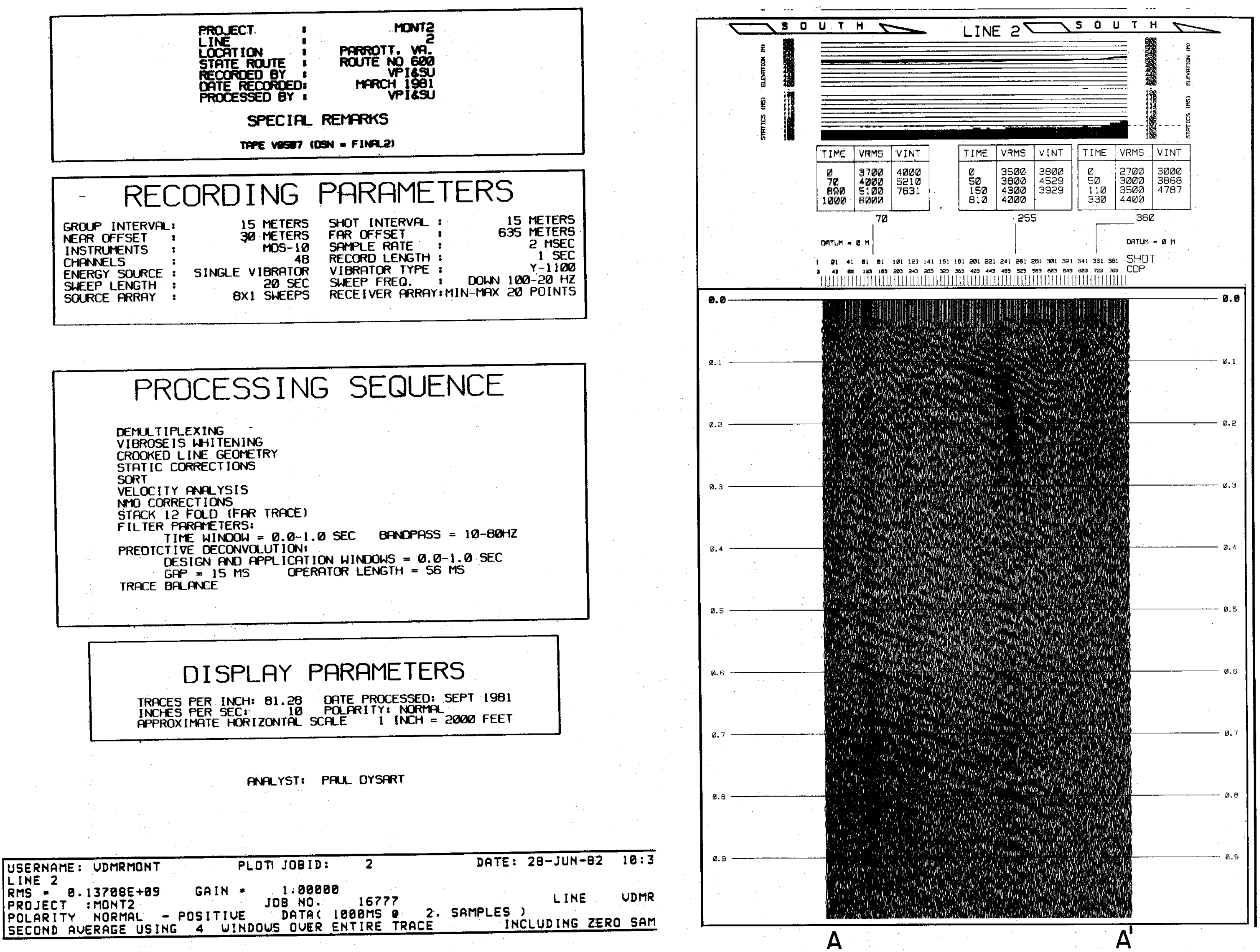
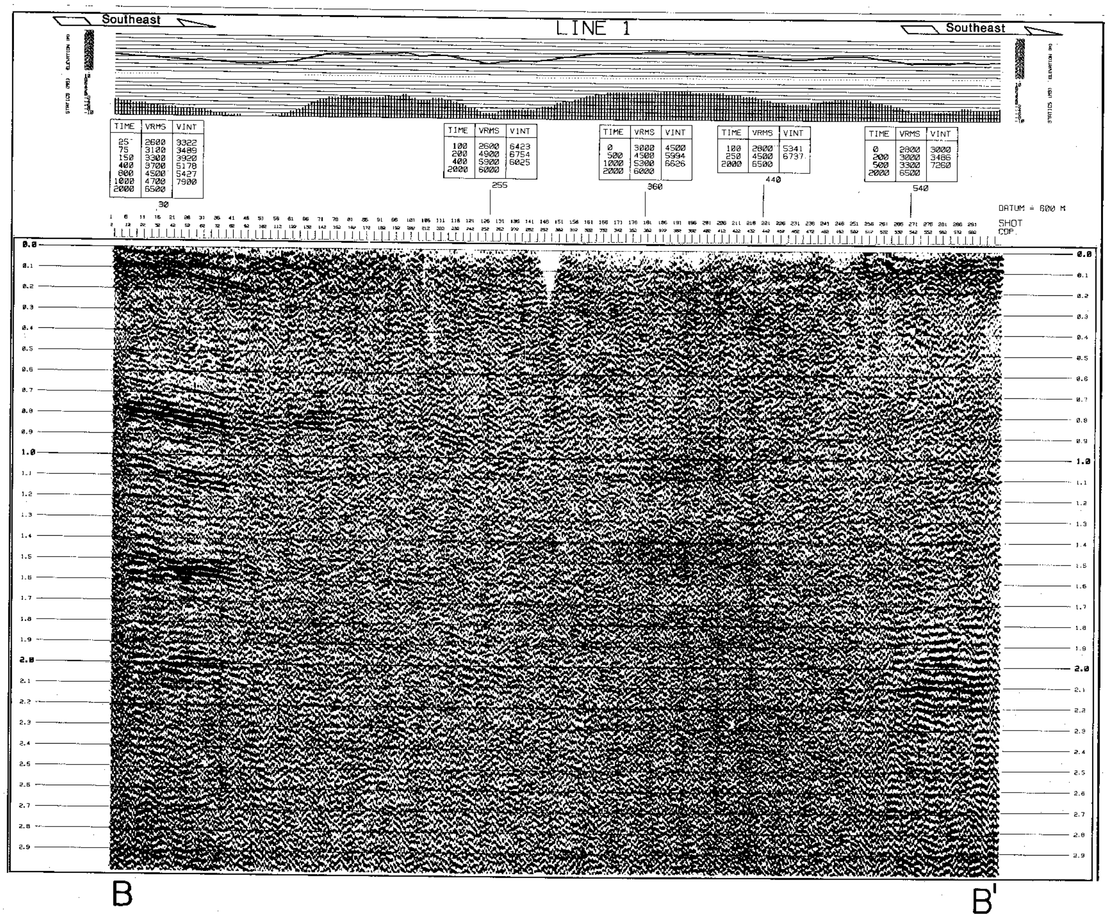


Figure 17. Seismic record section A-A′ near study area. See Figure 2 for location of seismic line.



PROJECT : MONT1
LINE : 1
LOCATION : PRICE MTN. VA.
STATE ROUTE : ROUTE NO 655
RECORDED BY : VPI&SU
DATE RECORDED: MARCH 1981
PROCESSED BY : VPI&SU

SPECIAL REMARKS

TAPE V0600 (DSN - FINAL1A)

RECORDING PARAMETERS

GROUP INTERVAL:	35 METERS	SHOT INTERVAL :	35 METERS
NEAR OFFSET :	70 METERS	FAR OFFSET :	1705 METERS
INSTRUMENTS :	MDS-10	SAMPLE RATE :	2 MSEC
CHANNELS :	48	RECORD LENGTH :	3 SEC
ENERGY SOURCE :	SINGLE VIBRATOR	VIBRATOR TYPE :	Y-1100
SWEEP LENGTH :	18 SEC	SWEEP FREQ. :	DOWN 100-20 HZ
SOURCE ARRAY :	16X1 SWEEPS	RECEIVER ARRAY:	MIN-MAX 20 POINTS

PROCESSING SEQUENCE

DEMULTIPLEXING
VIBROSEIS WHITENING
CROOKED LINE GEOMETRY
STATIC CORRECTIONS
SORT
VELOCITY ANALYSIS
NMO CORRECTIONS
STACK 24 FOLD
FILTER PARAMETERS:
TIME WINDOW = 0.0-3.0 SEC BANDPASS = 14-56 HZ
TIME VARIANT PREDICTIVE DECONVOLUTION
TRACE BALANCE

DISPLAY PARAMETERS

TRACES PER INCH: 34.83 DATE PROCESSED: SEPT 1981
INCHES PER SEC: 4 POLARITE: NORMAL
APPROXIMATE HORIZONTAL SCALE 1 INCH = 2000 FEET

ANALYST: PAUL DYSART

USERNAME: VDMRMONT PLOT JOBID: 2 DATE: 28-JUN-82 10:21:29
LINE 1
RMS = 0.13409E+09 GAIN = 1.00000
PROJECT :MONT1 JOB NO. 16772 LINE VDMR1
POLARITY NORMAL - POSITIVE DATA(3000MS @ 2. SAMPLES)
SECOND AVERAGE USING 4 WINDOWS OVER ENTIRE TRACE INCLUDING ZERO SAMPLES

Figure 18. Seismic record section B-B′ near study area. See Figure 2 for location of seismic line.

and heat generated by drilling may have influenced these results.

Geophysical well logs generally augment core and provide additional information on the physical characteristics of individual rock units. In addition, they provide valuable data that may help with regional stratigraphic correlations and in the development of future exploration strategies. If future exploratory holes are drilled with rotary-or percussion-type rigs, geophysical logs will provide the only means of accurately determining the thicknesses of coals encountered.

Seismic data across a portion of the valley field were gathered for the Virginia Division of Mineral Resources by the Department of Geological Sciences, Virginia Polytechnic Institute and State University utilizing the Department's VIBROSEIS system, processed by Paul Dysart, and two seismic record sections produced A-A′ (Figure 17) and B-B′ (Figure 18). Southeast dipping strata of the Saltville thrust sheet can be seen in A-A′ and in the northwestern (left) portion of B-B′. Resolution is drastically reduced when the Pulaski fault is crossed in section B-B′ as a result of the complexly deformed nature of rocks of the Pulaski thrust sheet. Gently northeast dipping strata become visible again as the line leaves the Pulaski sheet and crosses onto rocks of the Saltville thrust sheet exposed in the Price Mountain window.

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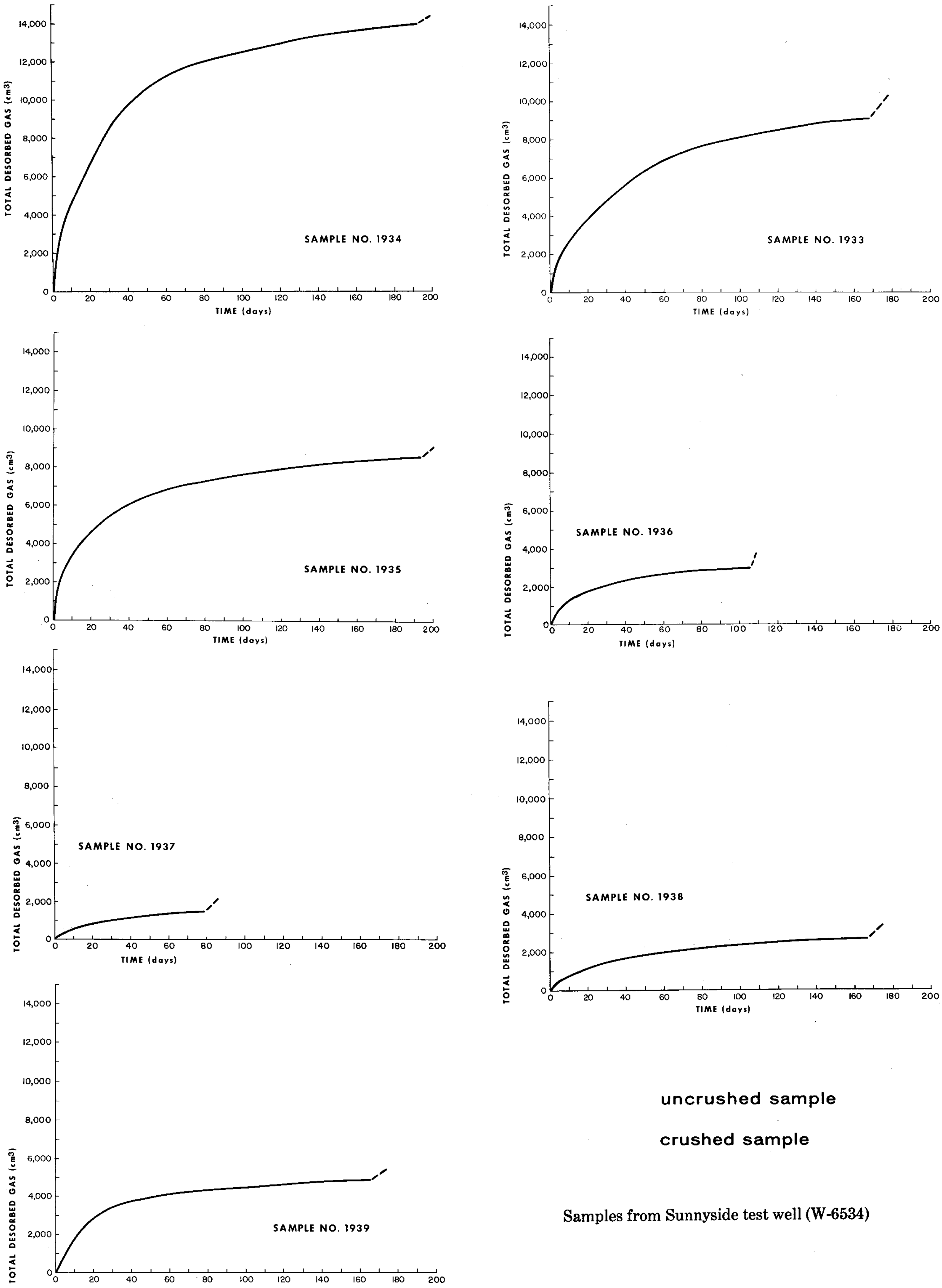
APPENDICIES

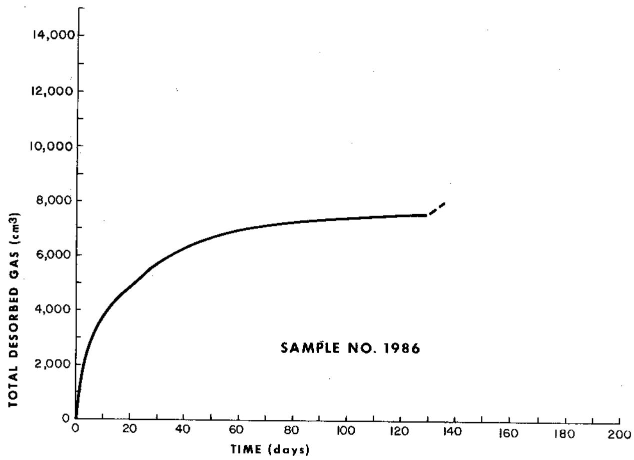
APPENDIX I. RESULTS OF DIRECT-METHOD GAS-CONTENT DETERMINATION ON PRICE FORMATION COALS FROM MONTGOMERY COUNTY, VIRGINIA

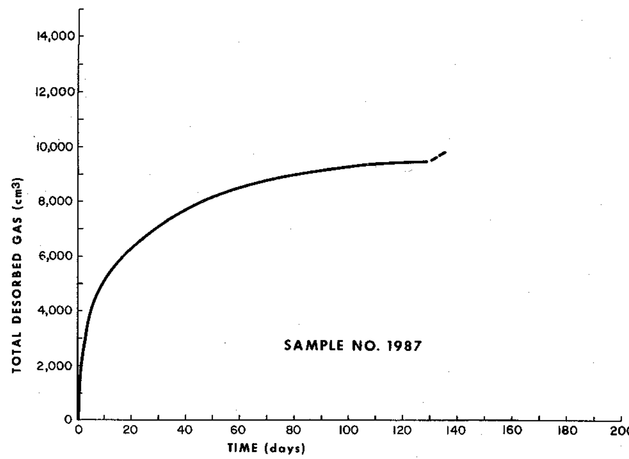
	Sample Number	Sample Interval feet	Coal Thickness feet	Sample Weight gm	Lost Gas cm^3	Desorbed gas cm^3	Gas Content cm^3 / gm (excludes residual gas)	Residual Gas cm^3 / gm	Total Gas cm^3 / gm
VDMR Well W-6534 Sunnyside test	1933	1110.05-1110.65 1110.9-1112.7	2.4	2121	262	9,094	4.4	1.3	5.7
	1934	1112.9-1113.2 1114.5-1115.7	1.5	2173	242	14,005	6.7	0.4	7.1
	1935	1116.5-1118.5	2.0	1350	269	8,663	6.8	0.8	7.6
	1936	1120.0-1120.8	.8	480	54	2,962	6.3	2.6	8.9
	1937	1136,4-1138.2	1.8	1222	26	1,452.5	1.2	1.3	2.5
	1938	1195.7-1196.9	1.2	984	20	2,695	2.8	1.8	4.6
	1939	1197.8-1198.55	.75	501	48	4,876	9.8	2.5	12.3
VDMR Well W-6535 Merrimac test	1986	1403.5-1404.95	1.45	1137	372	7,541	7.0	0.4	7.4
	1987	1407.7-1408.9 1410.45-1411.9	2.65	1273	1,621	9,431	8.7	0.4	9.1
	1988	1420.0-1421.15 1425.95-1426.35 1427.65-1428.15	2.05	1135	219	5,074	4.7	0.8	5.5
	1989	1444.95-1445.55	.6	333	25	606	2.0	2.9	4.9
	1990	1461.3-1462.1	.8	251	104	1,296.5	5.6	1.9	7.5

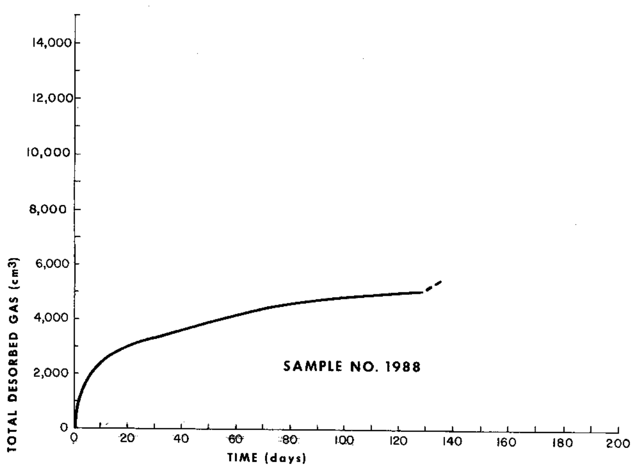
Cumulative description curves for coal samples from Sunnyside and Merrimac test wells.

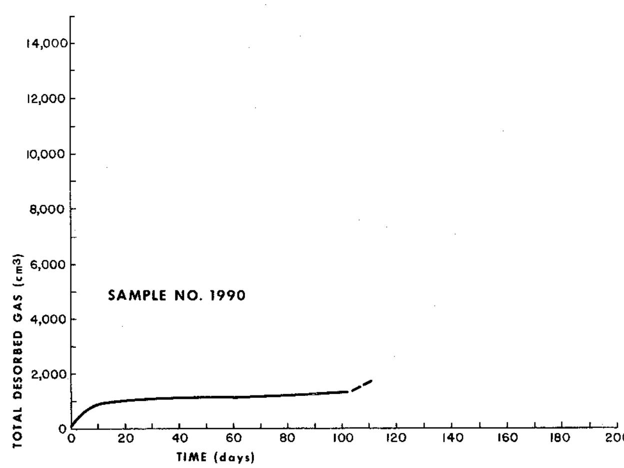


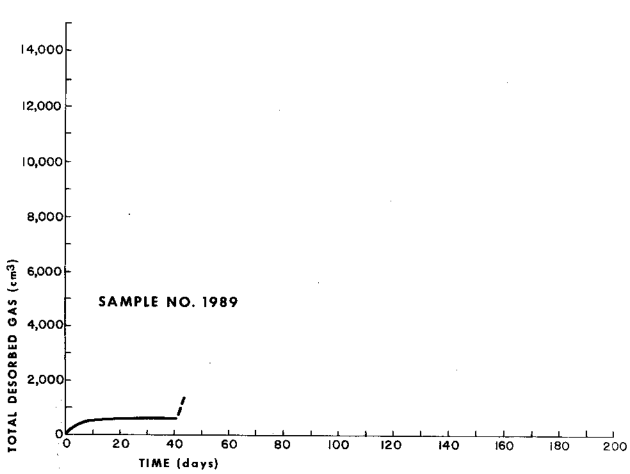
Samples from Sunnyside test well (W-6534)











uncrushed sample

crushed sample

Samples from Merrimac test well (W-6535)

APPENDIX II. COAL ANALYSES FOR TWELVE COAL SAMPLES FROM WELL NUMBERS W-6534 AND W-6535, MONTGOMERY COUNTY, VIRGINIA

All analysis except Btu/lb, free-swelling index and ash-fusion temperatures in percent. For each sample number the analyses are reported three ways: first, as-received, second, moisture free, and third, moisture and ash free. All analyses by Geochemical Testing, Somerset, Pennsylvania.

			Proximate Analysis				Ultimate Analysis				
VDMR Well W-6534 Sunnyside Test	Sample Number	Sample Interval Feet	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur
	1933	1110.05-1110.65	1.02	11.16	47.10	40.72	2.50	51.18	0.61	4.02	0.97
		1110.9 -1112.7	—	11.28	47.58	41.14	2.41	51.71	0.62	3.14	0.98
			—	19.16	80.84	—	4.09	87.85	1.05	5.35	1.66
	1934	1112.9-1113.2	1.07	13.33	57.44	28.16	2.99	63.63	0.27	4.51	0.44
		1114.5-1115.7	—	13.48	58.06	28.46	2.90	64.32	0.28	3.60	0.44
			—	18.84	81.16	—	4.05	89.91	0.39	5.03	0.62
	1935	1116.5-1118.5	0.92	11.69	66.75	20.64	3.32	71.30	0.82	3.52	0.40
			—	11.79	67.38	20.83	3.25	71.96	0.83	2.72	0.41
			—	14.89	85.11	—	4.11	90.89	1.05	3.43	0.52
	1936	1120.0-1120.8	0.71	11.31	78.53	9.45	3.76	83.26	0.75	2.41	0.37
			—	11.39	79.09	9.52	3.71	83.86	0.76	1.78	0.37
			—	12.59	87.41	—	4.10	92.68	0.84	1.97	0.41
	1937	1136.4-1138.2	1.06	10.58	72.48	15.88	3.36	76.23	0.71	3.49	0.33
			—	10.70	73.25	16.05	3.27	77.05	0.71	2.59	0.33
			—	12.75	87.25	—	3.90	91.78	0.85	3.08	0.39
	1938	1195.7-1196.9	1.03	11.70	75.43	11.84	3.56	80.30	0.78	3.17	0.35
			—	11.82	76.22	11.96	3.48	81.13	0.79	2.28	0.36
			—	13.43	86.57	—	3.95	92.15	0.90	2.59	0.41
	1939	1197.8-1198.55	0.93	13.00	74.00	12.07	3.58	80.08	0.83	3.07	0.37
			—	13.12	74.69	12.19	3.51	80.83	0.84	2.26	0.37
			—	14.94	85.06	—	4.00	92.05	0.96	2.57	0.42
VDMR Well W-6535 Merrimac Test											
	1986	1403.5-1404.95	0.75	11.75	68.37	19.13	3.21	71.63	0.89	4.35	0.79
			—	11.84	68.88	19.28	3.15	72.17	0.90	3.70	0.80
			—	14.67	85.33	—	3.90	89.40	1.11	4.60	0.99
	1987	1407.7 -1408.9	0.77	11.47	68.76	19.00	3.10	73.06	0.49	3.84	0.51
		1410.45-1411.9	—	11.56	69.29	19.15	3.04	73.63	0.49	3.17	0.52
			—	14.30	85.70	—	3.76	91.07	0.61	3.92	0.64
	1988	1420.0 -1421.15	1.05	9.40	67.10	22.45	2.94	69.35	0.66	3.98	0.62
		1425.95-1426.35	—	9.50	67.81	22.69	2.86	70.08	0.66	3.08	0.63
		1427.65-1428.15	—	12.29	87.71	—	3.70	90.64	0.85	4.00	0.81
	1989	1444.95-1445.55	0.89	10.56	55.31	33.24	2.71	58.67	0.57	4.36	0.45
			—	10.66	55.80	33.54	2.64	59.20	0.57	3.59	0.46
			—	16.04	83.96	—	3.97	89.08	0.86	5.40	0.69
	1990	1461.3-1462.1	0.69	11.96	59.62	27.73	2.78	64.28	0.58	3.97	0.66
			—	12.04	60.03	27.93	2.73	64.73	0.58	3.37	0.66
			—	16.71	83.29	—	3.79	89.81	0.80	4.68	0.92

VDMR Well W-6534 Sunnyside Test	Sample Number	Sample Interval Feet	Heat of Combustion Btu/lb	Air-dried Loss	Forms of Sulfur Sulfate	Pyritic	Organic	Free Swelling Index	Ash Fusion Temperatures F° Initial Deformation	Softening Temperature	Fluid Temperature	Dry Mineral Matter Free Fixed Carbon	Dry Mineral Matter Free Volatile Matter	Moist Mineral Matter Free Btu	Rank
	1933	1110.05-1110.65	8,619	0.19	0.01	0.64	0.32	0.5	2,690	2,800+	2,800+	86.4	13.6	15445	sa
		1110.9-1112.7	8,708	—	0.01	0.65	0.32	—	—	—	—				
			14,794	—	0.02	1.10	0.54	—	—	—	—				
	1934	1112.9-1113.2	10,681	0.39	0.01	0.10	0.33	0.5	2,670	2,780	2,800+	84.1	15.9	15370	lub
		1114.5-1115.7	10,797	—	0.01	0.10	0.33	—	—	—	—				
			15,093	—	0.01	0.14	0.47	—	—	—	-				
	1935	1116.5-1118.5	11,958	0.26	0.01	0.04	0.35	0.5	2,470	2,580	2,660	87.2	12.8	15406	sa
			12,069	—	0.01	0.04	0.36	—	—	—	—				
			15,244	—	0.01	0.05	0.46	—	—	—	—				
	1936	1120.0-1120.8	13,977	0.00	0.02	0.02	0.33	0.5	2,260	2,440	2,520	88.3	11.7	15580	sa
			14,077	—	0.02	0.02	0.33	—	—	—	—				
			15,558	—	0.02	0.02	0.37	—	—	—	—				
	1937	1136.4-1138.2	12,795	0.28	0.01	0.02	0.30	0.5	2,800+	2,800+	2,800+	88.8	11.2	15457	sa
			12,933	—	0.01	0.02	0.30	—	—	—	—				
			15,405	—	0.01	0.02	0.36	—	—	—	—				
	1938	1195.7-1196.9	13,537	0.10	0.01	0.01	0.33	0.5	2,800+	2,800+	2,800+	87.7	12.3	15536	sa
			13,678	—	0.01	0.01	0.34	—	—	—	—				
			15,536	—	0.01	0.01	0.39	—	—	—	—				
	1939	1197.8-1198.55	13,479	0.20	0.01	0.01	0.35	0.5	2,490	2,600	2,670	86.2	13.8	15514	sa
			13,605	—	0.01	0.01	0.35	—	—	—	—				
			15,493	—	0.01	0.01	0.40	—	—	—	—				
VDMR Well W-6535 Merrimac Test															
	1986	1403.5-1404.95	12,170	0.10	0.01	0.46	0.32	0.0	2,320	2,370	2,470	87.4	12.6	15373	sa
			12,262	—	0.01	0.46	0.33	—	—	—	—				
			15,190	—	0.01	0.57	0.41	—	—	—	—				
	1987	1407.7-1408.9	12,209	0.10	0.02	0.16	0.33	0.0	2,380	2,470	2,620	87.6	12.4	15383	sa
		1410.45-1411.9	12,304	—	0.02	0.17	0.33	—	—	—	—				
			15,218	—	0.02	0.21	0.41	—	—	—	—				
	1988	1420.0-1421.15	11,633	0.40	0.01	0.29	0.32	0.0	2,390	2,510	2,690	90.2	9.8	15384	sa
		1425.95-1426.35	11,757	—	0.01	0.29	0.33	—	—	—	—				
		1427.65-1428.15	15,207	—	0.01	0.38	0.42	—	—	—	—				
	1989	1444.95-1445.55	9,811	0.10	0.02	0.16	0.27	0.0	2,800+	2,800+	2,800+	87.8	12.2	15329	sa
			9,899	—	0.02	0.16	0.28	—	—	—	—				
			14,895	—	0.03	0.24	0.42	—	—	—	—				
	1990	1461.3-1462.1	10,750	0.00	0.01	0.30	0.35	0.0	2,440	2,640	2,740	86.4	13.6	15378	sa
			10,825	—	0.01	0.30	0.35	—	—	—	—				
			15,020	—	0.01	0.42	0.49	—	—	—	—				

Dry mineral-matter-free fixed carbon, dry mineral-matter-free volatile matter and moist mineral-matter-free Btu calculated using Parr formulas (ASTM D388-82 p 240).

APPENDIX III. PRELIMINARY COAL-RESOURCE ESTIMATE OF MONTGOMERY AND PULASKI COUNTIES

by

James A. Henderson, Jr.
(Virginia Division of Mineral Resources)

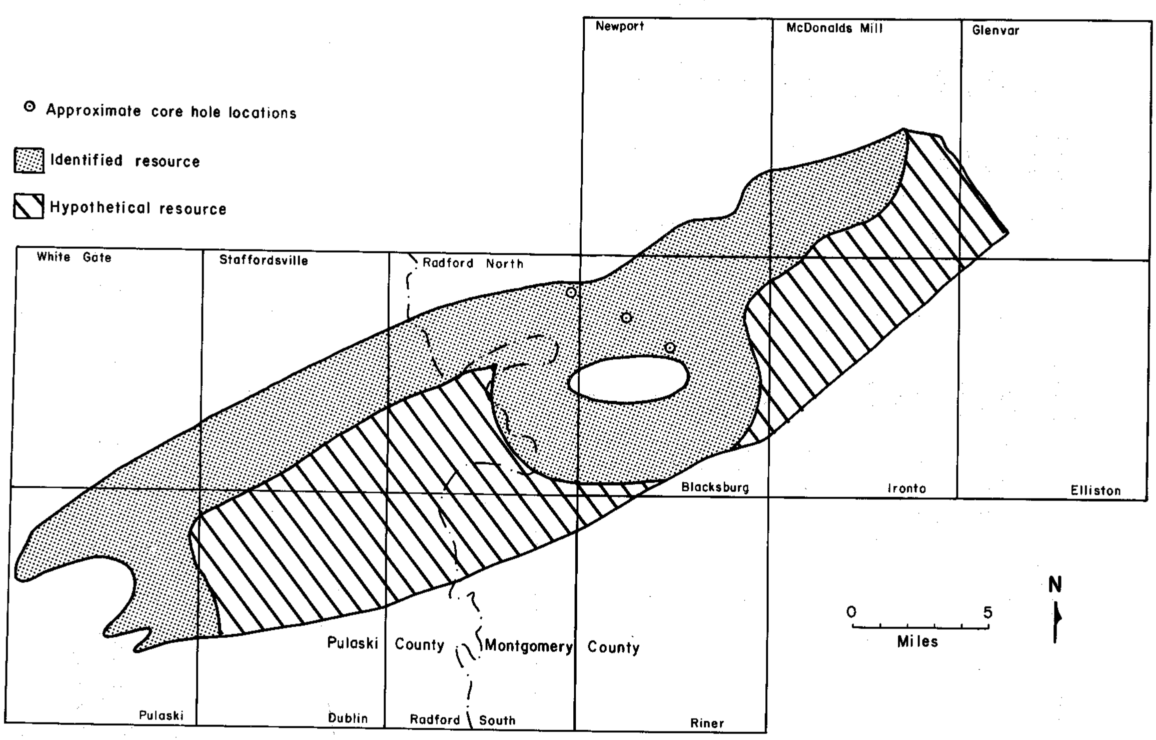
This coal-resource estimate should be used as a guide to the relative abundance of coal in Montgomery and Pulaski counties and not as an absolute quantity of coal. As more drilling and detailed mapping are done, this estimate should and will be revised to reflect new information.

The procedure and terminology used in this resource estimate are consistent with those outlined by the U.S. Geological Survey (Wood and others, 1983). Resources estimates in this report include identified (combination of measured, indicated, and inferred) and hypothetical. Because the data points are distributed non-uniformly along the coal outcrop, identified resources were grouped and estimated in a belt approximately three miles wide parallel to the outcrop. Hypothetical resources consist of those estimated from the identified resource line to the furthest extent of the coal under the thrust sheets to the southeast (see map). The limit of the coal under the thrust sheet was taken from Bartholomew (1979). These areas were outlined on a 1:24,000 map and planimetered using a Numonics 1224 digitizer. Areas were then calculated to the nearest acre. Although Montgomery and Pulaski counties are structurally complex, the coal was considered to occur on a plane.

The average thickness (5 feet) used for the estimate of identified resources is an average of 60 measurements. Because correlations in the Valley fields are tentative at best, no attempt was made to estimate resources by bed. In areas where published correlations or present exposures indicate two beds, the total coal thickness was used. It should be noted that most measurements are of one bed and not composite measurements. The average thickness was rounded to the closest lower whole foot even though accepted rounding procedures would round to the next higher whole foot. An average thickness estimate of 1.2 feet was used for the hypothetical resource area (Gordon Wood, personal communication, 1983).

The areas for identified and hypothetical resources were then multiplied by the average thickness in each category, 5 feet and 1.2 feet respectively, to obtain acre-feet. Acre-feet were then multiplied by 2,000 tons/acre-foot to get the estimated tonnage figure.

Coal resources in Montgomery and Pulaski coun-



Identified and hypothetical coal resources of Pulaski and Montgomery counties.

	Acreage			Acre-Feet			Tonnage		
	Montgomery	Pulaski	Total	Montgomery	Pulaski	Total	Montgomery	Pulaski	Total
Identified	58,583	43.344	101,927	292,915	216,720	509,635	585,830,000	433,440,000	1,019,270,000
Hypothetical	35,543	38,260	73,803	42,652	45,912	88,564	85,304,000	91,824,000	177,128,000
Total	94,126	81,604	175,730	335,567	262,632	598,199	671,134,000	525,264,000	1,196,398,000

ties are estimated at 1,196,398,000 short tons (see table).

Montgomery County contains 671,134,000 short tons or 56.1% of the total. Coal is estimated to occur under 175,730 acres in the Montgomery and Pulaski county area of which 53.6 percent of its acreage is in Montgomery County. Most of the estimated coal resource, 1,019,270,000 short tons (85.2% of the total), is in the identified resource category.

REFERENCES

Bartholomew, M. J., 1979, Preliminary report on the Valley coal fields as a potential source of gas, *in* Methane project: Virginia Division of Mineral Resources Open-file Report 79-1, 10 p.

Wood, Gordon H. Jr., and others, 1983, Coal resource classification system of the U.S. Geological Survey: U.S. Geol. Survey Circular 891, 65 p.

APPENDIX IV. FINANCIAL FEASIBILITY OF COAL-BED METHANE RESOURCES IN MONTGOMERY COUNTY, VIRGINIA

Gruy Petroleum Technology Incorporated
(Formerly Gruy Federal)

The determination of financial feasibility of coal-bed methane drainage in the Blacksburg-Radford area, Montgomery County, Virginia, requires analysis of the entire project through end use. A thorough feasibility analysis also is necessary to ensure that a full set of estimated economic data for each stage of the project will be available for government agencies and private investors. They will use it together with engineering and institutional information and test drilling data to assess the feasibility of developing and utilizing specific unconventional gas resources in the region and to assist in obtaining grants, loans, and loan assistance. Since the potential users of the information will vary widely in financial sophistication, the analytic techniques for determining financial feasibility also will have to be explained and detailed sufficiently to serve as a prototype for subsequent independent analyses.

An entire project through end use would include locating a likely resource, drilling, completion and testing of a production well, development of distribution facilities, and identification of a technically feasible end use. This proposal will fine-tune the siting and then obtain core data which will substantially characterize the resource methane potential and quality. The methane characteristics and resulting value together with flow estimates, royalty rates, estimated siting, drilling, completion, operating and distribution costs, and working capital will permit development of a financial analysis covering the economic life of a typical well.

Since the economic analysis will ultimately determine the attractiveness of the proposed project, the elements of this analysis are discussed in considerable detail in the section following.

Financial Analytic Process

The broad yet penetrating financial analysis of the type required by large corporations and which we propose to use integrates all the aspects of the project, including the magnitude of the unconventional gas resource itself, the facilities required for its production, the market for the product, the proposer's resources (e.g., management technical capability, and access to funds), current and future competitiveness, environmental impacts, and socio-economic effects. The output from the analysis helps identify the project's financial suitability, considering all the various inputs. Thus, the financial analysis provides the focus for integrated evaluation of the overall project as well as scrutiny of particular details.

The financial analytic process will include the following components:

1. Identify siting costs (assume leases, access and permits are in place).
2. Identify and analyze capital requirements and project economic life.
3. Estimate incremental costs and obtain valuation of methane from intended user.
4. Develop annual income statements and depreciation methods.
5. Develop annual cash flow estimates.
6. Calculate financial evaluation measures:
   - Profit margin after taxes
   - Payback
   - Internal (DCF) rate of return on investment
   - Internal rate of return on stockholders' equity
7. Identify other project-related costs.
8. Analyze the sensitivity of the project's financial profile.
9. Develop a risk analysis.
10. Review the economic and financial analysis and related recommendations with the intended user.
11. Prepare data and evaluation for inclusion in final report.

The purpose of investment analysis is to determine whether a project under consideration provides both a competitive product and an adequate return on investments for the level of risk involved. The adequacy of the return generated is measured in several ways; the various measures taken together provide a composite indication of the sufficiency of the return. The financial measures which are important to this feasibility study include operating income, return on sales, period and cumulative net cash flows, balance sheets, payback, and discounted cash flow internal rate of return. Each of these financial measures tells us something about the project, but not enough to be used exclusively.

Operating Income. During the overall economic life of the project, operating income is an important measure of the project's ability to generate a return on investment. An ability to maintain a substantial or growing operating income in constant-dollar terms is an important indication of the likelihood of generating the cash flows anticipated. Also, the larger the operating income, the greater the percentage depletion allowance chargeable against income, up to the legal limit. However, the operating income is only an indicator, since the maximization of the internal rate of return requires acceleration of the non-cash charges, such as depreciation, into the early years. The acceleration of depreciation tends to reduce operating income in the early years and creates a tax shield that defers some tax liabilities and related cash payments into later years. A trade-off is made in determining the most appropriate depreciation method. The deferral needs of the investors and the company must be balanced against the desire not to forego non-cash depletion allowance charges unnecessarily by reducing operating income in the project's early years through excessive depreciation acceleration.

Return on Sales. A stable or improving percentage return on sales is consistent with a healthy ability to recover costs and maintain profitability. Since the percentage margin is influenced by depreciation skewing, analytic adjustment of the data is required to understand the quality of the profit margin and its trend.

Cash Flow. Another vitally important measure is the cash flow on a period-by-period basis, as well as a cumulative net cash flow. The proposed project may be spectacularly profitable over the long run but beyond the means of the investing entity if the peak cumulative cash outflow is too large. The peak cash need (maximum cumulative net outflow) frequently is difficult to identify because it does not necessarily coincide with the end of the period analyzed. The peak may occur at some point within the period, for a number of reasons (e.g., seasonal factors, timing of tax debt and interest payments, unforeseen lags in collections of accounts receivable). If a company or individual is unaware of that hidden peak, an unknown risk of bankruptcy or extraordinarily expensive refinancing is present. Our analysis will identify the range of peak cumulative outflow to help avoid such a surprise.

Balance Sheet. Period and cumulative cash flows must be meshed with the company's balance sheet forecasts in order to identify the necessary external financing plan (e.g., choice of debt and equity mix, debt type and term, equity type). The financing plan must take into account the relative strength of the existing balance sheet and the ability to service debt and meet the anticipated schedule of principal repayment. The plan must be developed assuming a prudent debt/equity relationship capable of withstanding both cyclical business adversity and an investment outcome less profitable than expected. However, for this particular project, we will not attempt to differentiate between debt and equity financing. We will require a sufficiently high return on investment to cover either source of funds.

Payback. The period-by-period net cash flows for the project, exclusive of financing considerations, form the basis for a payback measure. The initial stages of an investment project involve substantial outlays of cash in anticipation of future inflows. Payback identifies the length of time required for the stream of cash proceeds produced by an investment to equal the original aggregate cash outlay required by the investment. In other words, payback determines the number of months or years that will elapse before the company reaches an undiscounted cash flow breakeven. Payback as a measure of an investment's merits has two weaknesses that prevent its exclusive use. It does not consider cash flows after payback is received, and it does not value cash proceeds differently based on when they were received. In periods of high inflation and where uncertainties are high, a relatively shorter payback is required.

Internal Rate of Return. The discounted-cash-flow internal rate of return is a financial evaluation technique that overcomes the shortcomings of other methods mentioned above (Bierman and Smidt, 1966; Merritt and Sykes, 1963). It assigns greater value to cash flows that occur earlier in the project life. It also considers cash flows over the entire life of the investment. The internal rate of return method (IRR) involves solving a simple mathematical relationship to determine the compound rate of interest that will make the present value of the cash proceeds expected from an investment equal to the present value of the cash outlays required by the investment. The solution interest rate is the IRR and is determined through a trial-and-error process. (Computer programs are readily available to minimize the otherwise cumbersome and time-consuming arithmetic process.) Complex cash flow patterns can give more than one solution IRR, but the present project should involve relatively straightforward cash-flow profiles that will not result in multiple solutions.

The discounted-cash-flow IRR, together with the other financial evaluation elements, will provide a composite basis for assessing the attractiveness of the investment proposal. The contribution of each measure is summarized in the following table.

Measure	*Information Provided*	*Use of Measure*
Income Statements	Annual operating incomes	Profit and cash generation indicator
Profit Margin	Relative margin stability	Identify profit stability and security
Cash Flow	Period and cumulative net outlays and inflows	Identify cash needs and inflows
Balance Sheet	Mix of assets and liabilities and available financing leverage	Serves as basis for financing plan in conjunction with cash flow and income statements
Payback	Length of time until cash inflows equal original outlays	Identifies length of time until bait is back
Discounted Cash Flow IRR	Compound rate of return on investment	Compare to hurdle rate of return, other project IRR's, and corporate IRR objectives

The components of our financial analysis—capital requirements, investment analysis, other project-related costs, sensitivity, and risk analysis—are discussed separately below.

Other Project-Related Costs. The other project-related costs, which we have defined as those outside the scope of the explicit project design, may be substantially beneficial. Since our project involves only the drainage of coal-bed methane and its low-pressure transmission, no significant "other costs" are anticipated. Instead, we envision substantial benefits, such as:

- Favorable local economic impact of a developing local energy resource
- Addition to the domestic energy supply
- Rendering a currently unmineable resource safe for further processing

Existing state, county, and municipal facilities and staffing are considered more than adequate to serve the very modest needs of the methane recovery project. In fact, the project will make resource and geologic information available to governmental offices and interested universities which they lack at present. If we do encounter any significant and unanticipated other costs that would impact the overall worth of the proposed project, we would develop a financial analysis incorporating those other costs to determine the relative merit of the overall project.

The analysis of costs associated with environmental considerations and any negative socioeconomic impacts would be incorporated similarly.

Sensitivity and Risk Analysis. Modern financial analysis of capital investment projects entails sensitivity analysis followed by risk analysis. Sensitivity analysis is the manipulation of the variables in a project to determine which ones have significant leverage on the financial evaluation measures. Frequently the variables are altered 5 or 10 percent on either side of the central estimate for the variable and the investment analysis is recalculated for each alteration. When a specific relevant range for manipulation is identified, it is used in place of the original alterations. This type of analysis identifies for management the specific financial implications of potentially uncontrollable variations. It also gives management an opportunity to identify possible responses that would capitalize on the favorable variations and that would blunt unfavorable impacts.

We anticipate that it will be necessary to develop sensitivities for several factors in the project. Significant sensitivities may include:

Well life
Well productivity
Capital expenditures
Natural gas price
Operating expenses
Distribution costs
Government incentives (e.g., depletion allowance, depreciation, grant repayment schedule)
Inflation rates
Cost of capital
Equipment and permit lead times

Some of these factors may turn out to be of little importance, while others may have a very significant leverage on the project's financial success.

Risk analysis will be applied to those factors that have significant leverage, as identified in the sensitivity analysis. There are several approaches to risk analysis, reflecting varying levels of sophistication and "real-world" experience regarding the proposed project. Although we are capable of performing a Monte Carlo simulation of our project, we feel that such an approach is not appropriate for this feasibility study. For the purpose of this study, we will utilize a simpler technique to identify the range of potential financial outcomes.

Our approach to risk analysis will encompass both uncertainty and statistical risk and will involve development of boundary data and a resulting envelope of outcomes around our central best estimate. The envelope will be determined by simultaneous assumption of first the more optimistic values and then the more pessimistic values for the variables demonstrating significant leverage on our project. This envelope of alternative outcomes will be developed for all the financial evaluation measures noted above, as well as for the period-by-period operating income projections, cash flow, and balance sheets.

Subjective probabilities will be estimated for the risk-analysis variables so that we can estimate the overall likelihood of achieving each of the three levels. Of course, the probability of reaching the pessimistic outcome will be greater than that of attaining the best-estimated level. The best estimate, in turn, will have a greater likelihood than the optimistic level. The relative likelihood of the three outcomes will be arrayed with the relative financial merits (e.g., IRR, payback, operating profit) of the three to increase management's understanding of the relative risks and rewards of the investment project.

The mechanics of the financial evaluation techniques, operating income statements, cash flow statements, balance sheets, financing plans and corporate debt capacity, sensitivity analysis, and risk analysis are well known. These concepts are presented in a variety of texts.

Partial Illustration of Financial Analysis

Gruy Federal's previous work with methane drainage engineering and financial feasibility analyses permits us to hypothesize a financial profile of such an investment. Thus, we can illustrate some of our analytic methodology although the data shown should not be construed as a target.

The following table shows a ten year projection of methane production, a related series of profit and loss statements, cash flows, and a discounted cash flow return on investment. We have assumed production of 55 Mcf/day for 3½ years with production declining at 15% per year thereafter. We also have assumed a well life of ten years and a constant intrastate price of $2.90 for natural gas. The initial well investment of $125,000 in the illustration is paid back in about 4½ years, and the discounted cash flow internal rate of return is 15%.

Final financial feasibility determination will require evaluation against the investment criteria used by the intended user.

CASH FLOW FOR A SINGLE METHANE-DRAINAGE WELL

Project Years:	1	2	3	4	5	6	7	8	9	10
Production, Mcf/day	55.0	55.0	55.0	50.9	43.2	36.7	31.2	26.6	22.6	19.2
$ 000's (1981 dollars)										
Revenue @ $2.90/Mcf	58.2	58.2	58.2	53.9	45.7	38.8	33.0	28.2	23.9	20.3
Override @ 12.5%	(7.3)	(7.3)	(7.3)	(6.7)	(5.7)	(4.9)	(4.1)	(3.5)	(3.0)	(2.5)
Operating Costs*	(12.5)	(12.5)	(12.5)	(12.5)	(12.5)	(12.5)	(12.5)	(12.5)	(12.5)	(12.5)
Straight-line depreciation	(12.5)	(12.5)	(12.5)	(12.5)	(12.5)	(12.5)	(12.5)	(12.5)	(12.5)	(12.5)
Depletion allowance**	(7.6)	(7.6)	(7.6)	(7.1)	(6.0)	(5.1)	(4.3)	(3.7)	(3.1)	(2.7)
Pre-tax income	18.3	18.3	18.3	15.1	9.0	3.8	(.4)	(4.0)	(7.2)	(9.9)
Tax @ 50%+	(9.1)	(9.1)	(9.1)	(7.6)	(4.5)	(1.9)	.2	2.0	3.6	4.9
Net Profit	9.2	9.2	9.2	7.5	4.5	1.9	(0.2)	(2.0)	(3.6)	(5.0)
+ Depreciation	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
+ Depletion	7.6	7.6	7.6	7.1	6.0	5.1	4.3	3.7	3.1	2.7
Annual Cash flow	29.3	29.3	29.3	27.1	23.0	19.5	16.6	14.2	12.0	10.2
Cumulative cash flow	29.3	58.6	87.9	115.0	138.0	157.5	174.1	188.3	200.3	210.5

DCF Return = 15% for $125,000 capital investment.

*At 10% of capital
**At 15% of 87.5%
+Or tax loss credit

Note: Depreciation and depletion as shown are ten year approximation and do not reflect fine-tuned timing, depreciation method and recognition of intangible costs.

APPENDIX V. DETAILED LITHOLOGIC DESCRIPTION OF CORE

Prices Fork Test Well

Well:	Prices Fork Test (W-6533)
Farm:	Virginia Polytechnic Institute and State University
Driller:	Joy Manufacturing Company
Location:	Blacksburg 7.5-minute quadrangle Lat.: 37°12′44″ N Long.: 80°29′19′W
Elevation:	2037 feet
Total depth:	1773.5 feet
Started drilling:	January 14, 1982
Finished drilling:	March 23, 1982

Sample descriptions by Virginia Divisions of Mineral Resources

Reference: Core obtained by Virginia Division of Mineral Resources through D.O.E. Grant number DE-FG44-81R410431.

INTERVAL (FEET)	*DESCRIPTION*
0.0-5.0	SOIL, light brown, clay rich
5.0-15.0	SUBSOIL, light red and brown mottled clay
15.0-23.0	SILTY-CLAY, light yellow to brown
23.0-46.5	SAPROLITE, dolomitic light yellowish brown to light brown
	MIDDLE CAMBRIAN ELBROOK FORMATION (lower part)
46.5-51.0	DOLOMITE, alternating tan and gray, fine grained with argillaceous partings, dip 55 degrees
51.0-53.0	DOLOMITE, gray, fine grained, mm laminated, argillaceous with calcite veins and vugs
53.0-60.0	DOLOMITE, light gray, fine to medium grained, mm-0.5 cm laminated; some wavy laminations; interlaminated with minor QUARTZ-SILT laminations (53.9-54.0), dip 50 degrees
60.0-60.35	CLAY, light, gray
60.35-69.75	DOLOMITE, light gray and tan, fine grained, cm bedded, interlaminated with DOLOMITE, light gray, mm-0.25 cm laminated, fine grained and QUARTZ-SILT, very light gray, 0.25 cm laminated
69.75-73.5	DOLOMITE, tan, fine grained, mm-cm laminated, with mudcracked-disrupted laminations, argillaceous partings, minor calcite veins; core is badly weathered
73.5-77.25	CLAY, light gray with dolomite chips
77.25-81.5	DOLOMITE, light tan and gray, fine grained, alternating mm laminated with 2.0cm bedded; QUARTZ-SILT laminations (79.5)
81.5-84.5	CLAY, with dolomite chips
84.5-88.5	DOLOMITE, light brown and gray, fine grained, mm laminated to cm bedded with black argillaceous partings (cuttings from 84.5-86.5), dip 40 degrees
88.5-94.5	DOLOMITE, light gray, fine grained, mm -0.25 cm laminated, with argillaceous partings and bedding parallel calcite veins (cuttings from 88.5-94.0)
94.5-96.75	DOLOMITE, light tan and gray, fine grained, mm-0.25 cm laminated
96.75-99.1	DOLOMITE, light gray, medium grained, 0.25 mm laminated to 1.0 cm bedded, vuggy
99.1-101.3	DOLOMITE, dark gray, coarse grained, mm laminated with QUARTZ-SILT laminations (100.3), vuggy
101.3-101.8	DOLOMITE, gray, fine grained, mm laminated
101.8-105.5	DOLOMITE, dark gray, fine grained, massive, very vuggy and argillaceous near top
105.5-107.8	DOLOMITE, tan and gray, fine to medium grained, mm laminated and cm bedded with argillaceous partings, calcite veins, weathered, dip 40 degrees
107.8-110.6	DOLOMITE, light gray, medium grained, mm laminated, some wavy laminations

110.6-113.7	DOLOMITE, light gray, fine grained, mm laminated and cm bedded with argillaceous partings (cuttings from 112.0-113.0)
113.7-116.0	DOLOMITE, dark gray, coarse grained, wavy mm laminated, minor vugs with calcite crystals
116.0-117.0	DOLOMITE, dark gray, fine grained, massive
117.0-125.7	DOLOMITE, light and dark gray, fine grained, 0.25 cm bedded with interlaminated quartz-silt laminations (cuttings form 117.0-124.0)
125.7-126.2	DOLOMITE, light gray, medium grained, cm bedded
126.2-132.0	DOLOMITE, tan and gray, mm laminated to cm bedded, with argillaceous partings (stylolitic), weathered and vuggy, folded (cuttings from 126.2-128.0)
132.0-135.1	BRECCIA, gray, fine grained, dolomite clasts in a dolomite cataclastic matrix
135.1-137.0	BRECCIA, gray and white, massive, dolomite clasts in a calcite matrix (possible solution breccia, or recrystalized matrix of tectonic breccia)
137.0-141.4	BRECCIA, gray, dolomite clasts in a dolomite cataclastic matrix
141.4-147.6	DOLOMITE, light gray, 0.25 cm-cm bedded with argillaceous partings, wavy soft-sediment disrupted laminations, mudcracked, very vuggy and fractured, folded
147.6-149.4	DOLOMITE, dark gray, fine grained, massive, highly fractured and vuggy
149.4-153.7	DOLOMITE, light gray, fine grained, mm laminated to cm bedded with argillaceous partings, fractured, weathered, dip 70 degrees (cuttings from 152-153.7)
153.7-160.8	BRECCIA, gray and white, dolomite clasts in a calcite matrix grading into zones of DOLOMITE, mm laminated to cm bedded wavy, disrupted laminations. very vuggy, highly fractured
160.8-165.9	BRECCIA, gray and white, dolomite clasts in a calcite matrix grading into zones of DOLOMITE, alternating light to dark gray, fine grained, massive to 3.0 cm bedded, vugs with calcite crystals
165.9-166.9	DOLOMITE, light gray, fine grained, 0.5 cm bedded, vuggy and fractured
166.9-167.8	CLAY, gray
167.8-168.5	BRECCIA, dolomite clasts in a cataclastic dolomite matrix
168.5-170.0	DOLOMITE, dark gray, fine grained, 0.25 cm laminated, dip 45 degrees
170.0-170.1	CLAY, gray
170.1-179.9	DOLOMITE, light gray, fine grained, mm laminated with argillaceous partings; bedding-parallel veins, folded
179.9-181.0	DOLOMITE, gray, coarse grained, 0.25 cm laminated, fractured and weathered
181.0-190.0	DOLOMITE, light gray, fine grained, mm laminated to 0.25 cm bedded with argillaceous partings (cuttings from 188.5-190.0)
190.0-194.5	DOLOMITE, tan and gray, fine grained, mm laminated to cm bedded, argillaceous and with argillaceous partings; vuggy, calcite crystals in vugs
194.5-201.5	DOLOMITE, light gray, fine grained, 0.5 cm-1.0 cm bedded, with very fine, black, argillaceous laminations and thin stringers of pyrite
201.5-206.5	DOLOMITE, light gray, fine grained, mm laminated to cm bedded with argillaceous partings; calcite veins, vugs near bottom; QUARTZ-SILT laminations at 201.5 and 203, dip 40 degrees
206.5-210.5	DOLOMITE, dark gray, fine grained, 0.5 cm and 1.0 cm bedded, pyrite rich zones, argillaceous partings, calcite veins
210.5-222.5	DOLOMITE, light gray, fine grained, mm laminated to cm bedded with argillaceous partings, calcite veins (cuttings from 210.5-222.5)
222.5-228.5	DOLOMITE, dark gray, coarse grained, 0.25 cm bedded, fractured, small vugs (cuttings from 222.5-228.5)
228.5-229.5	DOLOMITE, gray, medium grained, mm laminated to 0.5 cm bedded (cuttings from 228.5-229.5)
229.5-231.3	DOLOMITE, dark gray, coarse grained, vuggy (cuttings from 229.5-231.3)
231.3-232.0	DOLOMITE, dark gray, very fine grained, massive (cuttings from 231.3-232.0)
232.0-237.0	DOLOMITE, dark gray, very fine grained, massive, rare argillaceous partings, dip 40 degrees
237.0-240.5	DOLOMITE, dark gray, fine grained, mm laminated to cm bedded, argillaceous, vuggy and fractured
240.5-241.1	DOLOMITE, light gray, medium grained, mm laminated to 0.5 cm bedded with a few coarse-grained dolomtie laminations, clacite veins, dip 30 degrees
241.1-248.75	DOLOMITE, light gray, fine grained, mm laminated to cm bedded with argillaceous partings, vuggy and fractured near base

248.75-267.5	DOLOMITE, dark gray, fine grained, massive with interlaminatd DOLOMITE, fine grained, mm laminated to cm bedded, vuggy (cuttings from 248.75-256.0 and from 257.0-266.0), dip 0 degrees
267.5-271.2	DOLOMITE, light gray, fine grained, mm laminated to cm bedded with argillaceous partings, very vuggy, jointed
271.2-271.4	BRECCIA, gray and white, dolomite clasts in a crystalline calcite matrix
271.4-278.5	DOLOMITE, light gray, fine grained, mm laminated to cm bedded with argillaceous partings, weathered zones, dip 15 degrees
278.5-278.6	CHERT, black, fine grained
278.6-279.8	BRECCIA, gray and white, dolomite clasts in crystalline calcite matrix grading into highly fractured DOLOMITE, mm laminated to cm bedded near base
279.8-279.85	CHERT, black, fine grained
279.85-281.0	BRECCIA, gray and white, dolomite clasts in crystalline calcite matrix
281.0-281.9	DOLOMITE, gray, fine grained, massive, dip 5 degrees
281.9-282.1	CHERT, black, fine grained
282.1-289.8	DOLOMITE, light gray, fine grained, mm laminated with argillaceous partings, vuggy, calcite veins
289.8-306.5	BRECCIA, gray and white, dolomite clasts in crystalline calcite matrix, clasts range from less than 0.5 cm diameter to greater than 3.0 cm diameter, interbedded and grading into DOLOMITE, light gray, fine grained, mm laminated to 0.5 cm bedded with argillaceous partings, clacite veins and vugs (cuttings from 302.0-305.0), dip 40 degrees.
306.5-318.9	DOLOMITE, light gray, fine grained, mm laminated to cm bedded with argillaceous partings, vuggy and highly fractured near top, folded
318.9-330.4	DOLOMITE, light gray, medium grained, mm laminated to cm bedded grading into BRECCIA, gray and white, dolomite clasts in crystalline calcite matrix, calcite veins and vugs abundant, folded
330.4-331.0	BRECCIA, gray and white, dolomite clasts with calcite matrix
	FAULT
331.0-343.6	DOLOMITE, light gray, fine grained, mm laminated to cm bedded with argillaceous partings; pyrite rich lamiantions (335.0), stylolitic, dip ranges from 90 degrees near top to 75 degrees near base
343.6-351.0	DOLOMITE, light gray, medium grained, massive to very finely mm laminated, stylolitic with mm to 0.5 cm black argillaceous partings
351.0-365.8	DOLOMITE, light gray, fine grained, mm laminated to cm bedded, with argillaceous partings, several calcite matrix breccia pods; numerous vugs and calcite veins, stylolitic; medium grained loose sand was recovered from 2 vugs (approximately 362-363), dip 90 degrees
	FAULT
365.8-366.0	CLAY, black, fine grained, slickensided (fault gouge)
366.0-372.7	DOLOMITE, light gray, fine to medium grained, mm laminated to cm bedded, very fine stylolitic lamiantions near base, vuggy near base, dip 25 degrees
372.7-373.4	DOLOMITE, gray, medium grained, massive
373.4-374.0	BRECCIA, white and gray, dolomite clasts in crystalline calcite matrix
374.0-399.1	DOLOMITE, light gray, fine grained, mm laminated to cm bedded; minor calcite veins
399.1-408.5	DOLOMITE, light gray, fine grained, 0.5 cm-2.0 cm bedded, with numerous argillaceous partings, interbedded with BRECCIA, dolomite clasts in crystalline calcite matrix (cuttings from 407.0-408.5)
408.5-428.5	DOLOMITE, light gray, fine grained, mm laminated to cm bedded, with numerous argillaceous partings, minor calcite veins and vugs, breciated (approximately 425.0-425.5) and folded (408.5-411.5)
428.5-435.0	DOLOMITE, alternating light and dark gray, fine grained, mm laminated to cm bedded, argillaceous, vugs and disrupted wavy laminations near base (cuttings from 434.0-435.0)
435.0-437.0	DOLOMITE, dark gray, fine grained, mm laminated to cm bedded, very vuggy and folded
437.0-466.0	DOLOMITE, alternating light and dark gray, fine grained, mm laminated to cm bedded, with argillaceous partings, fractured, vuggy, stylolitic, dip 35 degrees (cuttings from 437.0-439.0 and 460.5-466.0)
466.0-469.0	DOLOMITE, dark gray, fine to medium grained, mm laminated, argillaceous (cuttings from approximately 467.0-468.5)
469.0-478.4	DOLOMITE, light to dark gray, fine grained, finely mm laminated, minor calcite veins
478.4-483.0	BRECCIA, gray and white, dolomite clasts in calcite matrix with interbedded DOLOMITE, light gray, fine grained, mm laminated, vuggy and highly fractured (cuttings from 480.5-481.5)

483.0-487.0	DOLOMITE, dark gray, medium to coarse grained, mm laminated to cm bedded with argillaceous partings, fractured (cuttings from 483.0-484.0 and 484.5-487.0), dip 15 degrees
487.0-490.0	DOLOMITE, sugary white and black, coarse grained, massive, vugs, calcite veins and stylolites, dip 28 degrees
490.0-494.5	DOLOMITE, light gray, fine grained, mm laminated to cm bedded with argillaceous partings, stylolitic (cuttings from 493.5-494.5)
494.5-495.8	DOLOMITE, light gray, medium grained, mm laminated to 0.5 cm bedded with argillaceous partings
495.8-498.5	BRECCIA, gray and white, dolomite clasts in crystalline calcite matrix interbedded with DOLOMITE, light gray, coarse grained, 0.5 cm bedded, numerous vugs and fractures
498.5-499.6	DOLOMITE, dark gray, fine grained, mm laminated to cm bedded with argillaceous partings
499.6-501.5	DOLOMITE, light gray, medium grained, massive to cm bedded (cuttings from 499.6-500.8); dip 45 degrees
501.5-514.5	DOLOMITE, light gray, fine grained, mm laminated to 2.0 cm bedded, with argillaceous partings, wavy laminated in places, QUARTZ-SILT laminations (507.0-508.0), BRECCIA, dolomite clasts in calcite matrix (513.5-513.7)
514.5-518.0	DOLOMITE, light gray, fine grained, 0.5 cm bedded with argillaceous partings, stylolitic, pyrite blebs near top, and QUARTZ-SILT laminations near base FAULT
518.0-539.75	DOLOMITE, light gray, fine grained, mm laminated to cm bedded with argillaceous partings, numerous calcite veins, crystal filled vugs, pyritic stylolite seams, interbedded with BRECCIA, dolomite clasts with calcite matrix (cuttings from appromimately 531.0-532.5 and 537.5-539.75)
539.75-562.5	BRECCIA, dark gray, dolomite clasts in coarse grained cataclastic dolomite matrix, clasts unsorted, angular to rounded, ranging from less than 1.0 cm to greater than 3.0 cm in diameter, very vuggy
562.5-563.4	BRECCIA, dolomite clasts in cataclastic dolomite matrix grades down into fractured DOLOMITE, mm laminated, interbedded with BRECCIA, dolomite clasts in calcite matrix
563.4-577.8	DOLOMITE, light gray, fine grained, mm laminated to cm bedded, with argillaceous partings, stylolitic in places, minor vugs and calcite veins, dip 70 degrees
577.8-584.1	BRECCIA, dolomite clasts in crystalline calcite matrix, interbedded with DOLOMITE, light to dark gray, fine grained, mm laminated to 2.0 cm bedded, fractured, stylolitic argillaceous partings
584.1-594.3	DOLOMITE, light gray, fine to medium grained, 0.5 cm-1.0 cm bedded with argillaceous partings (cuttings alternate with bedded dolomite throughout), dip 25 degrees
594.3-594.5	SHALE, black, fine grained
594.5-609.5	DOLOMITE, light gray, fine grained, mm laminatd with argillaceous partings, minor vugs and calcite fractures (cuttings from 597.0-599.5 and 601.0-606.3)
609.5-610.0	BRECCIA, dolomite clasts in cataclastic dolomite matrix
610.0-619.5	DOLOMITE, light to dark gray, fine to very fine grained, with argillaceous seams and mm thick partings
619.5-619.55	SHALE, black, fine grained, finely laminated
619.55-621.0	DOLOMITE, dark gray, very fine grained, massive with interlaminated SHALE, black, fine grained, mm laminated, stylolitic
621.0-623.6	DOLOMITE, light to dark gray, very fine grained, massive, minor calcite fractures and vugs
623.6-628.5	DOLOMITE, dark gray, fine grained, mm laminated to cm bedded, weathered "rotten rock" in zones (cuttings at top and base), dip 38 degrees
628.5-631.5	DOLOMITE, light gray, medium to coarse grained, mm laminated, highly brecciated with numerous vugs
631.5-635.4	DOLOMITE, alternating light and dark gray, mm laminated to cm bedded, fine to medium grained, argillaceous, limy
635.4-636.2	SHALE, black, very fine grained, mm laminated, interlaminated with LIMEY-DOLOMITE, gray, fine grained, very argillaceous
636.2-637.0	BRECCIA, dolomite clasts in cataclastic dolomite matrix
637.0-640.1	DOLOMITE, gray, fine to medium grained, mm laminated to cm bedded with stylolitic seams, limy
640.1-641.5	DOLOMITE, gray, fine grained, mm laminated, numerous fractures, dip 28 degrees FAULT
641.5-641.9	BRECCIA, dolomite clasts in cataclastic dolomite matrix
641.9-644.0	DOLOMITE, light gray, fine grained, mm laminated to cm bedded, stylolitic
644.0-646.4	DOLOMITE, dark gray, fine grained, mm laminated with interlaminated SHALE, black, fine grained, mm laminated, dip 71 degrees

646.4-653.0	DOLOMITE, light gray, medium grained, massive, very vuggy (cuttings from approximately 648.5-653.0)
653.0-658.7	DOLOMITE, alternating light and dark gray, fine to medium grained, massive to cm bedded, interbedded with BRECCIA, dolomite clasts in calcite matrix, very vuggy
658.7-705.0	DOLOMITE, alternating light and dark gray, fine grained, mm laminated to cm bedded with argillaceous partings, stylolitic, vuggy, fractured, folded and brecciated, and SHALE, black, fine grained, 2.0 cm bedded to very finely laminated (approximately 670.5-672.0) (cuttings numerous throughout section)
705.0-711.0	BRECCIA, dolomite clasts in cataclastic dolomite matrix with minor interbeds of DOLOMITE, light gray, fine grained, 0.5 cm bedded, highly fractured (cuttings at top and from 707.0-708.1)
711.0-724.0	DOLOMITE, light to dark gray, fine grained, mm laminated to cm bedded, with argillaceous partings, highly folded (cuttings from 713.9-717.5 and 721.5-724.0)
724.0-725.0	BRECCIA, light gray, dolomite clasts in clay matrix
725.0-740.5	DOLOMITE, light gray, fine grained, mm laminated to cm bedded with argillaceous partings, minor calcite veins, and QUARTZ-SILT laminations (736.0-736.5), dip 42 degrees
740.5-744.0	DOLOMITE, dark gray, fine grained, alternating mm laminated and cm bedded, with black, stylolitic, argillaceous partings, argillaceous to shaly near base
744.0-767.2	DOLOMITE, light gray, fine grained, mm laminated to cm bedded, with argillaceous partings, wavy laminated on part (cuttings numerous throughout section), dip 22 degrees at base
767.2-768.9	DOLOMITE, light gray, alternating medium and fine grained, mm laminated
768.9-773.0	DOLOMITE, light gray, fine grained, mm laminated to cm bedded with argillaceous partings, minor calcite fractures, dip 28 degrees
773.0-775.0	DOLOMITE, dark gray, fine grained, mm laminated to 0.5 cm bedded with black argillaceous partings
775.0-776.1	DOLOMITE, light gray, very fine grained, massive
776.1-776.6	DOLOMITE, light gray, fine grained, mm laminated, with mm laminations of disseminated pyrite
776.6-777.3	DOLOMITE, light gray, very fine grained, massive
777.3-778.2	BRECCIA, gray and white, dolomite clasts in a crystalline calcite matrix
778.2-781.3	DOLOMITE, light gray, very fine grained, massive with minor mm thick calcite veins
781.3-787.0	DOLOMITE, dark and light gray, fine grained, mm laminated to massive (cuttings from 781.3-787.0)
787.0-788.2	DOLOMITE, light gray, medium grained, cm bedded, vuggy and fractured, dip 28 degrees (cuttings 6 inches at top)
788.2-810.0	DOLOMITE, light gray, fine grained, mm laminated to cm bedded with argillaceous partings, numerous calcite veins, zones of highly fractured and brecciated rock (798.5), folded (cuttings from 800.1-801.0 and from 807.2-807.5)
810.0-824.5	DOLOMITE, dark gray, fine to very fine grained, 0.5 cm bedded with numerous argillaceous partings, becomes more argillaceous from 819.0-824.5, numerous calcite fractures, few pyrite blebs, dip 40 degrees (cuttings from 810.0-814.5, 817.5-818.5, 819.5-820.0 and 823.0-824.5)
824.5-835.4	DOLOMITE, light gray, fine grained, mm laminated to cm bedded, argillaceous, numerous calcite veins, disseminated pyrite, dip 43 degrees (cuttings from 824.5-827.5 and from 832.0-833.5)
835.4-837.75	DOLOMITE, dark gray, medium grained, mm laminated to 0.5 cm bedded, minor calcite veins, dip 44 degrees
837.75-839.7	DOLOMITE, light gray, fine grained, mm laminated to 0.5 cm bedded with argillaceous partings
839.7-853.0	BRECCIA, gray and white, dolomite clasts in a crystalline calcite matrix with interbedded DOLOMITE, light gray, fine grained, mm laminated, intensely folded and fractured, dolomite becomes more argillaceious down section and grades into a dolomitic-phyllitic argillite, pale green to gray (cuttings from 848.1-851.75)
853.0-879.75	BRECCIA, alternating green and gray, dolomite and/or phyllitic argillite clasts in a cataclastic dolomite (minor calcite) matrix, green phase is poorly consolidated, gray phase well indurated, interbedded with highly fractured zones of DOLOMITE, light gray, fine grained, mm laminated
879.75-885.5	BRECCIA, pale green and gray, dolomite and phyllite clasts in a poorly indurated dolomite-clay matrix (cuttings from 882.0-885.0)
885.5-886.25	SHALE, dolomitic; gray and green

LOWER CAMBRIAN ROME FORMATION

886.25-888.25	MUDSTONE, calcareous, mottled green, red-brown, fine grained, massive bedded, and DOLOMITE, gray, fine grained, fractured
888.25-888.65	MUDSTONE, calcareous, mottled red, brown and green, massive

888.65-891.5	MUDSTONE, calcareous, phyllitic green, fine grained, mm laminated, brecciated (all cuttings)
891.5-894.5	DOLOMITE, gray, fine grained, mm laminated with green argillaceous partings, dip 16 degrees
894.5-901.5	DOLOMITE, gray, fine grained, mm laminated to 0.5 cm bedded, interlaminated with MUDSTONE, phyllitic, calcareous, green (all cuttings)
901.5-905.0	MUDSTONE, calcareous, mottled red-brown and green, massive (all cuttings)
905.0-913.0	MUDSTONE, phyllitic, red-brown to dark red, interlaminated with DOLOMITE, gray to green, fine grained, mm laminated to 0.5 cm bedded with minor silty laminations and green argillaceous partings, dip 50 degrees
913.0-913.75	BRECCIA, phyllitic, green
913.75-919.5	MUDSTONE, phyllitic, dark red, green, massive with interbedded DOLOMITE, light gray, fine grained, 0.5 cm bedded, highly fractured with numerous calcite veins, dip 48 degrees
919.5-945.0	DOLOMITE, light gray, fine grained, mm laminated to cm bedded, with pale-green phyllitic partings, interbedded with PHYLLITE, mottled red-brown and green (all cuttings)
945.0-945.75	DOLOMITE, light gray, fine grained, mm laminated to cm bedded with MUDSTONE, phyllitic, red-brown with green argillacious partings, dip 35 degrees
945.75-946.9	MUDSTONE, dark red and mottled green
946.9-950.5	DOLOMITE, gray, fine grained, mm laminated
950.5-952.5	MUDSTONE, phyllitic green and dark red, with interbedded DOLOMITE, gray, fine grained, dip 34 degrees
952.5-956.0	MUDSTONE, calcareous, phyllitic, green, with minor dark red laminations
956.0-957.75	DOLOMITE, argillaceous, light to dark gray, mm laminated to 0.5 cm bedded, (all cuttings)
957.75-962.75	DOLOMITE, light gray, medium grained, mm laminated to cm bedded, with argillaceous partings, stylolitic and vuggy
962.75-966.25	DOLOMITE, argillaceous, dark gray, medium to fine grained
966.25-971.4	BRECCIA, light gray, fine grained, dolomite clasts in a very fine grained cataclastic dolomite matrix
971.4-994.1	DOLOMITE, light to medium gray, fine grained, mm to 0.5 cm lamianted, brecciated with MUDSTONE, light green, finely laminated with phyllitic green partings (cuttings dominate section)
994.1-1003.25	MUDSTONE, phyllitic, green and dark red streaked massive to mm laminated, brecciated; with minor DOLOMITE, light gray, fine grained
1003.25-1032.25	DOLOMITE, light to medium gray, fine grained, mm laminated to 2.0 cm bedded, argillaceous partings, stylolitic, vuggy, calcite veined with MUDSTONE, phyllitic, calcereous green, massive, brecciated (one-third of section is cuttings)
1032.25-1035.0	MUDSTONE, phyllitic, dark red with very minor green and gray dolomitic laminations
1035.0-1054.3	DOLOMITE, light gray, fine grained, argillaceous partings, vuggy with MUDSTONE, calcareous, dark green, calcite veined and brecciated (cuttings throughout section) dip 46 degrees
1054.3-1087.67	MUDSTONE, calcareous, phyllitic, alternating dark red and green interlaminated and interbedded with DOLOMITE, light gray, fine grained, stylolitic partings, minor calcite veins
1087.67-1113.58	DOLOMITE, alternating light and dark gray, fine grained, mm laminated to cm bedded, minor argillaceous partings and MUDSTONE, phyllitic, green, massive (cuttings from 1098.5-1101.0), dip 26 degrees
1113.58-1132.5	BRECCIA, alternating green and gray, phyllitic mudstone and dolomite clasts in a dolomite-calcite cataclastic matrix
1132.5-1165.17	DOLOMITE, light gray, mm laminated to massive, green phyllitic partings, brecciated and interbedded with MUDSTONE, green, phyllitic. Section is folded, brecciated, dips range from 5-20 degrees
1165.17-1179.0	BRECCIA, green and gray, dominantly phyllitic clasts in matrix of macerated mudstone and minor brecciated dolomite, well consolidated
1179.0-1211.0	MUDSTONE, alternating and mottled dark red and green, phyllitic, calcareous and DOLOMITE, light grayish-green, fine grained, massive to cm bedded, dips 32-51 degrees (cuttings throughout section)
1211.0-1256.25	DOLOMITE, light gray, fine to very fine grained, massive to 3.0 cm bedded, and MUDSTONE, green, phyllitic, calcareous, folded (cuttings numerous throughout section)
1256.25-1278.0	MUDSTONE, alternating dark red and green, mm laminated, brecciated, dip 40 degrees (entire section is cuttings and fractured pieces)
1278.0-1279.0	BRECCIA, green, phyllitic clasts in calcite matrix
1279.0-1295.33	DOLOMITE, light and dark gray, fine grained, mm laminated to cm bedded, with minor MUDSTONE, green, phyllitic, section is highly folded and brecciated, dip 35 degrees
1295.33-1301.0	BRECCIA, light gray, dolomite clasts in cataclastic calcareous matrix, vuggy
	FAULT (Breccia truncates vertical beds below.)

MIDDLE CAMBRIAN ELBROOK FORMATION

1301.0-1353.75	DOLOMITE, alternating light and dark gray, fine grained with minor green phyllitic partings, vuggy and fractured, brecciated zones, pyrite rich and minor MUDSTONE, green, phyllitic, calcareous. Beds are vertical in top of section and dip 50 degrees at bottom (cuttings throughout section)
1353.75-1396.0	BRECCIA, alternating gray and green, unsorted rounded and angular clasts of phyllitic mudstone and fine-grained dolomite ranging from less than 0.5 cm-5.0 cm long, in a well-indurated matrix of macerated phyllite and cataclastically crushed dolomite, clasts non-bedded, randomly scattered (cuttings throughout section)
1396.0-1422.0	MUDSTONE, light green, phyllitic, calcareous, with interbedded DOLOMITE, gray-green, fine grained (entire section is cuttings)
1422.0-1568.0	BRECCIA, alternating gray and green, well to poorly indurated, dolomite and phyllitic mudstone clasts in a cataclastic calcareous and phyllitic matrix (cuttings throughout section)
1568.0-1578.0	DOLOMITE, light gray, fine grained mm laminated to massive, vuggy, calcite veined, grading into highly brecciated zones
1578.0-1610.67	DOLOMITE, gray, fine grained, massive, stylolitic with numerous vugs, calcite veins and breccia zones, dip 70 degrees
1610.67-1642.8	BRECCIA, gray and green, dolomite clasts in poorly consolidated clay-dolomite matrix, zone of calcite dominated matrix near bottom
1642.8-1663.5	DOLOMITE, alternating light and dark gray, fine grained, black stylolitic partings, dip 40-50 degrees
1663.5-1672.6	BRECCIA, gray, well indurated, crudely layered to massive, dolomite clasts in a cataclastic matrix
1672.6-1690.0	DOLOMITE, alternating light and dark gray, fine grained, mm laminated to cm bedded, brecciated, stylolitic (cuttings throughout section)
1690.0-1724.5	BRECCIA, gray with minor green, dolomite clasts in very well-indurated cataclastic matrix, zones of recrystallized matrix, clasts range from less than 1.0 cm to greater than 8.0 cm long
1724.5-1750.0	DOLOMITE, dark gray, fine grained, argillaceous partings, folded and brecciated
1750.0-1771.0	BRECCIA, dark gray, dolomite clasts in a cataclastic dolomite matrix, very vuggy, crudely layered in zones, recrystallized matrix in zones
1771.0-17773.5	DOLOMITE, dark gray, fine grained, mm laminated to 0.5 cm bedded, calcite veined (cuttings in lower part)

(BOTTOM OF HOLE)

Sunnyside Test Well

Well:	Sunnyside Test (W-6534)
Farm:	South "40" Investments
Driller:	Joy Manufacturing Company
Location:	Radford North 7.5-minute quadrangle Lat.: 37°13′48″ N Long.: 80°32′30′W
Elevation:	2015 feet
Total depth:	1672.0 feet
Started drilling:	April 1, 1982
Finished drilling:	May 13, 1982

Sample descriptions by A. P. Schultz, C. B. Stanley, and M. J. Bartholomew; Virginia Divisions of Mineral Resources

Reference: Core obtained by Virginia Division of Mineral Resources through D.O.E. Grant number DE-FG44-81R410431.

INTERVAL (FEET)	*DESCRIPTION*
	MISSISSIPPIAN MACCRADY FORMATION
0.0-18.0	CASING - NO CORE RECOVERED, dark red and tan clay and weathered rock cuttings
18.0-38.0	MUDSTONE, dark red, with few well-bedded gray lenses, dip 32 degrees
38.0-40.8	MUDSTONE, gray, with mottled nodular IRONSTONE
40.8-44.1	SANDSTONE, dark red, fine grained, with rare green pods
44.1-70.0	MUDSTONE, dark red, irregularly bedded, with green mottles
70.0-81.0	SANDSTONE, dark red to light gray, fine grained, with abundant dark red siltstone lenses
81.0-83.0	SANDSTONE, light gray, fine grained, with minor mudstone streaks
83.0-85.45	SANDSTONE light gray, medium grained, with minor mudstone streaks
85.45-89.0	SANDSTONE, light gray, fine grained, with minor mudstone streaks
89.0-102.5	MUDSTONE, dark red with some green mottling, abundant carbonate lenses, rare ironstone nodules and rare siltstone streaks
102.5-106.0	CARBONATE, tan, with mottled green mudstone, irregularly bedded to massive
106.0-108.2	MUDSTONE, mottled dark red and olive green, with abundant carbonate nodules
108.2-121.3	SANDSTONE, light dark red to gray, fine grained, with siltstone partings and abundant carbonate lenses
121.3-145.4	SANDSTONE, light gray, medium grained, with silty partings, dip 28 degrees
145.4-147.4	MUDSTONE, dark red, minor green mottling
147.4-150.0	SANDSTONE, green with dark red partings, fine to medium grained, with carbonate nodules
150.0-155.5	MUDSTONE/FINE GRAINED SANDSTONE, interbedded, green with dark red mottling
155.5-159.5	MUDSTONE, dark red, massive
159.5-164.3	MUDSTONE, dark red, with tan carbonate nodules
164.3-169.4	MUDSTONE/SILTSTONE, interbedded, dark red and green, mottled
169.4-171.3	SANDSTONE, light gray, fine grained, thick bedded
171.3-175.2	SILTSTONE, dark red, with mottled green partings
175.2-176.9	SILTSTONE, dark red, with tan carbonate nodules
176.9-193.7	SILTSTONE, dark red with green mottling, with fine-grained dark red sandstone streaks and lenses, and rare dark red mudstone partings
193.7-201.0	MUDSTONE, green and dark red, mottled, with siltstone lenses
201.0-208.4	MUDSTONE, mottled dark red and green with abundant carbonate lenses
208.4-216.3	MUDSTONE, dark red/SANDSTONE, gray, fine grained, interbedded, with rare dark red siltstone partings

216.3-237.5	SANDSTONE, medium gray, medium grained with greenish lenses and mudstone partings
237.5-290.0	MUDSTONE, mottled dark red and green, irregularly bedded, with minor medium-gray massive to cross-bedded SILTSTONE beds near top of unit, rare carbonate nodules

MISSISSIPPIAN PRICE FORMATION (upper member)

290.0-306.2	SANDSTONE, gray to greenish gray, fine grained, with siltstone lenses and partings, dip 20 degrees
306.2-307.98	MUDSTONE, greenish gray, with siltstone lenses
307.98-310.8	SANDSTONE, gray, with minor siltstone and mudstone lenses
310.8-315.0	MUDSTONE, greenish gray, massive
315.0-328.6	SILTSTONE, greenish gray, to SANDSTONE, gray, fine grained, coarsening upward sequence, abundant greenish-gray mudstone partings near base
328.6-343.3	MUDSTONE, dark red and green, mottled, rare siltstone lenses and partings
343.3-344.0	MUDSTONE, dark red and green mottled, with abundant carbonate nodules
344.0-350.3	SANDSTONE, grayish green, fine grained, massive, with abundant siltstone partings, fining upward sequence
350.3-358.6	MUDSTONE, dark red, laminated to irregularly bedded
358.6-359.0	MUDSTONE, dark red, with abundant carbonate nodules
359.0-364.5	SILTSTONE, greenish-gray, fine grained, interbedded
364.5-380.0	MUDSTONE, dark red, laminated, with rare green mottled layers
380.0-383.45	SILTSTONE, dark red, massive
383.45-390.22	SANDSTONE, greenish gray, fine grained and SILTSTONE, greenish gray, interbedded, abundant carbonate nodules
390.22-393.3	MUDSTONE, mottled, dark red and greenish gray, massive
393.3-399.0	SANDSTONE, medium gray, fine grained, with abundant dark greenish-gray siltstone partings
399.0-406.8	MUDSTONE, dark red and green mottled, massive
406.8-407.8	SILTSTONE, dark greenish gray
407.8-409.5	MUDSTONE, dark red and green, mottled, massive
409.5-410.1	MUDSTONE, dark red, with abundant carbonate nodules
410.1-422.5	SANDSTONE, medium gray, fine grained, with abundant dark greenish-gray siltstone partings and lenses
422.5-444.3	MUDSTONE, dark red and dark greenish gray, mottled
444.3-453.0	SILTSTONE, dark greenish gray, massive
453.0-455.8	MUDSTONE, dark gray, massive
455.8-479.8	SANDSTONE, medium gray, fine grained and interbedded SILTSTONE, medium gray, massive
479.8-481.0	MUDSTONE, dark gray, with greenish-gray siltstone streaks
481.0-482.0	MUDSTONE, dark red and gray, mottled
482.0-487.5	MUDSTONE, dark gray, massive
487.5-490.0	MUDSTONE, dark red and dark gray, mottled
490.0-494.0	MUDSTONE, dark gray
494.0-515.0	MUDSTONE, dark red and dark gray, mottled
515.0-520.0	MUDSTONE, dark gray, with minor dark red mottling, disrupted bedding
520.0-522.0	MUDSTONE, dark red and dark gray, mottled
522.0-526.0	MUDSTONE, dark gray, disrupted bedding
526.0-535.0	MUDSTONE, dark red and gray green, mottled, rare green siltstone partings, dip 40 degrees
535.0-536.2	MUDSTONE, light olive green, massive, broken at top
536.2-537.7	MUDSTONE, light olive green with tan carbonate nodules
537.7-538.2	MUDSTONE, light olive green, massive
583.2-539.2	MUDSTONE, dark red, massive
539.2-539.6	MUDSTONE, olive green, massive
539.6-542.4	SILTSTONE, light olive green, finely laminated

542.4-543.8	MUDSTONE, olive green, silty
543.8-546.85	MUDSTONE, mottled dark red and olive green
546.85-547.3	MUDSTONE, olive green with minor dark red mottles
547.3-548.9	MUDSTONE, light olive green, with siltstone laminae
548.9-553.6	SANDSTONE, very fine grained, wavy laminated
553.6-555.05	MUDSTONE, dark olive green, massive
555.05-557.09	MUDSTONE, dark red and gray green, mottled
557.09-557.87	MUDSTONE, olive gray, massive
557.87-574.2	SANDSTONE, very fine grained, with interbedded SILTSTONES and minor mudstone partings, light olive green, and rare tan carbonate streaks
574.2-577.37	MUDSTONE, olive green, massive
577.37-588.13	MUDSTONE, dark red and light olive green, mottled to crudely layered
588.13-594.75	MUDSTONE, light olive green with interbedded SILTSTONE, minor tan carbonate blebs
594.75-595.47	MUDSTONE, dark olive gray with black partings and minor dark red mottles
595.47-597.9	SILTSTONE, olive green, massive, carbonate blebs near top
597.9-599.6	SANDSTONE, very fine grained, with SILTSTONE interbeds, light olive gray, minor carbonate blebs
599.6-602.1	MUDSTONE, dark olive green, massive, carbonate streaks
602.1-607.29	MUDSTONE, dark red with minor olive green mottles, massive
607.29-609.04	MUDSTONE, very silty, light olive green and rare dark red mottling, with tan carbonate nodules
609.04-612.07	MUDSTONE, light olive green, slightly silty, rare dark red mottling
612.07-612.72	MUDSTONE, dark red, massive
612.72-614.62	SANDSTONE, light olive green to dark red, fine grained, massive
614.62-617.85	MUDSTONE, olive green and dark red, laminated, mottled tan carbonate near top
617.85-619.05	MUDSTONE, tan and light olive green mottled, massive
619.05-619.65	MUDSTONE, dark red and green, silty, massive
619.65-622.74	CARBONATE, tan, and MUDSTONE, light olive green, mottled
622.74-625.5	MUDSTONE, light olive green, silty
625.5-630.93	MUDSTONE, dark red, minor olive green
630.93-632.53	MUDSTONE, light olive green, minor carbonte blebs
632.53-634.33	MUDSTONE/SILTSTONE, interbedded, light olive green
634.33-644.43	MUDSTONE, silty, interbedded dark red and dark olive green
644.43-646.37	SANDSTONE, very fine grained, with interbedded silty MUDSTONE, olive gray
646.37-651.42	MUDSTONE, silty, olive green with dark gray streaks, rare dark red laminae, rare carbonate blebs
651.42-655.2	MUDSTONE, gray green, massive, minor carbonate blebs, dip 10 degrees
655.2-657.85	MUDSTONE, dark olive green, with abundant tan CARBONATE
657.85-661.65	SILTSTONE, light gray, interbedded MUDSTONE, light gray
661.65-662.65	SANDSTONE, medium grained, light gray
622.65-669.4	MUDSTONE, gray with interbedded SILTSTONES, massive
699.4-669.8	FAULT ZONE, disrupted green MUDSTONE with calcite infilling, slickensided
669.8-674.68	MUDSTONE, gray, massive
674.68-677.49	SILTSTONE, gray, with interbedded MUDSTONE
677.49-686.7	MUDSTONE, olive, massive
686.7-690.25	MUDSTONE, dark red and light olive green, mottled, rare carbonate streaks
690.25-713.56	MUDSTONE, with interbedded SILTSTONE grayish green, rare carbonate streaks in top 3.0 ft.
713.56-714.57	SILTSTONE, tan with black streaks, massive
714.57-717.73	SILTSTONE, with interbedded MUDSTONES
717.73-728.16	MUDSTONE, dark olive green to gray, minor siltstone laminae, massive
728.16-749.74	MUDSTONE, dark red and light olive green, minor silt laminae, rare carbonate near top

749.74-750.86	MUDSTONE, light olive green, tan carbonate nodules abundant
750.86-756.44	SILTSTONE, with interbedded MUDSTONE, light gray, horizontally bedded
756.44-764.48	SANDSTONE, fine grained, and SILTSTONE, interbedded, light gray
764.48-773.7	SANDSTONE, fine to medium grained, alternating light and medium gray, 1-6 cm thick bedding, cross-bedded, rippled
773.7-781.11	SANDSTONE, medium to coarse grained, horizontal sets with subtle cross lamination, light gray, erosional base
781.11-786.98	MUDSTONE, alternating dark gray and gray green, soft sediment slump features
786.98-790.26	MUDSTONE, light gray with dark gray streaks
790.26-794.11	SILTSTONE, light gray, with medium gray mudstone lenses
794.11-795.0	MUDSTONE, medium gray, massive
795.0-797.25	SILTSTONE, with MUDSTONE interbedded, medium gray
797.25-811.43	MUDSTONE, medium to dark gray, alternating massive to thinly laminated coaly partings, rare burrows
811.43-815.08	MUDSTONE, black, finely laminated, rare coal partings
815.08-815.51	MUDSTONE/SILTSTONE, interbedded, medium gray
815.51-818.85	MUDSTONE, dark gray green, with black, irregular, mudstone flow structures, rare carbonate nodules
818.85-826.69	MUDSTONE, olive green, with mottled tan carbonate nodules
826.69-831.68	SILTSTONE, greenish gray with medium gray mudstone partings, ripple cross-laminated
831.68-833.73	MUDSTONE, medium gray, with light gray siltstone laminae
833.73-839.35	SANDSTONE, fine grained, light gray with interbedded and interlaminated dark-gray MUDSTONE, flaser bedded near base
839.35-842.63	MUDSTONE, dark gray, with interbedded SILTSTONES, light gray (mm laminae), flaser bedding, disrupted bedding
842.63-844.89	SANDSTONE, fine to medium grained, alternating light to medium gray, minor fracture at 844.6
844.89-847.39	MUDSTONE, dark gray with interbedded siltstones, light gray (mm laminae), flaser bedded
847.39-850.73	MUDSTONE, dark gray to black, massive, dip 17 degrees
850.73-851.97	MUDSTONE, dark gray, with mottled tan carboante burrow filling
851.97-852.97	CARBONATE, tan, and mudstone, medium gray, interbedded, disrupted bedding
852.97-853.59	CARBONATE, light gray, massive
853.59-859.7	MUDSTONE, gray green, massive
859.7-861.8	SANDSTONE, fine grained, light gray with dark gray mudstone lamine
861.8-863.05	SILTSTONE/MUDSTONE, alternating dark and medium gray, convoluted bedding
863.05-864.15	MUDSTONE, dark gray, soft sediment slump, carbonaceous blebs, abundant pyrite
864.15-867.8	SILTSTONE, gray green, massive, minor carbonate near top
867.8-880.35	MUDSTONE, gray green, massive
880.35-880.76	CARBONATE, light gray to white, massive
880.76-882.66	MUDSTONE, tan to olive, with black mottling
882.66-884.02	MUDSTONE, light olive green with tan to brown mottled ironstone
884.02-895.0	MUDSTONE, light olive green, rare ironstone nodules, massive, rare silty lenses
895.0-918.85	SILTSTONE with 1 to 3 cm interbedded fine grained SANDSTONES, some with ironstone nodules and stringers
918.85-926.55	SANDSTONE, medium grained, greenish gray, rare shale interclasts
926.55-944.72	MUDSTONE, dark olive gray, disrupted and convoluted bedding, rare pods of fine grained SANDSTONE and rare ironstone nodules
944.72-946.92	MUDSTONE, dark gray to black, minor silty laminae
946.92-951.08	SILTSTONE, medium gray, with 1 to 2 cm brown ironstone nodules that exhibit irregular boundaries, dip 0 degrees
951.08-953.38	MUDSTONE, grayish green, finely laminated

953.38-955.33	SANDSTONE, fine grained, medium gray, massive
955.33-958.23	MUDSTONE, olive gray, slightly silty, massive, rare dark-gray streaks
958.23-960.0	SILTSTONE, light olive gray with medium gray mottling and massive mudstone, olive gray, with brown ironstone and rare medium-gray silt partings, massive
960.0-967.61	MUDSTONE, dark gray to black, black mottling
967.61-973.06	MUDSTONE, light gray to pale olive gray, with black mottling and 0.5 to 1.0 mm ironstone nodules
973.06-974.6	MUDSTONE, dark gray to black, rooted, coaly partings
974.6-976.2	BONE, shaly
976.2-976.9	MUDSTONE, black, carbonaceous, and SILTSTONE, medium gray, interbedded, abundant plant fragments
976.9-980.8	MUDSTONE, gray green, mottled, massive, minor ironstone pebbles
980.8-984.3	MUDSTONE, alternating medium and dark gray, minor cm thick silty laminae
984.3-985.5	MUDSTONE, bony, black, massive
985.5-992.35	SANDSTONE, fine grained, medium gray, faint ripple cross-lamination, silty near base, gradational lower contact
992.35-995.25	MUDSTONE, medium to dark gray, with silty lenses, sharp lower contact
995.25-1001.0	SANDSTONE, very fine to fine grained, fining upward, faintly ripple cross-laminated
1001.0-1009.12	SANDSTONE, medium gray, medium grained, faintly laminated to massive
1009.12-1020.0	SANDSTONE, medium gray, coarse grained, massive to very faintly cross-laminated, rare plant fragments
1020.0-1020.15	LITHIC CONGLOMERATE, ironstone and shale pebble, matrix supported, very coarse sand
1020.15-1020.8	SANDSTONE, medium gray, very coarse grained, massive
1020.8-1026.22	SANDSTONE, light gray, medium grained, massive
1026.22-1026.29	BONE
1026.29-1026.49	LITHIC CONGLOMERATE, shale pebble, coarse sandstone matrix
1026.49-1027.01	MUDSTONE, dark olive gray, mottled
1027.01-1027.7	SANDSTONE, coarse grained, light gray, shale partings and rare coal spars
1027.7-1027.83	LITHIC CONGLOMERATE, shale pebble, coarse sandstone matrix
1027.83-1035.1	SANDSTONE, light gray, medium grained, massive, coarsens near base, rare coal spars
1035.1-1035.47	LITHIC CONGLOMERATE, ironstone pebble, sand matrix
1035.47-1041.97	SANDSTONE, light gray, coarse grained, light to medium gray, with abundant 1-cm long ironstone and shale pebbles, plant fragments, cross-bedded
1041.97-1044.34	SANDSTONE, very coarse grained, light to medium gray, with abundant 1-cm-long ironstone and shale pebbles, plant fragments, cross-bedded
1044.39-1072.2	SANDSTONE, medium grained, light gray, cross-bedded to massive, rare pebbles and shale partings
1072.2-1072.35	LITHIC CONGLOMERATE, shale pebbles, medium-grained sand matrix
1072.35-1074.44	MUDSTONE, dark gray to black, with interbedded light-gray silt lenses that exhibit ripple cross-laminations
1074.44-1074.72	SANDSTONE, light gray, medium grained, massive
1074.72-1078.88	MUDSTONE, dark gray to black, massive, minor light gray silt lenses
1078.88-1079.18	SANDSTONE, light gray, fine to medium grained, ripple cross-laminated
1079.18-1086.17	MUDSTONE, dark gray, laminated, with interbedded ripple cross-laminated siltstone lenses
1086.17-1088.88	SANDSTONE, light gray, fine grained, with mudstone streaks and dark gray mudstone beds up to 0.2 ft. thick, ripple cross-laminated
1088.88-1089.58	MUDSTONE, black, massive
1089.58-1091.05	SANDSTONE, light gray, medium grained, with mudstone streaks, flaser bedded
1091.05-1093.05	MUDSTONE, dark gray, with fine-grained sandstone lenses, dip 4 degrees
1093.05-1094.95	MUDSTONE, dark gray, and SANDSTONE, light gray, fine grained, interbedded ripple cross-laminated
1094.95-1098.19	MUDSTONE, dark gray with silty laminae, ripple cross-laminated, numerous dewatering structures
1098.19-1099.03	SILTSTONE, medium gray, massive
1099.03-1104.33	MUDSTONE, dark gray, with interbedded silts, ripple cross-laminated

1104.33-1105.0	SANDSTONE, light gray, very fine grained, ripple cross-laminated
1105.0-1108.42	MUDSTONE, dark gray, with interbedded ripple cross-laminated silts
1108.42-1110.05	MUDSTONE, dark gray, massive
1110.05-1110.65	COAL, dull, blocky
1110.65-1110.9	BONY MUDSTONE, black, massive
1110.9-1112.7	COAL, dull, blocky with minor black mudstone partings
1112.7-1112.9	MUDSTONE, bony, black, massive
1112.9-1113.2	COAL, dull, blocky with minor black mudstone streaks
1113.2-1114.5	MUDSTONE, black, bony
1114.5-1115.7	COAL, dull, blocky
1115.7-1116.5	MUDSTONE, black, bony
1116.5-1118.5	COAL, dull blocky
1118.5-1118.7	MUDSTONE, black, massive
1118.7-1120.0	SILTSTONE, light gray, with dark gray mudstone partings, bioturbated
1120.0-1120.8	COAL, dull, blocky
1120.8-1128.03	MUDSTONE, dark gray to black, massive, dull coal partings
1128.03-1134.22	SANDSTONE, light gray, fine grained, with interbedded MUDSTONE, ripple cross-laminated, with soft sediment deformation, calcite filled fractures
1134.22-1136.4	MUDSTONE, black, massive, calcite-filled fractures
1136.4-1138.2	COAL, dull, blocky
1138.2-1139.18	MUDSTONE, black, massive
1139.18-1139.88	MUDSTONE, black, and SILTSTONE, light gray, interlaminated
1139.88-1140.88	MUDSTONE, black, massive
1140.88-1142.46	MUDSTONE, black, and SILTSTONE, light gray, interlaminated
1142.46-1146.65	MUDSTONE, medium gray, massive
1146.65-1146.85	MUDSTONE, medium gray, and SILTSTONE, light gray, interlaminated
1146.85-1150.7	MUDSTONE, black to dark gray, massive, minor siltstone partings
1150.7-1151.3	SANDSTONE, light gray, fine grained, rip-up clasts and convolute bedding
1151.3-1156.45	MUDSTONE, dark gray to black, minor coaly partings and siltstone lenses
1156.45-1183.4	SILTSTONE, medium gray, with interlaminated fine grained, light gray SANDSTONE, massive to ripple cross-laminated
1183.4-1184.8	SANDSTONE, light gray to medium gray, ripple cross-laminated, mudstone partings
1184.8-1187.4	SILTSTONE, argillaceious, medium gray, subtle ripple cross-laminated
1187.4-1192.35	SANDSTONE, medium gray, medium grained, massive
1192.35-1194.4	SANDSTONE, light gray, very fine grained, ripple cross-laminated
1194.4-1194.95	SANDSTONE, light gray and MUDSTONE, dark gray, interbedded, ripple cross-laminated
1194.95-1195.7	MUDSTONE, black, massive
1195.7-1196.9	COAL, dull, blocky
1196.9-1197.8	MUDSTONE, black, massive
1197.8-1198.55	COAL, dull, blocky
1198.55-1202.5	SANDSTONE, medium gray, very fine grained, ripple cross-laminated
1202.5-1207.37	SANDSTONE, light gray, fine grained and MUDSTONE, dark gray, interlaminated, ripple cross-laminated
1207.37-1213.1	MUDSTONE, dark gray to black, with minor interlaminated SILTSTONE, minor coal partings
	MISSISSIPPIAN PRICE FORMATION (lower member)
1213.1-1223.21	SANDSTONE, light gray, fine grained, cross-laminated, wavy dark gray to black mudstone partings
1223.21-1232.05	SILTSTONE, alternating light to medium gray, with dark gray mudstone, ripple cross-laminated
1232.05-1233.63	SILTSTONE, medium to dark gray, interlaminated with MUDSTONE, dark gray to black, wavy laminated, ripple/cross-laminated

1233.63-1237.23	SANDSTONE, light to medium gray, medium grained with dark gray to black mudstone partings
1237.23-1239.23	MUDSTONE, dark gray interlaminated with light gray SILTSTONE, wavy laminated
1239.23-1243.59	SILTSTONE, light to medium gray, interlaminated with wavy, dark gray MUDSTONE
1243.59-1244.99	SANDSTONE, light gray, fine to medium grained, interlaminated with dark gray MUDSTONE, disrupted
1244.99-1249.47	MUDSTONE, dark gray, irregularly laminated with minor fine grained sandstone partings
1249.47-1260.16	SANDSTONE, light gray, medium grained, with dark gray mudstone streaks, dip 3 degrees
1260.16-1265.9	SANDSTONE, light gray, coarse grained, with minor coaly partings and fractures
1265.9-1266.5	SANDSTONE, light gray, medium grained, extensively fractured with calcite filled veins
1266.5-1270.3	SANDSTONE, light gray, medium grained, fractured
1270.3-1272.38	SANDSTONE, light gray, medium grained, with numerous mm coal partings and calcite filled fractures
1272.38-1276.66	SANDSTONE, light gray, fine grained, laminated, minor mudstone streaks and ironstone chips
1276.66-1294.23	SANDSTONE, light gray, with alternating medium gray laminae, medium grained, flat laminated, few ironstone pebbles, rare 1 to 3 mm-thick coaly partings
1294.23-1294.28	LITHIC CONGLOMERATE, ironstone pebbles in coarse grained sand matrix
1294.28-1294.4	SANDSTONE, light gray, medium grained with interbedded coal partings
1294.4-1316.61	SANDSTONE, light gray, medium to coarse grained, ripple cross-laminated to massive with up to 2 cm black mudstone partings, rare ironstone and shale pebbles
1316.61-1320.66	MUDSTONE, dark gray to black, with interlaminated siltstone, ripple cross- laminated
1320.66-1337.15	SANDSTONE, light gray, medium to coarse grained, dominantly massive
1337.15-1370.35	SANDSTONE, medium to fine grained, dominantly massive, with mudstone partings, shale and ironstone pebbles
1370.35-1373.46	MUDSTONE, dark gray and SANDSTONE, light gray, medium grained, alternating, massive to finely laminated, rare ironstone pebbles
1373.46-1383.43	SANDSTONE, light gray, medium grained, massive, with very minor shale rip-up features, dip 0 degrees
1383.43-1383.91	MUDSTONE, dark gray, massive
1383.91-1385.86	SANDSTONE, light gray, medium to fine grained, mudstone partings rare
1385.86-1386.03	LITHIC CONGLOMERATE, shale pebbles in a medium grained, light gray sandstone matrix
1386.03-1392.68	SANDSTONE,medium gray, medium to coarse grained, fining upward, dominantly massive
1392.68-1394.5	SILTSTONE, medium gray and MUDSTONE, dark gray, interbedded, cross-bedded, rip-up features, dip 0 degrees
1394.5-1405.0	SANDSTONE, light gray, fine to medium grained, massive, with interbedded SILTSTONE, minor plant fragments
1405.0-1407.35	SANDSTONE, light gray, coarse grained, massive to laminated, cross-bedded, graded beds
1407.35-1415.0	SANDSTONE, light gray, medium grained, massive to laminated, with conglomeratic lenses of ironstone and mudstone pebbles in a medium grained sandstone matrix
1415.0-1417.65	MUDSTONE, dark gray, with lenses of fine grained sandstones
1417.65-1468.7	SANDSTONE, medium to dark gray, medium grained, ripple cross-laminated with interlaminated dark gray mudstones and rare conglomeratic lenses
1468.7-1493.2	SANDSTONE, medium gray, fine grained with minor lithic conglomerates, some containing quartz pebbles
1493.2-1506.0	SANDSTONE, medium gray, fine grained and SILTSTONE, with interbedded dark gray mudstone
1506.0-1517.2	SANDSTONE, medium gray, fine grained, with lithic conglomerates containing broken fossils at: 1507.4-1508.0 and 1516.0-1517.2
1517.2-1528.28	SILTSTONE/MUDSTONE, dark gray, interbedded, with disrupted bedding
1528.28-1528.8	SILTSTONE, medium gray, extensively fractured, with calcite filled veins and vugs
1528.8-1530.0	SILTSTONE, medium gray, fractured and broken
1530.0-1534.68	SILTSTONE, medium gray, with fossil hash lenses containing marine brachiopods at 1530.0-1530.25, 1530.87-1531.07, and 1531.67-1532.22, and interbedded dark gray mudstone
1534.68-1534.98	POLYMICTIC LITHIC CONGLOMERATE, greywacke and orthoquartzite pebbles up to 6 cm, with a matrix of siltstone and fossil hash
1534.98-1557.23	SANDSTONE, medium gray, fine grained, dominantly massive, with minor rippled mudstone partings, lithic conglomerate lenses, and fossil hash concentrations at: 1543.47-1543.97, 1553.08-1553.78, 1556.96-1557.11

1577.23-1560.33	SILTSTONE, very pale moderate red, with scattered fossil lags and rare lithic conglomerate lenses
1560.33-1573.64	SANDSTONE, medium gray, fine grained, with lithic conglomerate lenses and fossil-hash concentrations at: 1563.03-1563.71, 1564.78-1565.03
1573.64-1573.84	CALCITE FILLED FRACTURE, vuggy euhedral calcite rhombs
1573.84-1574.49	SANDSTONE, medium gray, fine to medium grained, laminated, with dark gray mudstone streaks
1574.49-1575.54	POLYMICTIC LITHIC CONGLOMERATE containing siltstone, quartzite, ironstone, and shale pebbles, up to 2 cm, fines upward, scoured base
1575.54-1576.44	SANDSTONE, medium fine grained, cross-laminated, with rare quartzite pebbles
1576.44-1577.04	LITHIC CONGLOMERATE, with quartzite, ironstone and shale pebbles up to 2 cm in diameter
1577.04-1578.69	SANDSTONE, light gray, medium grained, with dark gray mudstone streaks
1578.69-1580.09	LITHIC CONGLOMERATE, containing flat pebbles of mudstone and ironstone, and mudstone rip-up clasts
1580.09-1581.84	MUDSTONE, dark gray, massive
1581.84-1583.02	SILTSTONE, medium gray, very finely laminated
1583.02-1585.1	MUDSTONE, medium gray, with light gray flecks
1585.1-1630.03	SANDSTONE, light gray, fine grained, with interbedded silty dark gray MUDSTONES, wavy laminated to bedded, extensively burrowed, minor LITHIC CONGLOMERATES
1630.03-1630.76	SANDY SHALE MUDFLOW, medium gray
1630.76-1633.19	SANDSTONE, light gray, fine grained, massive, with 1-cm-laminated MUDSTONES
1633.19-1639.33	SANDY SHALE MUDFLOW
1639.33-1645.82	SANDSTONE, light gray, fine grained, with interbedded dark gray SILTSTONE
1645.82-1646.25	SANDY SHALE MUDFLOW
1646.25-1672.0	SANDSTONE, light gray, fine grained, with interbedded dark gray MUDSTONES, extensively burrowed, dip 0 degrees

(BOTTOM OF HOLE)

Merrimac Test Well

Well:	Merrimac Test (W-6535)
Farm:	Virginia Polytechic Institute and State University
Driller:	Joy Manufacturing Company
Location:	Blacksburg 7.5-minute quadrangle Lat.: 37°12′08″ N Long.: 80°25′47′W
Elevation:	2090 feet
Total depth:	1674.0 feet
Started drilling:	May 20, 1982
Finished drilling:	June 28, 1982

Sample descriptions by C. B. Stanley and A. P. Schultz, Virginia Divisions of Mineral Resources

Reference: Core obtained by Virginia Division of Mineral Resources through D.O.E. Grant number DE-FG44-81R410431.

INTERVAL (FEET)	*DESCRIPTION*
	MIDDLE CAMBRIAN ELBROOK FORMATION
0.0-45.0	DOLOMITE, dark gray, fine grained, chips, rotary drilled
45.0-49.5	DOLOMITE, dark gray, massive, fractured
49.5-60.0	DOLOMITE, medium gray, 0.5 cm-1.0 cm laminae, stylolitic partings and calcite filled fractures
60.0-76.2	DOLOMITE, dark gray, fine to medium grained, fractured and veined, irregular stylolites
76.2-93.5	DOLOMITE, dark gray, laminated, highly fractured, with calcite filled vugs and veins
93.5-104.6	DOLOMITE, dark gray, brecciated, abundant stylolites, 0.5 at base is black stylolitic clay-rich gouge
	PULASKI FAULT
	MIDDLE MISSISSIPPIAN MACCRADY FORMATION
104.6-111.5	MUDSTONE, dark red and mottled green, massive, highly fractured
111.5-111.0	MUDSTONE, dark red, brecciated, with well developed foliation
114.0-137.1	MUDSTONE, dark red, and SILTSTONE, dark red, interbedded and interlaminated, with rare brecciated zones
137.1-195.0	MUDSTONE, dark red, rare siltstone partings, and rare brecciated zones
195.0-196.0	SANDSTONE, dark red, fine grained
196.0-197.4	MUDSTONE, dark red and mottled gray, massive
197.4-207.1	MUDSTONE, dark red and mottled gray, and SILTSTONE, dark red, finely lamianted, interbedded
207.1-214.4	MUDSTONE, dark red, massive
214.4-214.55	SANDSTONE, greenish gray, fine grained, massive
214.55-225.2	MUDSTONE, dark red, with interbedded finely laminated SILTSTONE, dark red
225.2-229.0	MUDSTONE, dark red, laminated
229.0-229.3	SILTSTONE, dark red and gray, mottled
229.3-230.9	MUDSTONE, dark red, laminated
230.9-232.15	MUDSTONE, dark red, massive, with abundant carbonate nodules
232.15-233.15	MUDSTONE, dark red, massive
233.15-238.1	SANDSTONE, mottled dark red and gray, fine to medium grained
238.1-242.2	SILTSTONE, dark red, with interlaminated and interbedded MUDSTONE, dark red
242.2-245.1	MUDSTONE, dark red, laminated
245.1-256.3	SILTSTONE, dark red, laminated/MUDSTONE, dark red to greenish gray, interbedded

256.3-318.2	MUDSTONE, dark red to dark greenish gray, laminated to mottled, with minor dark red and gray mottled siltstone partings
318.2-321.8	SANDSTONE, dark red, fine grained, massive
321.8-324.0	MUDSTONE, dark red, massive
324.0-330.1	MUDSTONE, dark red and gray-green and SILTSTONE, greenish gray to dark red, interbedded
330.1-335.0	SANDSTONE, dark red and gray, mottled, fine grained, with minor siltstone streaks and lenses
335.0-337.8	MUDSTONE, dark red and gray, mottled, laminated
337.8-342.8	SILTSTONE, dark red and green, mottled, with interbedded dark red MUDSTONE and dark red, medium grained SANDSTONE
342.8-349.5	MUDSTONE, dark red to greenish gray, massive to laminated
349.5-352.7	SILTSTONE, dark red and gray, mottled, massive, and SANDSTONE, dark red and gray, fine to medium grained, interbedded
352.7-355.0	MUDSTONE, dark red and gray, mottled, massive
355.0-355.2	SILTSTONE, dark red and green mottled
355.2-356.1	MUDSTONE, dark red and green, mottled
356.1-357.2	SANDSTONE, dark red and gray-green, mottled, silty to fine grained, massive
357.2-359.5	MUDSTONE, dark red and green, mottled, massive
359.5-361.0	SILTSTONE, dark red and green, mottled
361.0-363.8	MUDSTONE, dark red and green, mottled, massive
363.8-379.0	SANDSTONE, dark red, massive to cross-bedded, silty near top of unit, rare LITHIC CONGLOMERATE near base
379.0-381.2	MUDSTONE, dark red, massive
381.2-381.6	CARBONATE, tan, massive
381.6-384.1	SILTSTONE, dark red and green mottled, with tan carbonate nodules
384.1-386.8	SANDSTONE, dark red, fine grained, massive to cross-bedded
386.8-392.2	MUDSTONE, dark red with minor gray lenses
392.2-401.8	MUDSTONE, dark red and gray, mottled to streaked, with mottled dark red and gray SILTSTONE, fine grained sandstone lenses and partings
401.8-403.9	MUDSTONE, mottled gray and dark red
403.9-404.9	MUDSTONE, medium gray, massive
404.9-408.5	SILTSTONE, dark red to mottled dark red and gray, with minor mottled dark red and gray mudstone partings
408.5-411.5	MUDSTONE, dark red and gray, mottled
411.5-415.3	SANDSTONE, dark red and gray, mottled, fine grained, with dark red mudstone partings
415.3-418.0	MUDSTONE, dark red and gray, mottled
418.0-419.0	SANDSTONE, medium gray to mottled gray and dark red, fine grained
419.0-419.45	CARBONATE, tan, with mudstone streaks
419.45-424.8	MUDSTONE, dark red and gray, mottled, with minor tan carbonte nodules near top
424.8-430.01	SANDSTONE, gray to dark red, with interbedded to interlaminated dark red and gray MUDSTONE and SILTSTONE
430.01-435.0	MUDSTONE, dark red and gray, mottled, massive
435.0-444.82	SANDSTONE, dark red, fine grained, cross-bedded to massive, with interbedded and interlaminated MUDSTONES and SILTSTONES
444.82-450.01	MUDSTONE, dark red, laminated to massive, with minor dark red siltstone streaks
450.01-459.2	SILTSTONE, MUDSTONE, and fine grained SANDSTONE, interlaminated to interbedded, dark red to mottled dark red and gray
459.2-470.1	SANDSTONE, dark red, fine grained, minor gray mottled zones
470.1-474.7	MUDSTONE, dark red and gray, mottled, massive
474.7-478.95	SANDSTONE, dark red to mottled dark red and gray, fine grained, with interbedded dark red SILTSTONE and MUDSTONES

478.95-481.09	MUDSTONE, dark red, massive
481.09-483.8	SANDSTONE, dark red, fine grained, massive
483.8-487.2	MUDSTONE, mottled dark red, green, and gray, massive
487.2-488.2	MUDSTONE, mottled dark red and gray, with tan carbonate nodules
488.2-499.5	MUDSTONE, mottled dark red and grayish green, massive, with minor dark red siltstone partings
499.5-502.1	SILTSTONE, gray with minor dark red mottling, calcite veins and nodules
502.1-508.6	MUDSTONE, dark red with minor gray laminae
508.6-509.98	SILTSTONE, dark red and gray mottled, with minor dark red mudstone partings
509.98-517.9	MUDSTONE, gray to mottled dark red and gray, laminated, with minor siltstone partings and tan carbonate nodules near base
517.9-522.6	SILTSTONE, dark red and gray, with mottled dark red and gray MUDSTONE and dark red, fine grained sandstone partings
522.6-525.2	MUDSTONE, dark red, laminated
525.2-530.8	SANDSTONE, mottled dark red and gray, fine grained, silty near top, massive
530.8-566.0	MUDSTONE, dark red and minor grayish green mottling, and minor interbedded grayish-green massive SILTSTONE, dark red fine grained SANDSTONE, and rare carbonate nodules
566.0-567.0	SILTSTONE, mottled dark red and grayish green, massive
567.0-568.4	SANDSTONE, mottled gray and dark red, fine grained
568.4-568.9	SILTSTONE, mottled dark red and gray, massive
568.9-570.2	MUDSTONE, mottled dark red and gray, massive
570.2-570.55	SILTSTONE, medium gray, massive
570.55-572.23	SANDSTONE, dark red, fine grained
572.23-575.52	MUDSTONE, dark red, massive, abundant tan carbonate nodules in bottom half of unit
575.52-579.75	SANDSTONE, dark red to mottled dark red and gray, massive to ripple cross-laminated, medium to fine grained, fining upward, rare tan carboante nodules near top
579.75-593.53	SILTSTONE, dark red and medium gray, mottled, minor very fine-grained sand lenses and mudstone streaks
593.53-595.87	MUDSTONE, dark red, massive
595.87-601.17	SILTSTONE, dark red nad medium gray, mottled
601.17-604.19	MUDSTONE, dark red and medium gray, mottled, with calcite filled fractures, fault contact at base
	FAULT
	MIDDLE MISSISSIPPIAN PRICE FORMATION (upper member)
604.19-608.55	SILTSTONE, light gray, massive to finely laminated
608.55-610.5	SILTSTONE, medium gray, with numerous dark gray to black organic-rich, pyritic streaks
610.5-616.7	MUDSTONE, dark red with minor grayish-green streaks and mottles
616.7-617.3	SILTSTONE, light gray, massive
617.3-620.35	MUDSTONE, dark red and medium gray, mottled
620.35-624.63	SILTSTONE, light to medium gray, with dark gray wavy laminae
624.63-628.41	MUDSTONE, medium gray, with interbedded SILTSTONE, dark gray, massive
628.41-630.16	MUDSTONE, light grayish green with minor dark red mottling
630.16-647.29	MUDSTONE, dark red with minor medium gray mottles, silty
647.29-649.96	SANDSTONE, medium gray, very fine grained, massive, finely laminated
649.96-675.47	MUDSTONE, dark red and light gray, mottled and streaked, silty, numerous tan carbonate nodules and streaks
675.47-676.02	SANDSTONE, light gray, fine grained, massive
676.02-677.25	MUDSTONE, dark red and light gray streaks, alternating
677.25-689.3	SANDSTONE, medium gray, medium grained, massive
689.3-693.44	SANDSTONE, medium to light gray, medium to coarse grained, with medium gray mudstone chips and laminae

693.44-698.61	SANDSTONE, light gray, medium grained, massive, numerous calcite filled fractures
698.61-708.07	SILTSTONE, medium gray, massive, with interlaminated and interbedded fine grained sandstone
708.07-713.8	SANDSTONE, medium gray, fine to medium grained, with dark gray laminations
713.8-717.34	MUDSTONE, dark red, massive, with rare greenish gray mottling
717.34-721.0	SILTSTONE, medium gray, with fine grained SANDSTONE, light gray
721.0-727.25	MUDSTONE, dark red, massive
727.25-730.7	MUDSTONE, light olive gray, laminated
730.7-740.82	SILTSTONE, light gray, laminated, with minor mudstone streaks, calcite filled fractures
740.82-743.67	MUDSTONE, medium to dark gray, minor dark red mottles
743.67-760.8	SILTSTONE, medium gray, with dark gray to black mudstone partings
760.8-768.0	MUDSTONE, olive green and dark gray mottled, interbedded silts, with rare carbonate nodules and ironstone pebbles
768.0-771.32	MUDSTONE, dark red and grayish-green, mottled
771.32-779.43	SILTSTONE, medium gray massive, rare dark gray mud streaks
779.43-787.61	MUDSTONE, interlaminated and mottled dark red and dark gray, calcite filled, slickensided fractures
787.61-789.87	SILTSTONE, medium gray, massive
789.87-800.09	MUDSTONE, dark red, to gray, massive, mottled, calcite filled fractures, slickensided
800.09-804.55	SILTSTONE, medium gray with thinly bedded very fine-grained SANDSTONE
804.55-807.45	SANDSTONE, medium to dark gray, medium to coarse grained, fining upward, with minor carbonaceous streaks
807.45-808.65	MUDSTONE, dark red and dark gray, mottled
808.65-820.26	SILTSTONE, medium to dark gray, mudstone streaks and numerous calcite filled fractures
820.26-829.0	MUDSTONE, dark red to mottled dark red and medium gray, massive
829.0-832.08	MUDSTONE, olive green, with abundant tan mottled carbonate nodules and streaks
832.08-838.66	SILTSTONE, light gray-green and SANDSTONE, light gray-green, very fine grained, interbedded, calcite filled fractures
838.66-841.76	MUDSTONE, medium gray with dark red mottles, with minor siltstone lenses
841.76-843.5	SANDSTONE, light gray, very fined grained, with very finely laminated MUDSTONE
843.5-848.1	MUDSTONE, dark gray to grayish green, bioturbated, minor irregular black stringers
848.1-850.28	SILTSTONE, greenish gray, with light tan mottled CARBONATE
850.28-858.25	SILTSTONE, grayish green, laminated with minor black streaks
858.25-860.88	MUDSTONE, dark red and medium gray, mottled, to massive dark red
860.88-863.46	MUDSTONE, olive gray and tan, mottled, dominantly CARBONATE
863.46-866.11	SANDSTONE, medium to light gray, fine to medium grained, massive
866.11-880.76	MUDSTONE, alternating dark red and medium gray, massive
880.76-884.73	SANDSTONE, medium gray, fine grained, silty, massive
884.73-887.23	MUDSTONE, dark grayish green with dark red streaks, massive to finely laminated
887.23-912.04	SILTSTONE, medium gray, finely laminated, with minor dark red siltstone streaks, calcite and pyrite filled fractures
912.04-926.5	MUDSTONE, dark red, massive and SILTY MUDSTONE, grayish green, interbedded
926.5-932.93	SILTSTONE, light gray, with interbedded very fine grained SANDSTONE, massive
932.93-934.33	MUDSTONE, dark grayish green, minor dark red streaks extensively burrowed
934.33-936.85	SILTSTONE, mottled light gray-green and dark red
936.85-941.35	SANDSTONE, light to medium gray, fining upward sequence, fine to medium grained, calcite filled fractures
941.35-941.85	FAULT ZONE, brecciated gray MUDSTONE, disrupted bedding, large calcite filled fractures
941.85-943.9	MUDSTONE, medium gray, massive
943.9-946.22	SILTSTONE, medium gray, laminated and massive with interbedded SANDSTONE, light gray, fine grained, laminated

946.22-966.75	MUDSTONE, medium to dark gray, with interbedded SILTSTONE, light gray, laminated, mottled IRONSTONE, bioturbated
966.75-969.57	SILTY MUDSTONE, dark red and light grayish green, mottled
969.57-984.45	SILTSTONE, medium gray, with interbedded, interlaminated medium to dark gray mudstone
984.45-1008.6	SILTSTONE, medium gray, massive and MUDSTONE, mottled dark red and gray to massive dark red
1008.6-1014.35	SANDSTONE, light gray, fine to medium grained, massive, with minor silty streaks
1014.35-1018.55	MUDSTONE, dark gray, with interlaminated light gray SILTSTONE
1018.55-1021.3	SANDSTONE, light gray, medium grained, massive
1021.3-1031.6	MUDSTONE, medium to dark gray massive
1031.6-1033.9	SILTSTONE, medium gray, minor dark grayish-green blebs
1033.9-1038.9	SILTSTONE, medium gray to greenish gray, with minor tan carbonate nodules and streaks
1038.9-1039.6	CARBONTE, tan with minor medium gray mudstone mottles
1039.6-1045.59	MUDSTONE, grayish green, massive, with zones of carbonate partings
1045.59-1049.84	SILTSTONE, grayish green, argillaceous, with ironstone nodules
1049.84-1051.85	MUDSTONE, light olive green to gray, burrowed
1051.85-1053.95	CARBONATE MUDSTONE, tan and grayish green
1053.95-1063.21	SILTSTONE, grayish green, with interbedded very fine grained massive SANDSTONE, minor carbonate blebs and mottled organic-rich pods
1063.21-1067.36	MUDSTONE, greenish gray, with minor dark red mottling, massive, and minor carbonate nodules
1067.36-1068.84	MUDSTONE, dark red with minor gray mottling, massive
1068.84-1079.07	MUDSTONE, grayish green, with tan carbonate mottles, black organic-rich streaks, and irregular ironstone nodules
1079.07-1099.36	SANDSTONE, medium gray, medium to coarse grained, massive
1099.36-1104.21	MUDSTONE, dark to medium gray, massive to burrowed, abundant pyrite in organic-rich partings
1104.21-1108.17	SILTSTONE, medium gray, massive to laminated
1108.17-1112.95	MUDSTONE, black to dark gray, irregularly laminated, slumped
1112.95-1127.78	SILTSTONE, grayish green, massive, minor calcity veins, minor dark gray, organic-rich MUDSTONE beds
1127.78-1131.58	SANDSTONE, light gray, fine to medium grained, massive
1131.58-1132.79	SILTSTONE, medium to dark gray, massive
1132.79-1142.35	MUDSTONE, dark gray, finely laminated to massive, burrowed, with numerous tan ironstone nodules and streaks
1142.35-1144.77	SILTSTONE, medium grayish green, minor ironstone nodules, and black organic-rich streaks
1144.77-1153.83	MUDSTONE, dark gray to grayish green, massive to burrowed, with few large ironstone blebs at base
1153.83-1157.95	SILTSTONE, medium gray, massive, with interbedded fine grained SANDSTONE, light gray
1157.95-1173.58	MUDSTONE, dark gray, finely laminated, with interbedded and interlaminated light gray SILTSTONE, finely laminated to massive, minor coaly partings, ripple cross-laminated, slightly fractured, small scale ball and pillow structures abundant in interlaminated units
1173.58-1176.66	SANDSTONE, medium to light gray, very coarse to fine grained, with interbedded/interlaminated SILTSTONE and MUDSTONE, abundant coal spars, and ironstone chips, with LITHIC CONGLOMERATE at base, consisting of shale chips and ironstone pebbles, erosional base, fining upward sequence
1176.66-1178.86	MUDSTONE, black, coaly, massive to finely laminated
1178.86-1183.37	MUDSTONE, dark greenish gray, carbonate rich, with abundant tan irregular carbonate nodules and streaks, with rare irregular ironstone nodules and streaks
1183.37-1184.99	MUDSTONE, grayish green, with black organic-rich streaks, massive
1184.99-1188.35	SILTSTONE, medium gray, interlaminated with dark gray MUDSTONE, rare massive IRONSTONE
1188.35-1189.05	SANDSTONE, light gray, medium to fine grained, finely laminated
1189.05-1197.72	MUDSTONE, dark gray and black, mottled, with minor ironstone blebs, massive
1197.72-1203.0	SILTSTONE, medium gray, massive to finely laminated
1203.0-1208.16	MUDSTONE, medium to dark gray, with interbedded, interlaminated SILTSTONE, medium gray

1208.16-1208.3	COAL, bright, highly sheared, slickensided
1208.3-1212.85	MUDSTONE, medium to dark gray, abundant tan ironstone nodules, coaly partings near top of unit
1212.85-1221.99	SILTSTONE, grayish green, with numerous ironstone nodules, massive to laminated
1221.99-1232.55	MUDSTONE, medium to dark gray with interbedded, interlaminated SILTSTONE, medium gray, massive to finely ripple cross-laminated, abundant bedding-parallel films of pyrite
1232.55-1233.0	MASSIVE IRONSTONE, light brown to tan
1233.0-1239.54	MUDSTONE, medium gray, massive, and SILTSTONE, medium gray, massive, abundant ironstone blebs, interbedded
1239.54-1248.0	MUDSTONE, dark gray to black, massive, with numerous coal streaks and spars, silty in places
1248.0-1249.52	SANDSTONE, very fine grained, with interbedded SILTSTONE and MUDSTONE, medium to light gray, with LITHIC CONGLOMERATE at base, containing ironstone clasts, scoured base, wavy bedded, anastomosing organic partings
1249.52-1254.0	MUDSTONE, dark gray to black, abundant plant fragments, fracture surfaces have abundant pale green copper mineral residue and crusts of bornite, chalcopyrite, and pyrite
1254.0-1254.95	NODULAR IRONSTONE, dark brown, with grayish-green MUDSTONE
1254.95-1271.06	SILTSTONE, light gray, massive to finely ripple cross-laminated, with brown ironstone nodules
1271.06-1285.85	SANDSTONE, light gray, medium to coarse grained, massive to faintly ripple cross-laminated, rare ironstone pebbles and coal spars near base
1285.85-1286.4	MUDSTONE, dark gray, massive, with ironstone blebs
1286.4-1297.98	SANDSTONE, light gray, medium to coarse grained, ripple cross-laminated, with numerous coal spars and partings and minor shale and ironstone pebbles, fractures have films of pyrite, bornite, and chalcopyrite
1297.98-1306.0	SILTSTONE, medium gray, laminated
1306.0-1337.7	SANDSTONE, medium to light gray, medium to coarse grained, massive to ripple cross-laminated, numerous coal spars, partings, and shale chips, rare ironstone pebbles, numerous calcite filled fractures
1337.7-1356.98	SANDSTONE, medium gray, fine grained, with mudstone streaks, ripple cross-laminated, and LITHIC CONGLOMERATE, with shale, siltstone and ironstone pebbles in a matrix of light gray, medium grained sandstone
1356.98-1366.22	SANDSTONE, light gray, fine to coarse grained, with interbedded medium gray SILTSTONES, rare ironstone pebbles and abundant coal spars near base, erosional base
1366.22-1369.15	MUDSTONE, medium to dark gray, burrowed, with coal partings, and SILTSTONE, medium gray, ripple cross-laminated, interbedded
1369.15-1403.5	MUDSTONE, black, massive, abundant coal partings and laminae, with minor silty beds that are ripple cross-laminated
1403.5-1404.95	COAL, bright, sheared
1404.95-1407.7	MUDSTONE, dark gray, with silty lenses, common coaly partings, rare calcite filled fractures
1407.7-1408.9	COAL, bright, sheared
1408.9-1410.45	MUDSTONE, dark gray to black, silty in places, calcite filled fractures, abundant coal partings
1410.45-1411.9	COAL, bright, sheared
1411.9-1420.0	MUDSTONE, black to dark gray, massive, rooted near top of unit
1420.0-1421.0	COAL, bright, sheared
1421.-1421.15	BONE, sheared
1421.15-1425.95	MUDSTONE, black, massive, with abundant coal partings up to 0.3 ft. thick
1425.95-1426.35	COAL, bright, sheared
1426.35-1427.65	MUDSTONE, black, massive, abundant coal partings
1427.65-1428.15	COAL, bright, sheared
1428.15-1444.95	MUDSTONE, black, massive, with coal near base, folded
1444.95-1445.55	COAL, bright, sheared
1445.55-1450.0	SANDSTONE, light gray, medium to fine grained, massive and ripple cross-laminated
1450.0-1451.2	SILTSTONE, medium gray with polymodal ripple cross-lamination
1451.2-1453.2	SANDSTONE, light gray, medium grained, massive to finely laminated with minor shale chips and carbonaceous partings

1453.2-1461.3	SILTSTONE, medium gray, with fine grained sandstone lenses, ripple cross-laminated, rare coal partings
1461.3-1462.1	COAL, bright, sheared
1462.1-1478.95	MUDSTONE, medium to dark gray, massive, silty in places, fracture zone at 1467.0-1468.0
1478.95-1479.15	COAL, bright, sheared
1479.15-1480.2	MUDSTONE, black, massive, abundant coal partings
1480.2-1480.45	COAL, bright, sheared
1480.45-1481.0	MUDSTONE, black, with abundant bone and coal partings
	MIDDLE MISSISSIPPIAN PRICE FORMATION (lower member)
1481.0-1547.6	SILTSTONE, medium to light gray, massive to interlaminated with dark gray MUDSTONE, polymodal oscillation ripple cross-lamination, rare LITHIC CONGLOMERATE at 1528.0-1529.0, *major fracture zone*, with disrupted and trulncated bedding surfaces and numerous calcite veins from 1496.2-1500.2
1547.6-1549.75	MUDSTONE, medium to dark gray, with interlaminated light gray SILTSTONE
1549.75-1597.43	SANDSTONE, light to medium gray, fine to medium grained, massive to laminated, with minor dark gray mudstone streaks
1597.43-1598.78	SANDSTONE, light gray, coarse grained, massive
1598.78-1628.4	SILTSTONE, medium gray, ripple cross-laminated , shale chips
1628.4-1634.07	LITHIC CONGLOMERATE, mudstone and ironstone pebbles, with interbedded light gray, medium grained SANDSTONE
1634.07-1644.0	MUDSTONE, black, with interlaminated fine grained, light gray SANDSTONE
1644.0-1645.54	MUDSTONE, dark gray, and light gray medium grained SANDSTONE, interlaminated and interbedded
1645.54-1659.4	SANDSTONE, light gray, medium to coarse grained, with rare mud chips and mudstone laminae
1659.4-1660.33	LITHIC CONGLOMERATE, ironstone and shale pebble in a medium-grained, light gray sandstone matrix
1660.33-1671.3	SANDSTONE, light gray, fine to medium grained, mudstone streaks rare, massive, calcite filled fractures, with a 0.15 ft. basal LITHIC CONGLOMERATE, consisting of siltstone and shale pebbles
1671.3-1674.0	MUDSTONE, dark gray, massive

(BOTTOM OF HOLE)