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The subsurface stratigraphy of the Middle and Upper Devonian clastic sequence in northwestern West Virginia

by

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Submitted by

West Virginia Geological and Economic Survey

to

U.S. Department of Energy

under

Contract No. DE-AC21-76MC05199

Robert B. Erwin
Director and State Geologist

May 1980

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encouragement have made many things possible through the years.

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The subsurface stratigraphy of the Middle and Upper Devonian clastic sequence in northwestern West Virginia

by

Mary Elizabeth Dowse

ABSTRACT

The Middle and Upper Devonian clastic sequence of northwestern West Virginia previously has been undivided in the subsurface. The subdivision of the clastic sequence into formations which can be correlated with surface exposures in New York and Ohio is based on the recognition of black shale marker units. Gamma-ray logs, drillers' logs, cores, and sample studies were used to establish the stratigraphic framework for the clastic sequence in northwestern West Virginia. Isopach maps were constructed for each formation and its members in the study area to illustrate the areal distribution of the units and cross sections were constructed to show the stratigraphic relationships. These maps and sections illustrate that each of the Middle and Upper Devonian formations thickens to the east with the greatest change occurring in the units with thick accumulations of black shale in the western part of the area.

Two named gas field in the study area have produced from fractured reservoirs in thick sequences of black shale for many years. Additional scattered production occurs throughout Mason, Putnam, Jackson, and Wood Counties. Exploration for future gas production should focus on the Rhinestreet Shale Member of the West Falls Formation and the Huron Member of the Ohio Shale in Putnam, Mason, Jackson, and Wood Counties,

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and should concentrate on isolating structures that may have produced fractured reservoirs.

The Devonian clastic sequence was deposited in a relatively shallow basin which was deepest in the eastern part of the study area and shallowed to the west. The clastic source was to the east as indicated by coarser-grained sediments in the eastern part of the area. Finer-grained sediments, often rich in organic detritus, were deposited in shallow water farther to the west. Black shale intervals are shown to correlate with thicker sequences of clastics in the east, which are here interpreted to represent times of more rapid sedimentation. The preservation of organic matter in the shale seems to have been the result of the influx of large amounts of organic matter which underwent more rapid burial because of higher sedimentation rates. Gray shale, conversely, represents periods of slower deposition, with less organic detritus entering the environment, and more complete decomposition of organic matter taking place.

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INTRODUCTION

In recent years America has become increasingly energy conscious, and the search for domestic energy supplies has received a great deal of renewed interest. One large potential source of natural gas is the Devonian "brown" shale of the Appalachian basin, which has yielded gas for more than 60 years from shallow, low-volume wells. Brown (1976) estimated that 3 trillion cubic feet of gas could ultimately be recovered from the shale in the Appalachian basin. This study is part of an on-going United States Department of Energy project to characterize the Devonian shale in general and to determine the most efficient methods of recovering the natural gas it holds. The primary purpose of this study is to describe the stratigraphy of the Devonian clastic sequence in northwestern West Virginia and from these data to suggest a depositional model for the region during the Devonian. A second objective is to relate the stratigraphy to current gas production and suggest areas for future exploration.

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The study area is located in northwestern West Virginia and covers over 5,000 square miles including 14 counties: Braxton, Calhoun, Doddridge, Gilmer, Jackson, Mason, Putnam, Ritchie, Roane, Tyler, Wetzel, Wirt and Wood (Figure 1). The area, located along the western margin of the Appalachian basin, includes the Rome Trough, and a very pronounced structural feature, the Burning Springs Anticline (Figure 2). In addition, many small, broad, low amplitude, open folds are present within the region.

This study deals with the stratigraphic interval known as the Devonian shale, or the Middle and Upper Devonian clastic sequence.

STUDY AREA

APPALACHIAN BASIN

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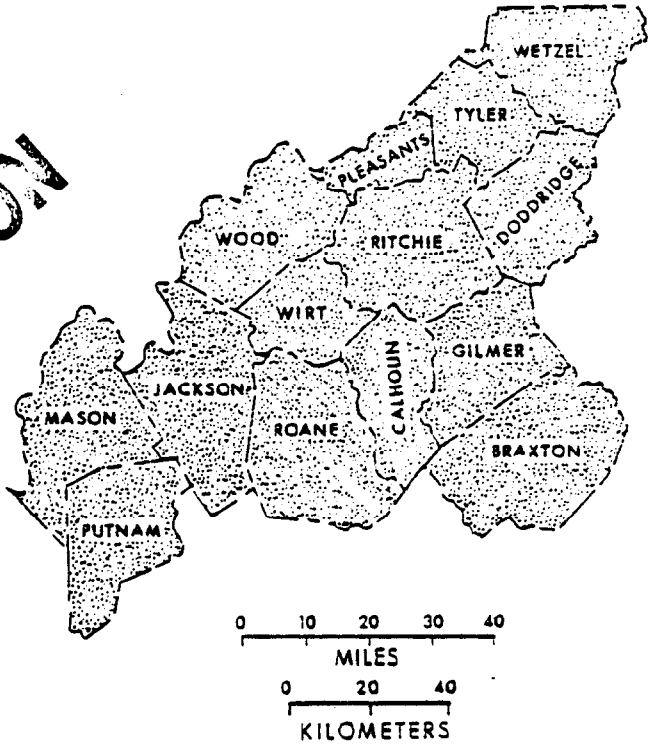

Figure 1. Location of study area.

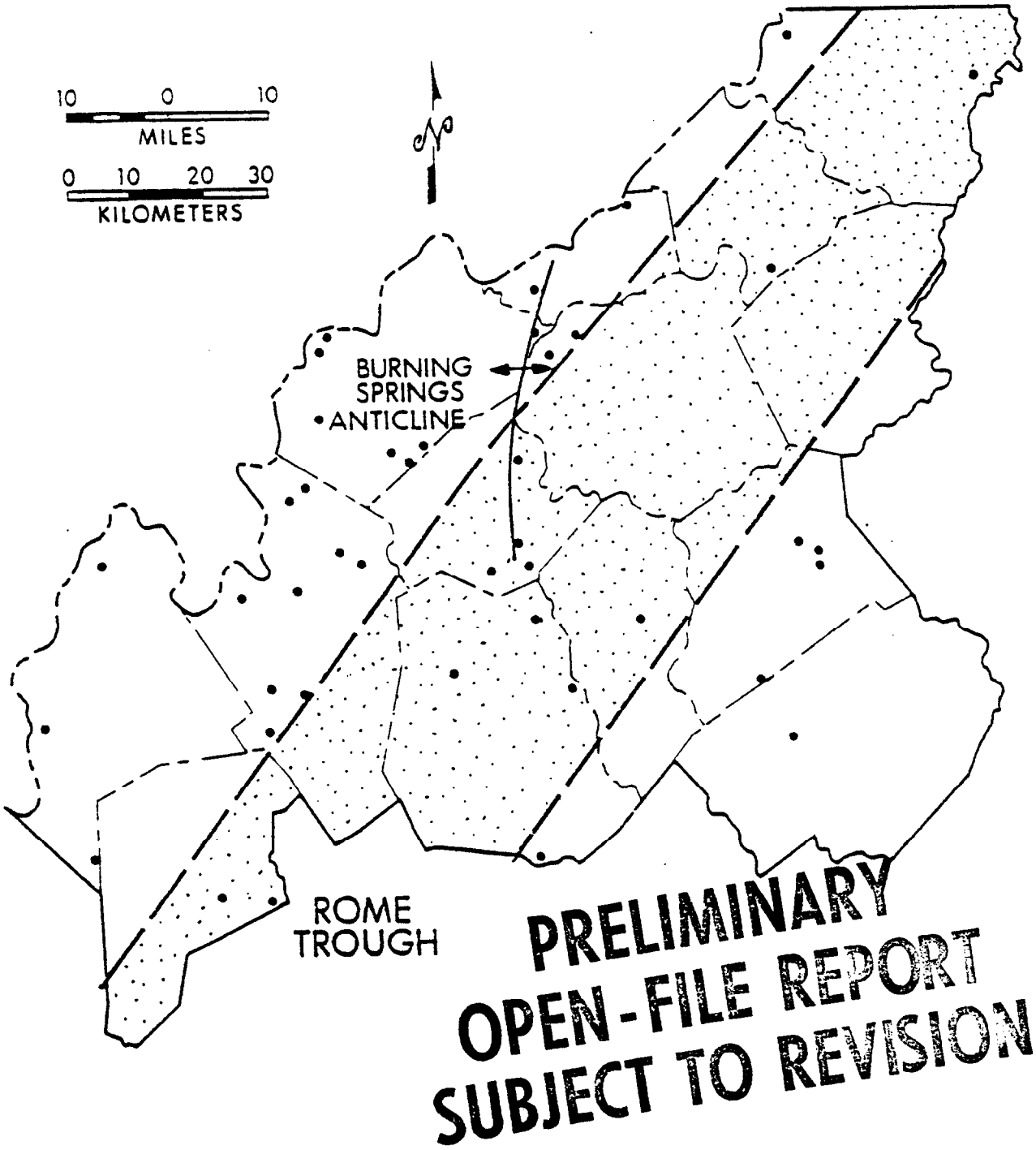

Figure 2. Major structural features in northwestern West Virginia.

The interval overlies the Middle Devonian Onondaga Limestone and its facies equivalent, the Huntersville Chert, and is overlain by the Berea Sandstone of Early Mississippian age. In the eastern portion of the study area the Berea Sandstone is not present, and the differentiation of the uppermost Devonian clastics from the Pocono Formation of Mississippian age is difficult. The Middle and Upper Devonian clastic sequence ranges in thickness from 1500 feet in the west to 4700 feet in the east (Figure 3). Correlative units crop out to the east in the mountains of West Virginia and to the west in Ohio, but the units are entirely subsurface in the study area. In the outcrop belt in eastern West Virginia, the Middle and Upper Devonian clastic sequence is composed of gray to green and red shale, siltstone, and sandstone with a small amount of black shale. In central and southern Ohio, the clastic sequence is composed of intercalated dark-gray to black shale, rich in organic matter, and gray shale. Within the study area, the lithology varies from gray shale and black shale in the west to gray and red shale and siltstone with minor black shale in the east. In the subsurface of western West Virginia, the dark shale with abundant organic matter has historically been called "brown" shale because when powdered in drilling it colored drilling fluids brown.

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The principal source of data for this study was the gamma-ray log. Gamma-ray logs of natural radioactivity were available from 82 wells that penetrated the entire clastic section and an additional 9 wells that penetrated to within 100 feet of the base of the section. Logs from wells that penetrated only part of the section also were examined,

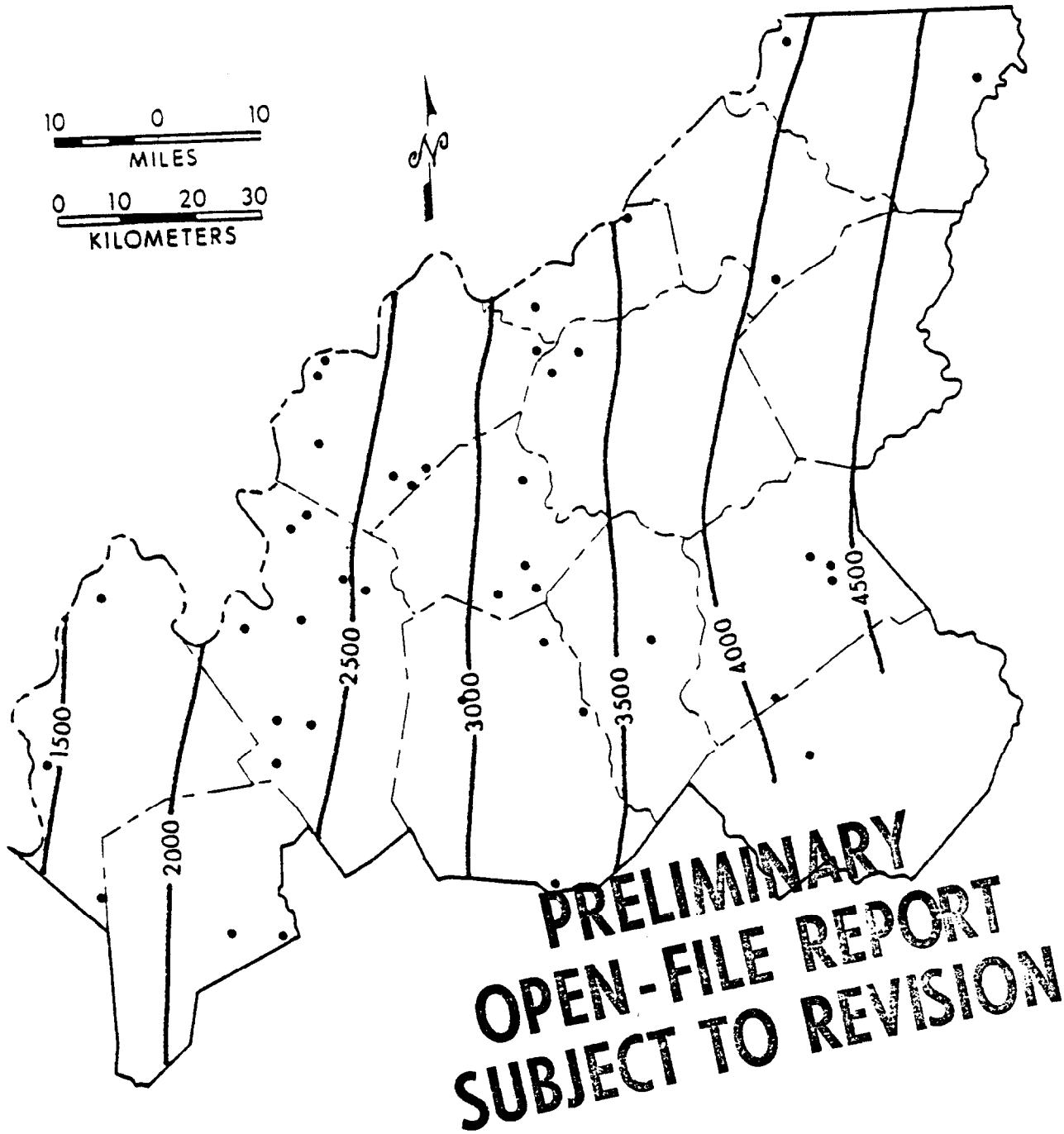

Figure 3. Isopach map of the Middle and Upper Devonian clastic sequence in northwestern West Virginia. Contour interval is 500 feet.

but the lack of adequate marker beds in the upper part of the sequence made correlation difficult. Drillers' logs, published sample studies, and cores were used to supplement the gamma-ray logs. Approximately 250 drillers' logs were used in the western portion of the study area. Logs of wells drilled with cable tools tend to be more reliable than logs of wells drilled with rotary tools. Twenty sample studies by Martens (1939, 1945) were used in the study. Although many more sample studies have been published, they are not useful for this interval because the Devonian shale section was either not described or was lumped as 3,000 feet of undivided dark-gray to black shale. Under the auspices of the Eastern Gas Shales project four cores were recovered from the shale in the study area. The Jackson 1063 and Jackson 1172 cores (numbers are state permit numbers) are from the upper part of the shale section, and although I did not examine these cores personally they have been described in several publications of the Eastern Gas Shales Project. I examined the core from Mason 146 which is the most complete section of core obtained. The Wetzel 645 core is from the lower part of the section, and I described it in detail (Appendix 1). I also examined cuttings from a cable tool well, Wood 72 (Appendix 2), but did not continue sample studies because they did not appear to supply any new data. The location of the well control within the study area (Plate 1) illustrates the poor distribution of the data. The maximum amount of data is along a producing trend of the Lower Devonian Oriskany Sandstone in Jackson and Wood County. Of the 82 logs used in the study, 48 were from the central portion of Jackson County.

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Previous Work

Until recently the subsurface stratigraphy of the Devonian clastic sequence in West Virginia had not been studied in detail. Tucker (1936) published an isopach map of the Devonian shale in his report on deep wells drilled in the state. Woodward (1943) compiled information from county reports and from his own work into a single volume on the Devonian of West Virginia. In discussing the subsurface occurrence of the Devonian shale, he states:

> "...the thick clastic or terrestrial deposits of the late Devonian thin westward and pass into marine sandstones and shales; these grow more shaly to the west, and ultimately are displaced by thin black shales. (p. 529)"

Schwietering (1970) worked from outcrops in Ohio into the subsurface of West Virginia, and his study provided the basic framework for the stratigraphy used in this report. The United States Geological Survey has published a number of preliminary cross sections for the basin in conjunction with the Eastern Gas Shales Project (Wallace and others, 1977, 1978; Roen and others, 1978; and West, 1978). Other recent papers dealing the Devonian clastic sequence include: Patchen and Larese (1976), Martin and Nuckols (1976), Patchen (1977a), Harris, deWitt and Colton (1978) and the proceedings volumes for the Eastern Gas Shales Project's annual symposia (U.S. Department of Energy, 1978a, 1978b, 1980). In West Virginia, the most detailed stratigraphic study of the Devonian clastic sequence has been the work of Neal (1979) in southern West Virginia.

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STRATIGRAPHIC FRAMEWORK

The stratigraphy of the Middle and Upper Devonian clastic

sequence has been studied in surface exposures around the margin of the Appalachian basin for the past 150 years, and a variety of names have been used at different localities throughout the basin for the units of the Devonian clastic sequence (Figure 4). The stratigraphic framework used in this report (Figure 5) is based on correlations to surface exposures in Ohio and New York and follows the nomenclature adopted for southern West Virginia by Neal (1979).

In New York, Devonian rocks are exposed across the basin roughly parallel to depositional dip. The cyclic nature of the rocks of the Devonian clastic sequence in the Appalachian basin was first recognized in this area (Pepper, deWitt and Colton, 1956). Each cycle consists of a basal black shale overlain by gray shale, green shale and siltstone. The base of each cycle is thought to represent a time line and each cycle is considered to be broadly time-equivalent (see Pepper, deWitt and Colton, 1956; Colton and deWitt, 1956; and deWitt and Colton, 1978). Formation boundaries coincide with cycle boundaries which can be traced laterally in western New York. To the east, the cyclic nature of these units is not preserved as facies change and coarser clastics predominate in the section. In addition to the clastic deposits, limestones are present in the Hamilton Group in New York, and the Tully Limestone separates the Genesee Formation from the Hamilton Group. An unconformity is present beneath the Tully Limestone in central New York and increasing amounts of section are missing at the position of the unconformity to the west and southwest (Figure 5).

In the eastern outcrops of New York, Pennsylvania and West Virginia, formations are defined by lithology, but contacts are

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OHIO	VIRGINIA	PENNSYLVANIA / WEST VIRGINIA	NEW YORK		
BEREA SANDSTONE	POCONO FORMATION	POCONO FORMATION		MISSISSIPPIAN	
BEDFORD SHALE	HAMPSHIRE FORMATION	HAMPSHIRE FORMATION	CONEWANGO GROUP	DEVONIAN	UPPER
OHIO SHALE: CLEVELAND MEMBER					
OHIO SHALE: CHAGRIN SHALE	CHEMUNG FORMATION	CHEMUNG FORMATION	CONNEAUT GROUP		
OHIO SHALE: HURON MEMBER			CANADAWAY GROUP		
UPPER OLENTANGY SHALE	BRALLIER FORMATION	BRALLIER FORMATION	JAVA FORMATION		
			WEST FALLS FORMATION		
			SONYEA FORMATION		
	MILLBORO SHALE	HARPER SHALE	GENESEE FORMATION		
LOWER OLENTANGY SHALE		TULLY LIMESTONE	TULLY LIMESTONE		MIDDLE
		MAHANTANGO FORMATION	MOSCOW FORMATION		
			LUDLOWVILLE FORMATION		
			SKANEATELES FORMATION		
DELAWARE LIMESTONE		MARCELLUS SHALE	MARCELLUS SHALE		
COLUMBUS LIMESTONE	ONONDAGA LIMESTONE / HUNTERSVILLE CHERT / NEEDMORE SHALE /	ONONDAGA LIMESTONE / HUNTERSVILLE CHERT / NEEDMORE SHALE /	ONONDAGA LIMESTONE		

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Figure 4. Stratigraphic nomenclature of Middle and Upper Devonian rocks in the Appalachian basin.

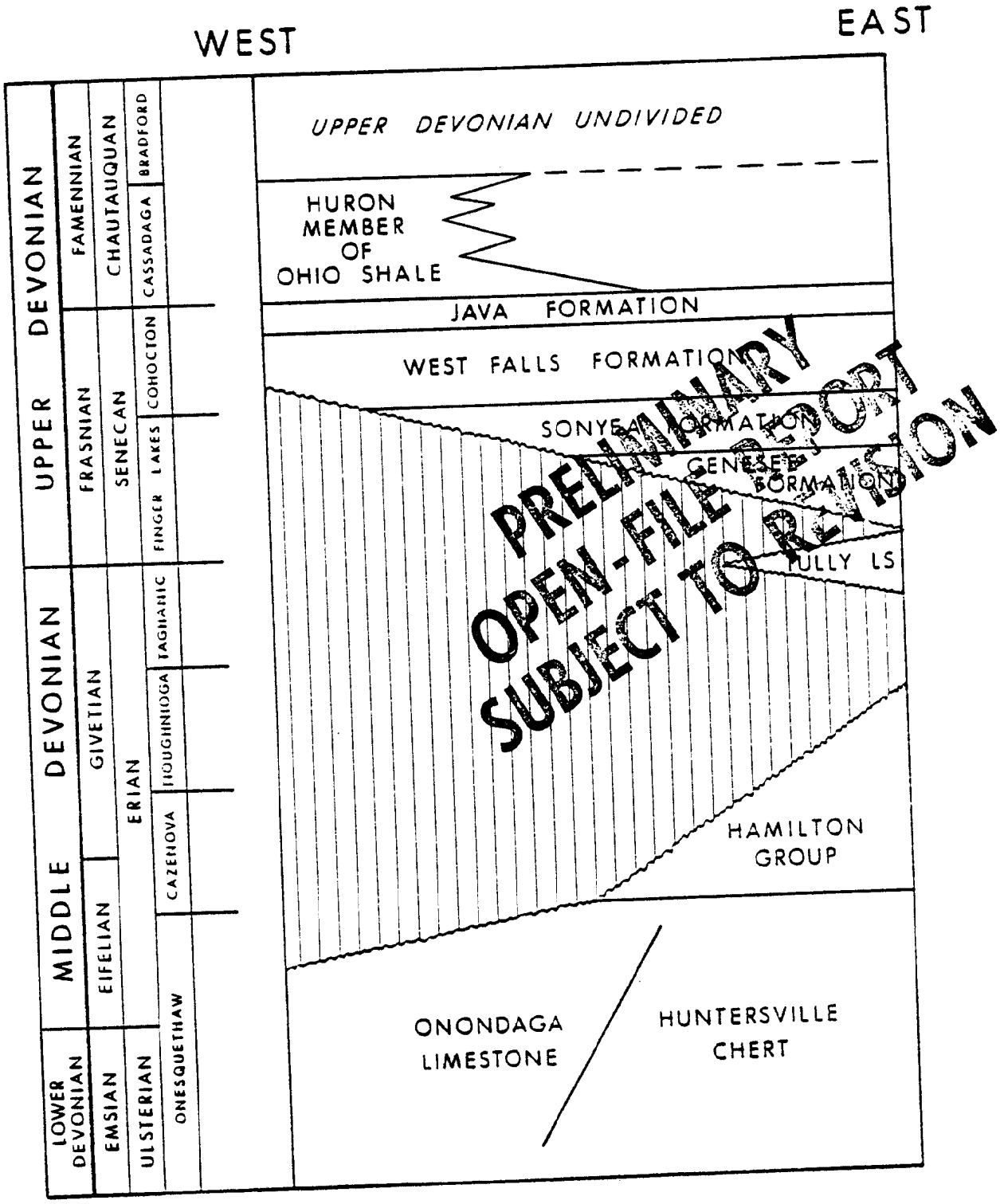

Figure 5. Stratigraphic nomenclature of the Middle and Upper Devonian clastic sequence in northwestern West Virginia.

frequently transitional and adjacent units interfinger. In eastern West Virginia, the Hamilton Group is subdivided into the Marcellus Shale, a black shale, and the Mahantango Formation, which is composed of dark-gray to gray shale and siltstone. The Hamilton is overlain by the Tully Limestone, an argillaceous limestone, which is overlain by the Harrell Shale. The Harrell Shale is composed of olive-gray shale with the black Burket Shale at the base, and is overlain by green to brown shale interbedded with thin, fine-grained sandstone, making up the Brallier Formation. Overlying the Brallier Formation is the Chemung Formation, which contains marine shale and siltstone with more sandstone than the Brallier Formation. The latest Devonian Hampshire Formation is composed largely of non-marine sandstone and shale.

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In Ohio, the Middle and Upper Devonian clastic sequence is composed mainly of black and gray shale. The basal Olentangy Shale is gray in color and is overlain by the black Ohio Shale. The Ohio Shale has two members, the Huron Member and the Cleveland Member which are separated by gray-green shale and siltstone of the Chagrain Shale.

The development of a useful stratigraphic framework in the subsurface of western West Virginia has only recently been accomplished. Lithologies change across the study area from gray shale and siltstone in the east to gray and black shale in the west. Early workers in West Virginia tried to apply eastern outcrop stratigraphy to the subsurface with little success. Martens (1939) suggested that in the subsurface the general term Devonian shale should be used for the Devonian sequence between the Huntersville Chert and the Berea

Sandstone, because satisfactory criteria were not available to subdivide the interval. He also noted that the amount of sandy material decreases and the color of the shale darkens down-section. In a paper on the central Appalachian basin, Lafferty (1941) did not discuss the Devonian shale; however, his sections across the basin showed three zones of dark shale in the west and illustrate the interfingering of the dark shale with coarser clastics to the east. Other workers in the study area followed Martens' suggestion and lumped the whole interval as Devonian shale (Woodward, 1943; Haught, 1955a, 1955b; and Overbey, 1961).

Schwietering (1970), using wire line logs supplemented with lithologic and paleontologic data, worked from surface sections in Ohio into the subsurface and was able to subdivide the Devonian shale sequence in West Virginia using stratigraphic units from Ohio outcrops. He also demonstrated the equivalence of stratigraphic units in Ohio and New York. Neal (1979) recognized cycles in southern West Virginia similar to those in western New York and was able to show that they are correlative with units in western New York by correlating units around the western margin of the basin. Neal's subsurface stratigraphy for southern West Virginia is based on New York nomenclature in the lower part of the sequence and Ohio nomenclature in the upper part of the sequence. In southern West Virginia, and in the study area, cycles with a basal black shale overlain by gray shale and small amounts of intercalated siltstone can be correlated with the Hamilton Group and the Genesee, Sonyea, West Falls and Java Formations in New York. The basal Dunkirk Shale Member of the Perrysburg Formation can

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be correlated with the basal part of the Ohio Shale in north-central Ohio (Schwietering, 1970); above this unit the Ohio terminology has been adopted for use in West Virginia because post-Dunkirk units of New York cannot be recognized in West Virginia. Individual stratigraphic units are easily recognized in the western part of the study area but change facies to coarser-grained rocks with lower concentrations of organic matter in the eastern part of the study area. Where the black shale units are not present, I did not attempt to subdivide the section.

Nomenclature from the eastern outcrop belt can not be applied in the subsurface because of pronounced facies changes, transitional formation boundaries and the lack of recognizable key beds. Woodward (1943, 1959) applied outcrop terminology to the section in some wells but believed that only generalized determinations could be made and that "beyondthese approximations it is unwise to proceed (1959, p. 17)." A cross section illustrating the relationship between the eastern and western facies (Figure 6) shows that there is not a direct correlation between units in the east and west. The eastern facies correlations are based on units recognized on the gamma-ray log for Lewis 1864 (Patchen, 1977b) and tops of units from sample studies for Doddridge 71 (Woodward, 1943) and Wood 351 (Woodward, 1959). Western facies correlations were determined from gamma-ray logs, drillers' logs, and sample studies from the same wells. If the base of the black shale units are assumed to represent time lines, the cross section shows the migration westward of coarser clastics with time.

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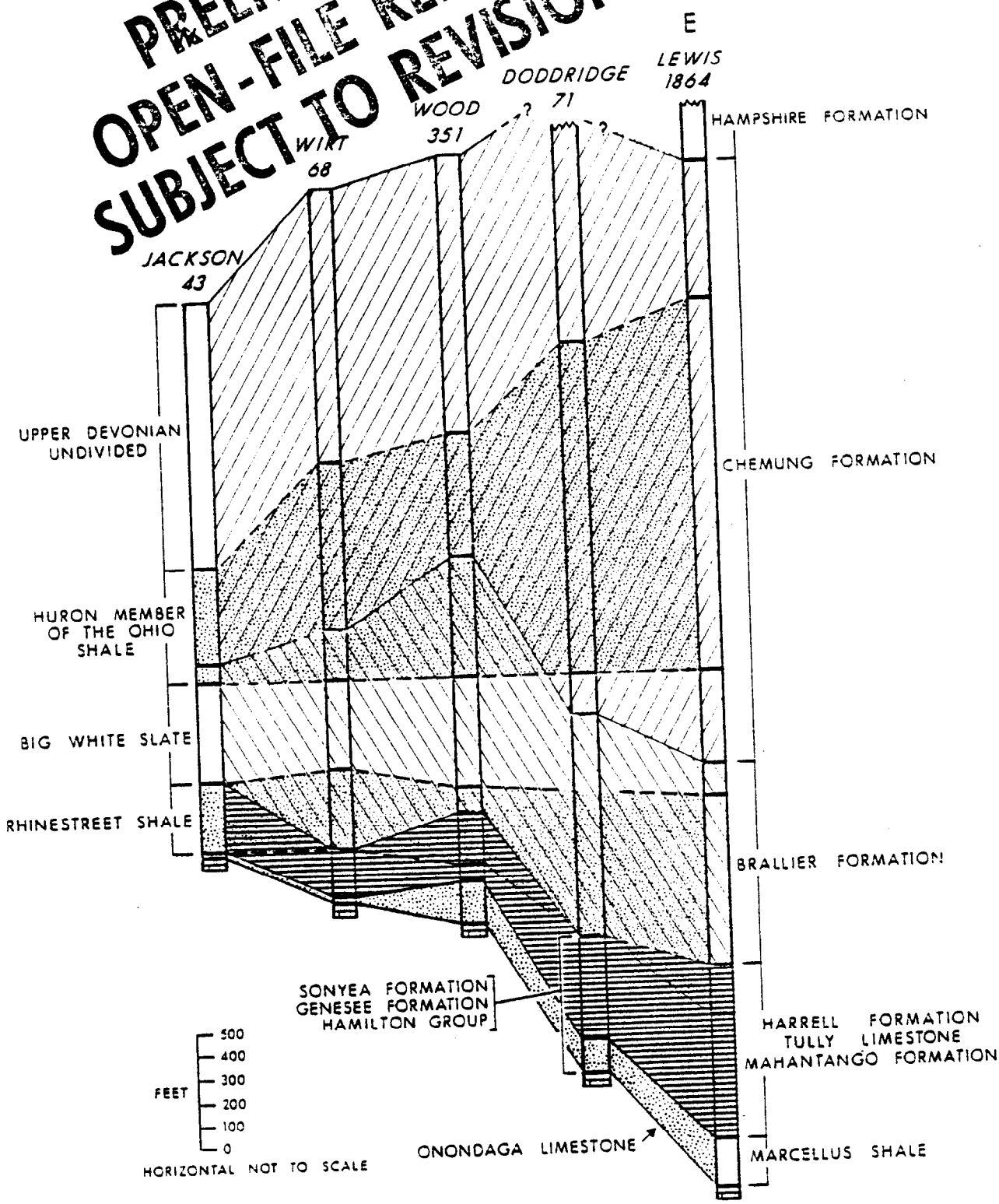

Figure 6. Relation of eastern and western facies nomenclature.

Three-gamma ray log cross sections were constructed in the study area (Figure 7). Cross section A-A' (Plate 2) trends east-west and approximates a dip section through the area. Cross section B-B' (Plate 3) trends northeast-southwest, generally parallel to the western margin of the Rome Trough and the strike of the basin. Cross section C-C' (Plate 4) is a north-south line along the Burning Springs Anticline and connects the midpoints of cross section A-A' and B-B'. The datum for the cross sections is the base of the Ohio Shale because it is easily recognized in both well logs and drill cuttings. The selection of a datum in the middle of the section tends to counter-balance the rapid thickening of the section to the east and makes correlation lines appear more reasonable.

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A gamma-ray log is a measure of emissions from the radio-active minerals uranium, thorium, and potassium. Leventhal and Goldhaber (1978) found that cores from West Virginia showed marked changes in uranium content unattended by visible changes in lithology; however, the uranium content did correlate with organic carbon content. Although in other parts of the basin the uranium content may correlate with shale color (Leventhal and Goldhaber, 1978; West Virginia Geological and Economic Survey, 1978), in the study area, the high-radioactive zones may not correlate with specific color of the rock, but only iwth organic content. Conversely, low gamma-ray response can be correlated with sandstone, siltstone or limestone units having lower radioactive content that shale.

Cross section A-A' illustrates the cyclic nature of the units with a basal high-radioactive zone overlain by less radioactive units.

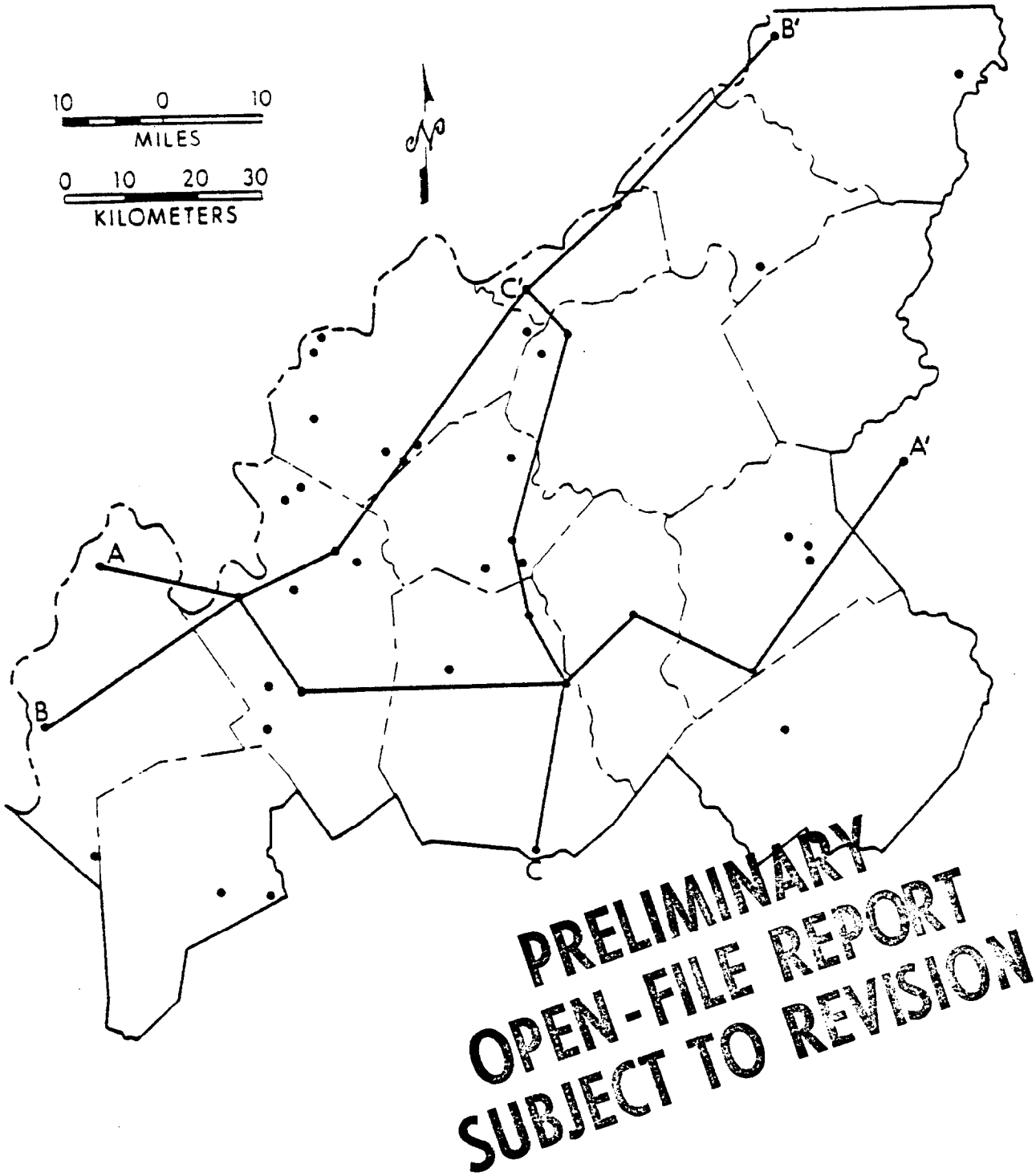

Figure 7. Location of gamma-ray cross sections.

In the lower part of the section the high-radioactive units are present throughout the study area. Higher in the section the units lose their radioactive character in the middle of the study area.

In New York, an unconformity has long been recognized between the Tully Limestone and the Hamilton Group. Rickard (1975) suggested that a disconformity may be present between the Genesee Formation and the Tully Limestone near the western margin of the Tully Limestone. To the west, where the Tully is absent, only one unconformable surface is present. Schwietering (1970) recognized this unconformity in the Olentangy Shale of Ohio and traced the unconformity into the subsurface of West Virginia. The unconformity is recognized in the study area, where progressively older units are absent under the unconformity and successively younger units onlap the unconformity to the west and south (Figure 5, Plates 2, 3 and 4).

The Middle and Upper Devonian clastic sequence is underlain by cherty limestone and chert of the Onesquethaw Stage. Where the underlying rock is composed of more than 50% chert, it is the Huntersville Chert; otherwise it is the Onondaga Limestone, although both names have been used extensively and often interchangeably. East of the study area the Onesquethaw Stage is composed of calcareous shale of the Needmore Formation. Figure 8, after Dennison (1961), illustrates the distribution of facies underlying the clastic sequence in the study area. By definition, the top of the Onesquethaw Stage is marked by the Tioga Bentonite according to Dennison and Textoris (1978), who noted that the bentonite can be recognized by a characteristic gamma-ray peak. Flowers (1952) summarized the occurrence of

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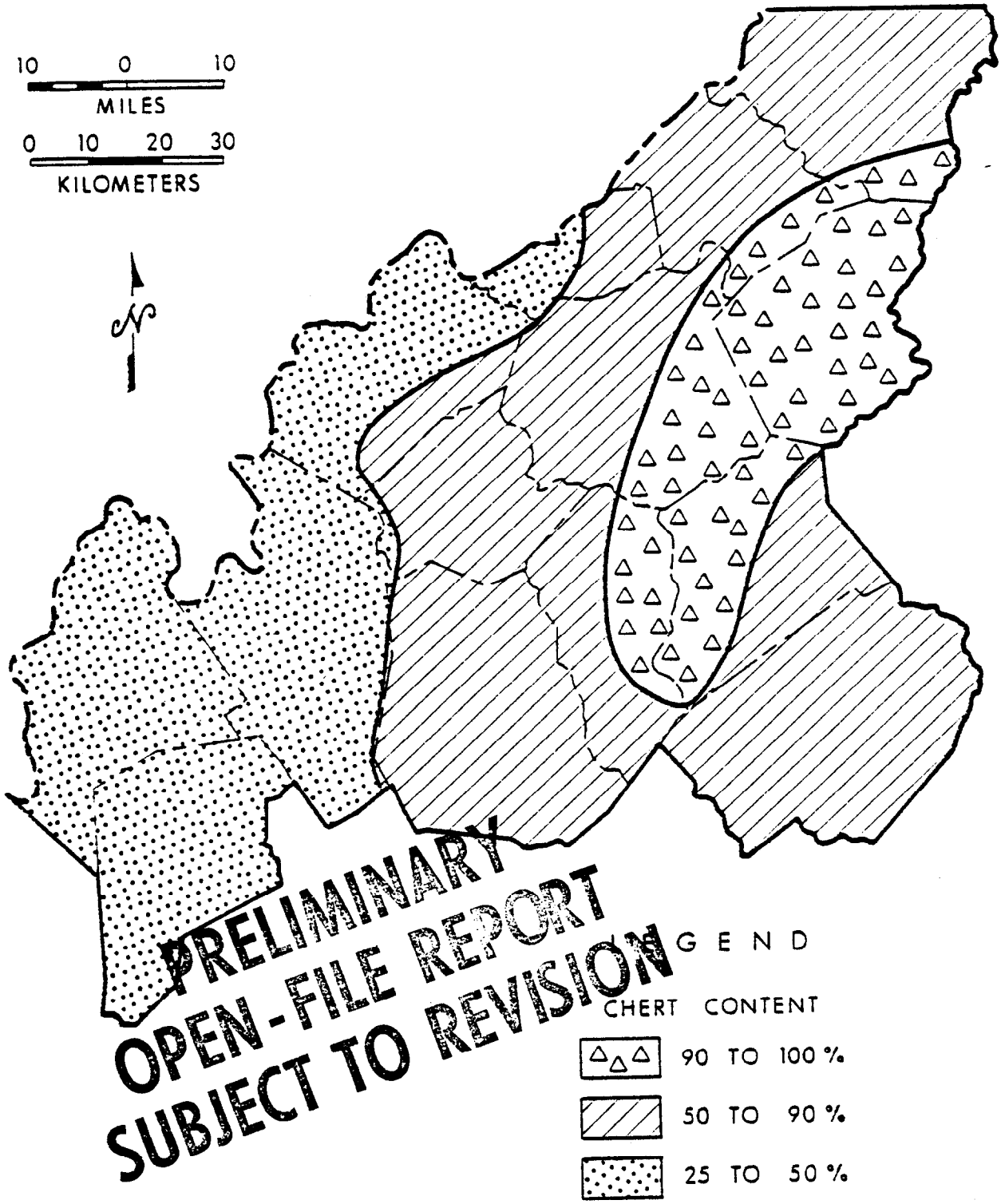

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Figure 8. Facies of the Onesquethaw Stage in northwestern West Virginia, from Dennison (1961).

bentonite at the top of the Huntersville Chert from well sample studies in West Virginia. Several beds of bentonite may be present, and at least two have been recognized in eastern Ohio (Collins, 1979). A bentonite recovered from a core in Lincoln County, West Virginia is early Late Devonian in age (Duffield, 1978) and may correlate with the Frasnian age Center Hill Bentonite of Tennessee. Flowers (1952) noted that the abundance and character of the biotite in bentonite from well samples taken in western West Virginia was similar to an Upper Devonian bentonite from Tennessee. Bentonite is present at the top of the Onondaga Limestone in the study area, but a definite age has not been established for it and the bentonite may be younger than the Tioga. The base of the section is characterized by a very high radioactive peak throughout the study area except in western Mason County. The persistent character of this peak, independent of the immediately superjacent lithology, suggests that it may be a bentonite zone or an erosional remnant of material rich in organic matter associated with the unconformity on the top of the Onondaga.

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The Middle and Upper Devonian clastic sequence is overlain by the Berea Sandstone in western West Virginia. Locally the Bedford Shale may also be present (Pepper, deWitt and Demarest, 1954). The Sunbury Shale overlies the Berea Sandstone, and its higher radioactive response makes an excellent marker even where the Berea is thin or absent. To the east the Sunbury Shale is not present except capping channels of the Berea Sandstone (Figure 9). Where the Sunbury Shale and Berea Sandstone are absent, the top of the Devonian is not readily apparent. In this region, logs were correlated from the base of the Greenbrier Limestone to pick the top of the Devonian.

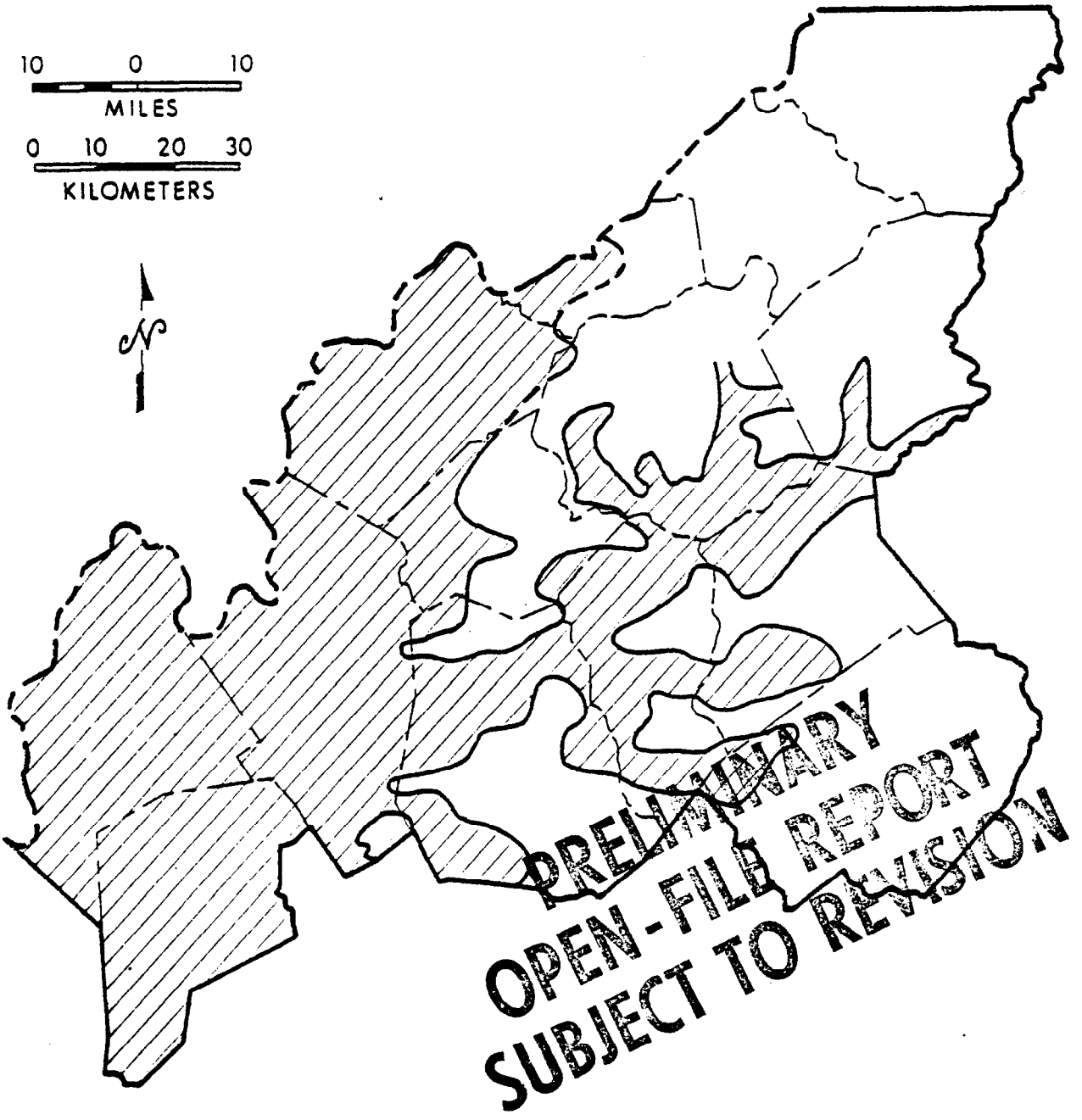

Figure 9. Distribution of the Berea Sandstone in northwestern West Virginia, from Larese (1974).

DESCRIPTIVE STRATIGRAPHY

Hamilton Group

The Hamilton Group of Middle Devonian age was named by Vanuxem (1840) for shale outcropping in the vicinity of Hamilton Village, Madison County, New York. In New York, four formations are included in the Hamilton Group: the basal Marcellus Shale, the Skaneateles Formation, the Ludlowville Formation, and the Moscow Formation (Rickard, 1975). To the south in Pennsylvania, the formations overlying the Marcellus Shale cannot be distinguished, and Willard (1935) proposed the name Mahantango Formation for the shale, siltstone, and sandstone of the Hamilton Group above the Marcellus Shale in Pennsylvania.

In the study area, the Marcellus Shale and the Mahantango Formation are recognized. The Marcellus Shale rests on the Huntersville Chert and the Mahantango Formation is overlain by the Tully Limestone or the Genesee Formation. The Marcellus Shale is composed of calcareous, black, fissile shale, with occasional thin limestone beds and calcareous concretions. It is recognized on gamma-ray logs as a zone of high radioactivity and low density (Figure 10). The Mahantango Formation is composed of gray shale with a lower radioactive response and a higher density than the Marcellus Shale. The Hamilton Group has a maximum thickness of 150 feet in eastern Wetzel County and thins to the west. It is not present in the western half of the study area (Figure 11). The Marcellus Shale ranges in thickness from zero to more than 50 feet (Figure 12). The Mahantango Formation thickens from a zero edge in the middle of the study area to 100 feet in

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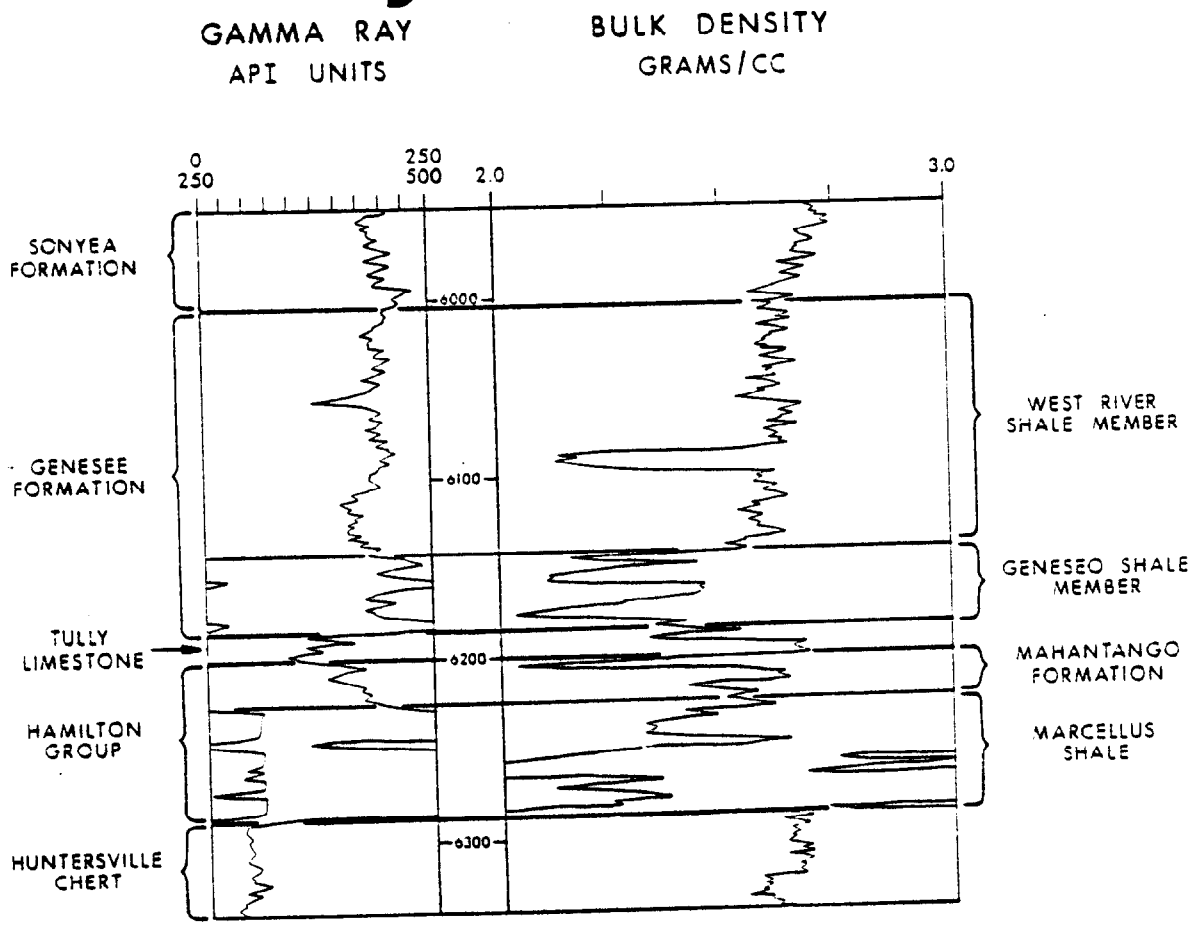

Figure 10. Typical gamma-ray log of the Hamilton Group, Tully Limestone, and Genesee Formation (Gilmer 2943).

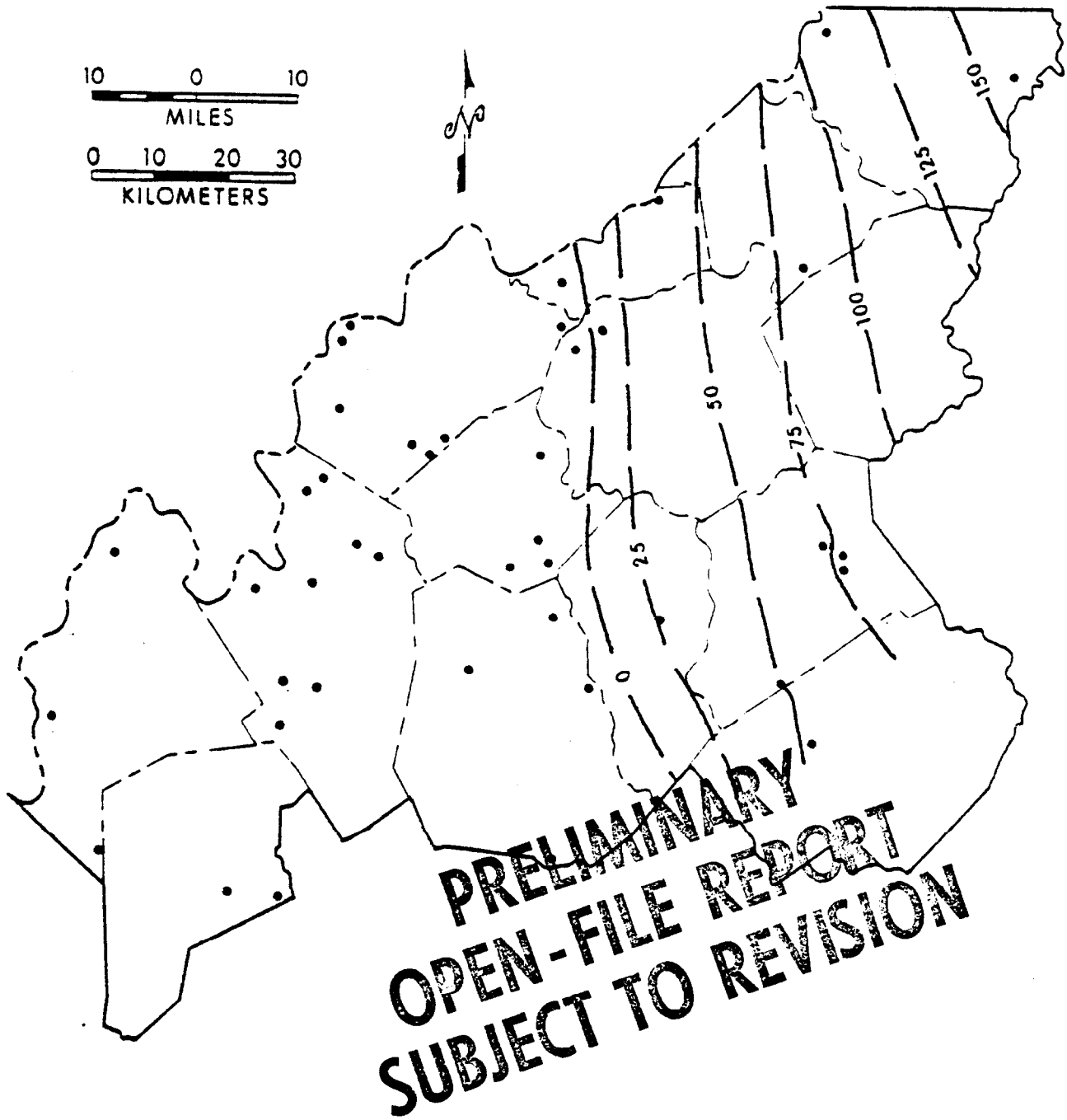

Figure 11. Isopach map of the Hamilton Group. Contour interval is 25 feet.

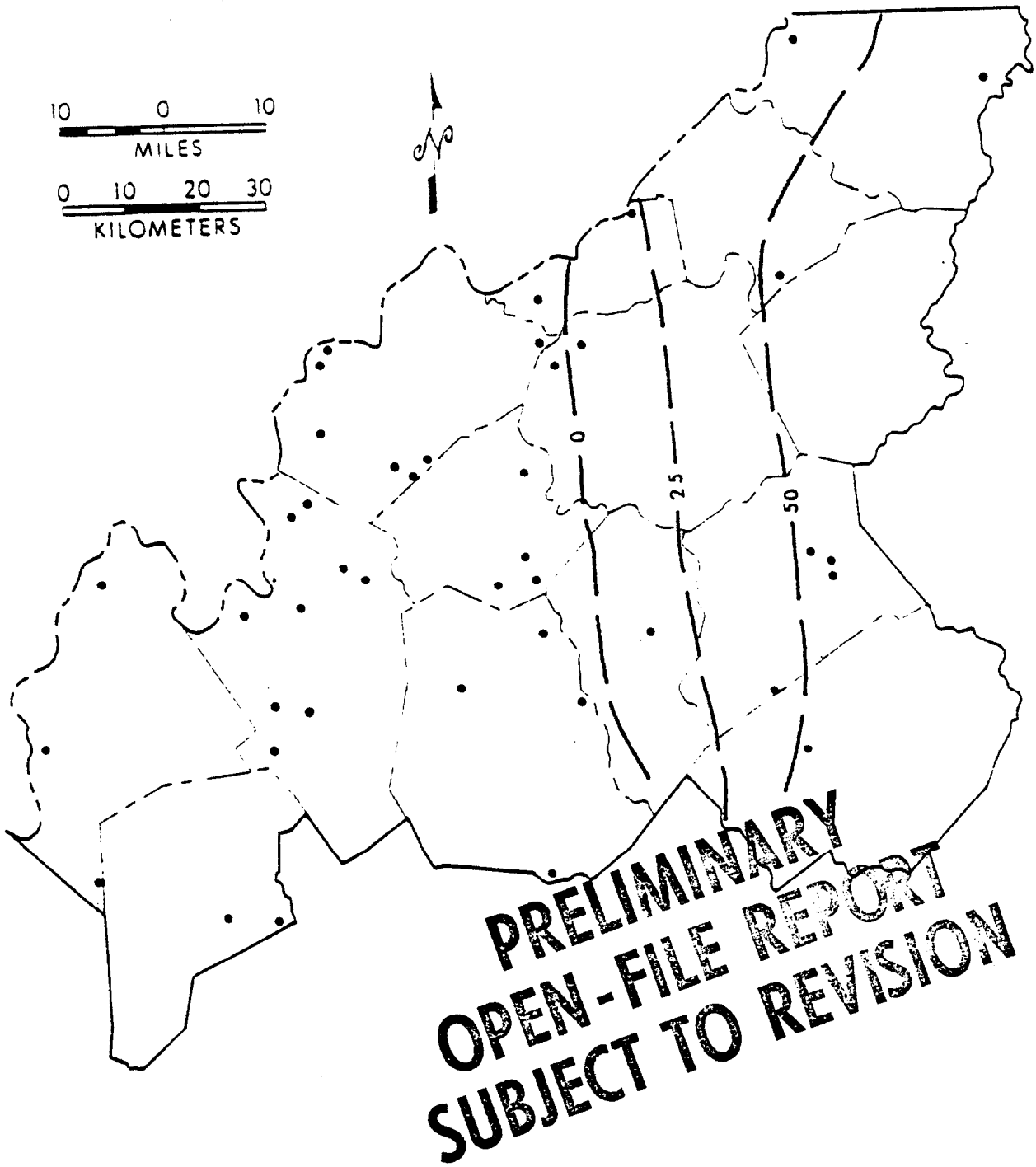

Figure 12. Isopach map of the Marcellus Shale. Contour interval is 25 feet.

Wetzel County (Figure 13).

Although I used all of the available control points in the eastern part of the study area for the isopach maps for the Hamilton Group, the control is poor and the isopach maps are very generalized. The Marcellus Shale shows a very regular change in thickness across the area. The Mahantango Formation is thickest in the northeastern part of the study area and thins to the south and west. The thinning to the south and west is the result of erosion of the Mahantango Formation prior to deposition of the Genesee Formation and perhaps the Tully Limestone. East of the study area, the Mahantango Formation thickens (Schwietering, Neal and Dowse, 1978). This thickening reflects deposition of the Mahantango Formation in a subsiding depocenter farther to the east.

Tully Limestone

The Tully Limestone was named for exposures near Tully, Onondaga County, New York by Vanuxem (1839). In New York the Tully Limestone is subdivided into an upper and lower unit with several named members and beds (Heckel, 1974).

Locally in West Virginia the Tully Limestone rests on the Mahantango Formation and underlies the Genesee Formation. It is composed of dark olive-green, shaly limestone and is recognized on gamma-ray logs by its very low radioactive response (Figure 10). The Tully has a maximum thickness of 20 feet along the eastern border of the study area and wedges out 10 to 25 miles to the west (Figure 14).

The correlation of the Tully Limestone in the subsurface of

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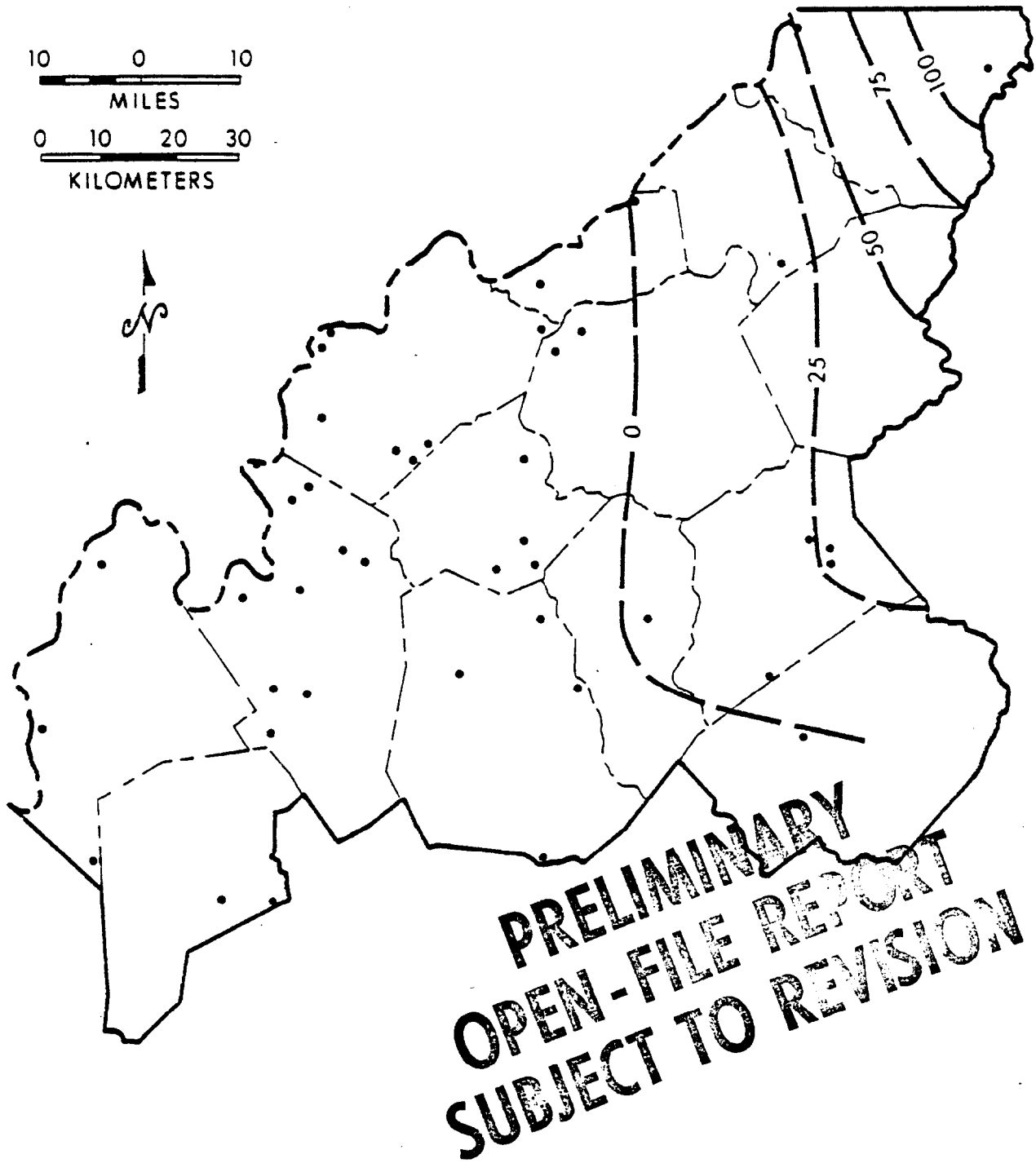

Figure 13. Isopach map of the Mahantango Formation. Contour interval is 25 feet.

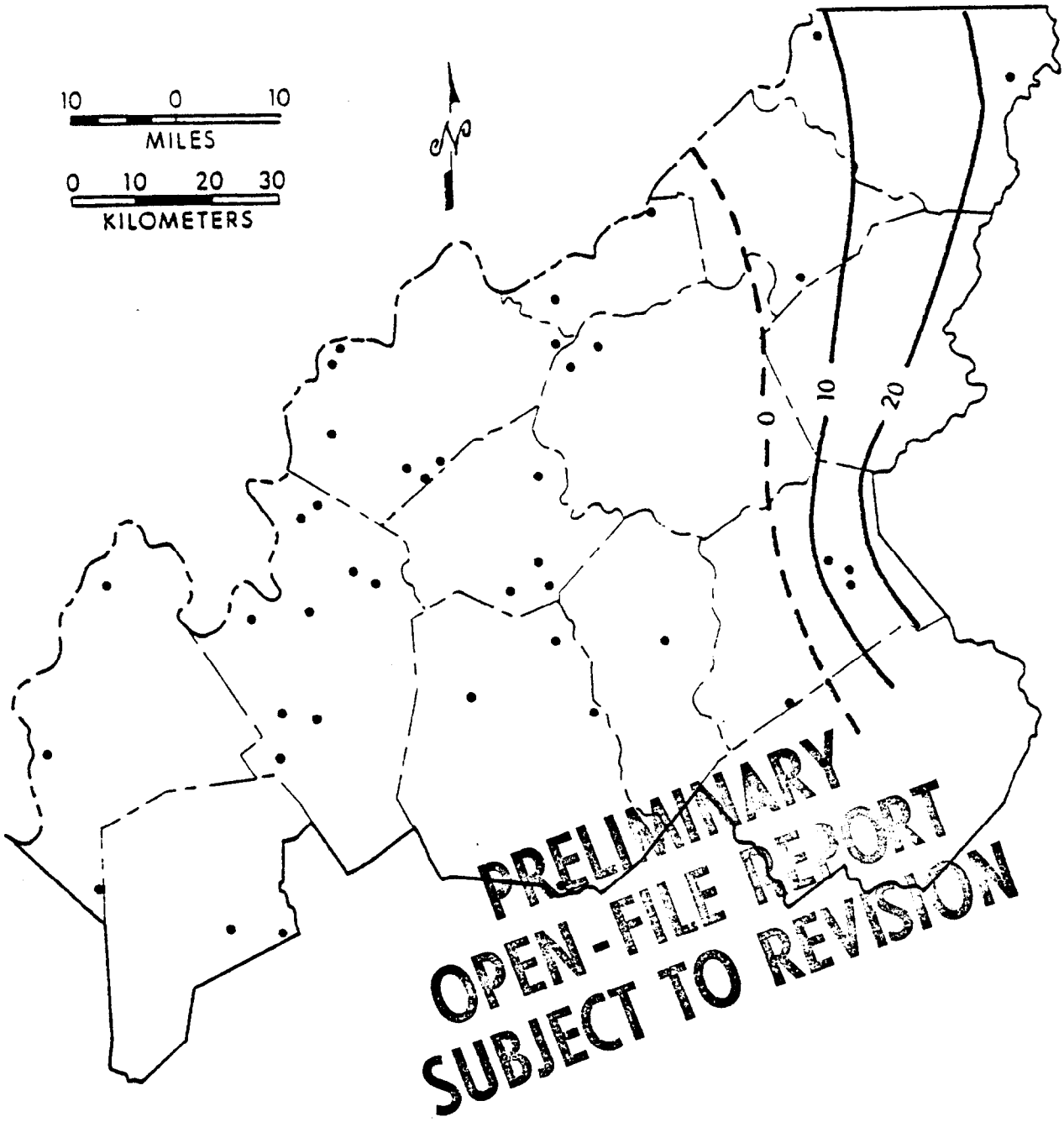

Figure 14. Isopach map of the Tully Limestone. Contour interval is 10 feet.

West Virginia with the Tully Limestone of New York is tentative. Heckel (1973) discussed the regional correlation of the Tully Limestone and suggested that the unit identified as Tully Limestone in the subsurface of West Virginia is correctly correlated. He cited faunal evidence from outcrops in West Virginia and thickness trends to support the correlation. This correlation also is supported by a gamma-ray log cross section from New York to West Virginia (West, 1978). Paleontologic evidence is necessary to confirm the correlation and the biostratigraphy of the lower part of the limestone recovered from the MERC 1 (Monongalia 370) core is presently under study (K. McCartney, personal communication, 1979). The complete limestone interval was cored in the Wetzel 645 well, but its biostratigraphy has not been studied.

In New York, the Tully Limestone rests disconformably on the Hamilton Group. Locally the upper boundary is transitional with the Genesee Formation east of Cayuga Lake, but to the west, the transitional beds are absent and the upper contact also is disconformable (Heckel, 1973). Heckel also recognized a disconformity between the upper and lower units of the Tully Limestone. Data on the boundary relationships of the Tully Limestone in the study area are limited, because the limestone is present only in six wells. The Tully Limestone was examined in the Wetzel 645 core, and at the upper contact there is a sharp change in color and lithology between the Tully Limestone and the overlying Genesee Formation (Appendix 1, 6511.9). Gamma-ray log cross sections presented by Schwietering, Neal and Dowse (1978),

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particularly B to B', suggest that the upper contact is disconformable. However, east of the study area the contact between the Tully Limestone and the Hamilton Group is conformable (Schwietering, Neal, and Dowse, 1978). In the Wetzel 645 core, a five-foot limestone bed is underlain by four feet of calcareous shale with thin interbedded limestone. If the base of the Tully Limestone is placed at the base of the limestone unit, then the lower contact appears gradational. However, the gamma-ray character suggests that the base of the formation is at the bottom of the calcareous shale unit, thus I included the calcareous shale and intercalated thin limestone beds in the Tully. The contact at the base of the calcareous shale unit is sharp. This interpretation is consistent with lithofacies maps presented by Heckel (1973) showing a facies change from limestone to calcareous shale to the south and west. Gamma-ray log correlation from Wetzel 645 to Tyler 427 suggests that the upper portion of the Mahantango Formation is absent below the Tully Limestone (Figure 15). The upper part of the Mahantango Formation also is missing between Lewis 1864 and Gilmer 3012. Preliminary results indicate that in the study area, both the upper and lower contacts of the Tully Limestone are disconformable.

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Genesee Formation

The Genesee Formation was named from exposures in the Genesee River Gorge of New York by Vanuxem (1842). In western New York, four members are recognized, in ascending order: the Geneseo Shale Member, composed of brown to black shale; the Penn Yan Shale, made up of light to dark-gray mudrock with scattered beds of brown to black

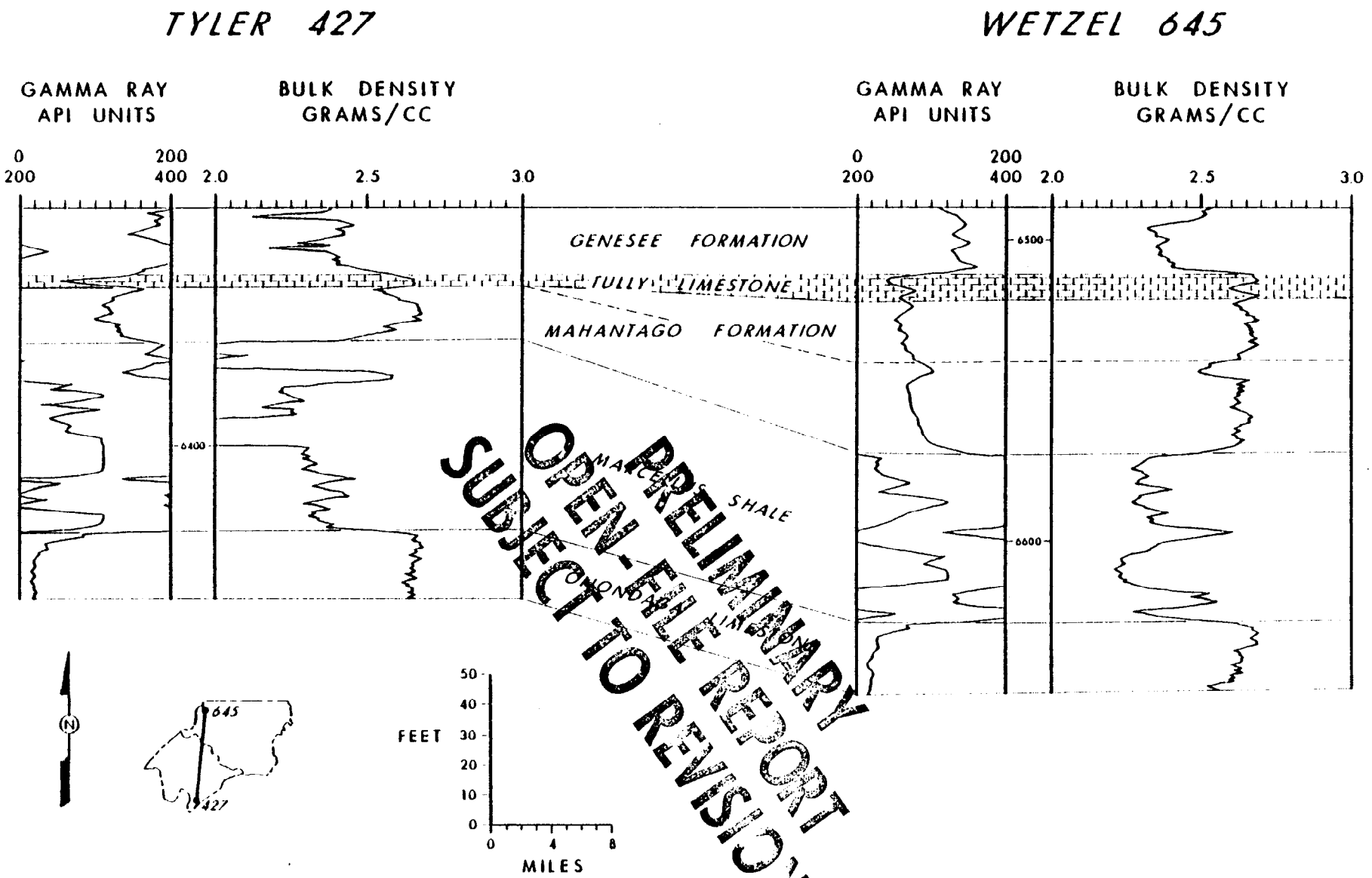

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Figure 15. Cross section from Tyler 427 to Wetzel 645 illustrating the thickening of the Mahantango Formation.

shale; the Genundewa Limesotne, composed of styliolinid limestone; and the West River Shale Member, a dark to medium light-gray shale and mudrock unit (deWitt and Colton, 1978).

In the study area, two units are recognized, a basal black shale member, tentatively correlated with the Geneseo Shale Member, and the West River Shale Member. The Geneseo Shale Member rests on the Tully Limestone in the eastern part of the study area and the Hamilton Group and the Onondaga Limestone to the west. The West River Shale Member is overlain by the Sonyea Formation. The Geneseo Shale Member is composed of dark gray to black shale and is recognized on gamma-ray logs by its higher radioactive intensity than adjacent units (Figure 10). The West River Shale Member is made up of lighter gray shale, and is recognized on the gamma-ray log by a lower radioactive intensity than the Geneseo Shale Member. The Genesee Formation ranges in thickness from zero to 180 feet (Figure 16). It is thickest in the eastern portion of the study area and onlaps the unconformity to the west. The Geneseo Shale Member ranges in thickness form zero to 40 feet (Figure 17) and the West River Shale Member ranges in thickness from zero to 130 feet in thickness (Figure 18).

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The basal black shale present in the Genesee Formation in the study area has not been definitively correlated with the Geneseo Shale Member in New York. It may be correlative with one of the dark shale tongues in the Penn Yan Shale Member. West (1978) worked on the eastern side of the basin and showed black shale of the Penn Yan pinching out in central Pennsylvania and extended the Geneseo Shale Member into West Virginia. A cross section across northern New York

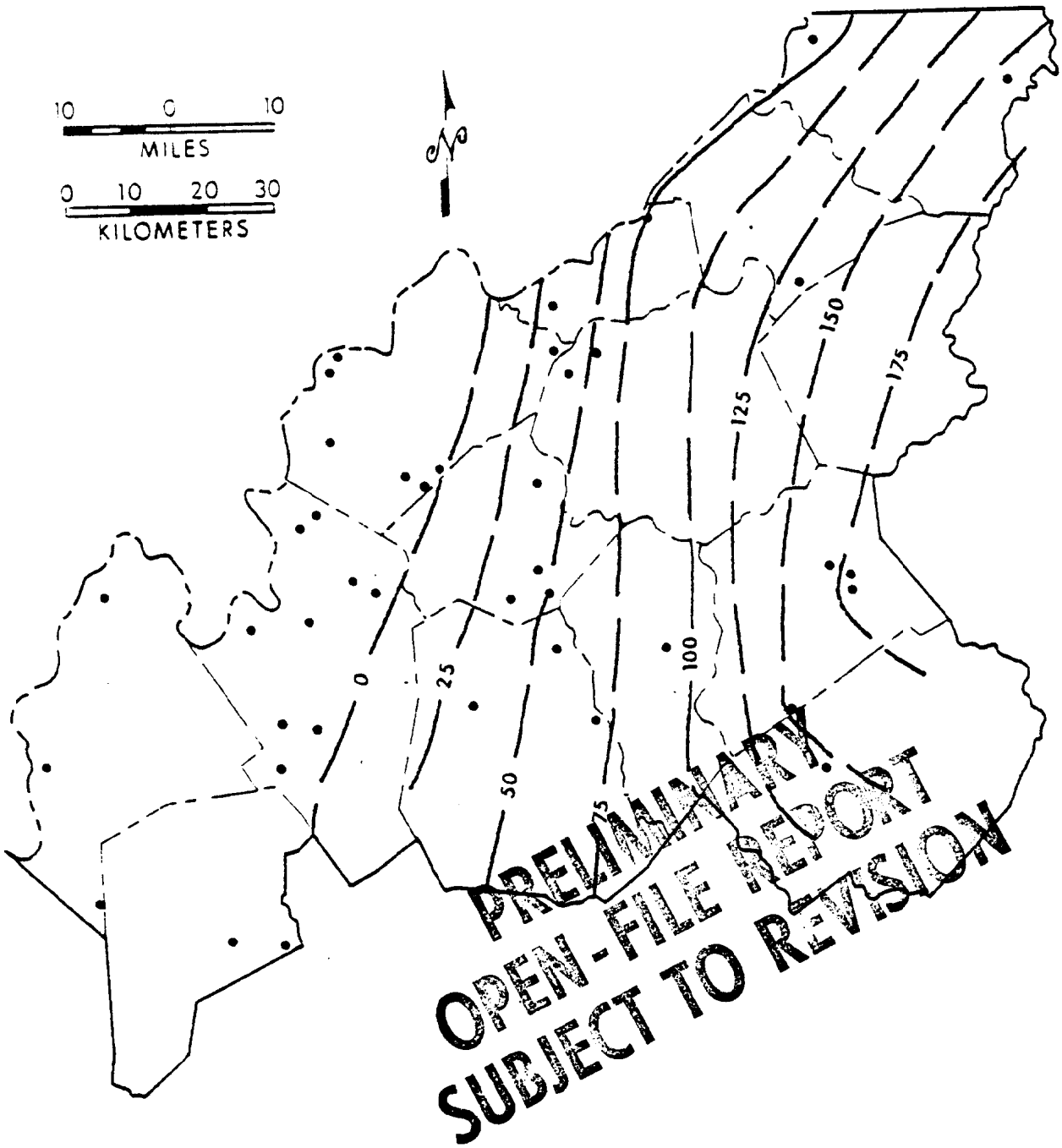

Figure 16. Isopach map of the Genesee Formation. Contour interval is 25 feet.

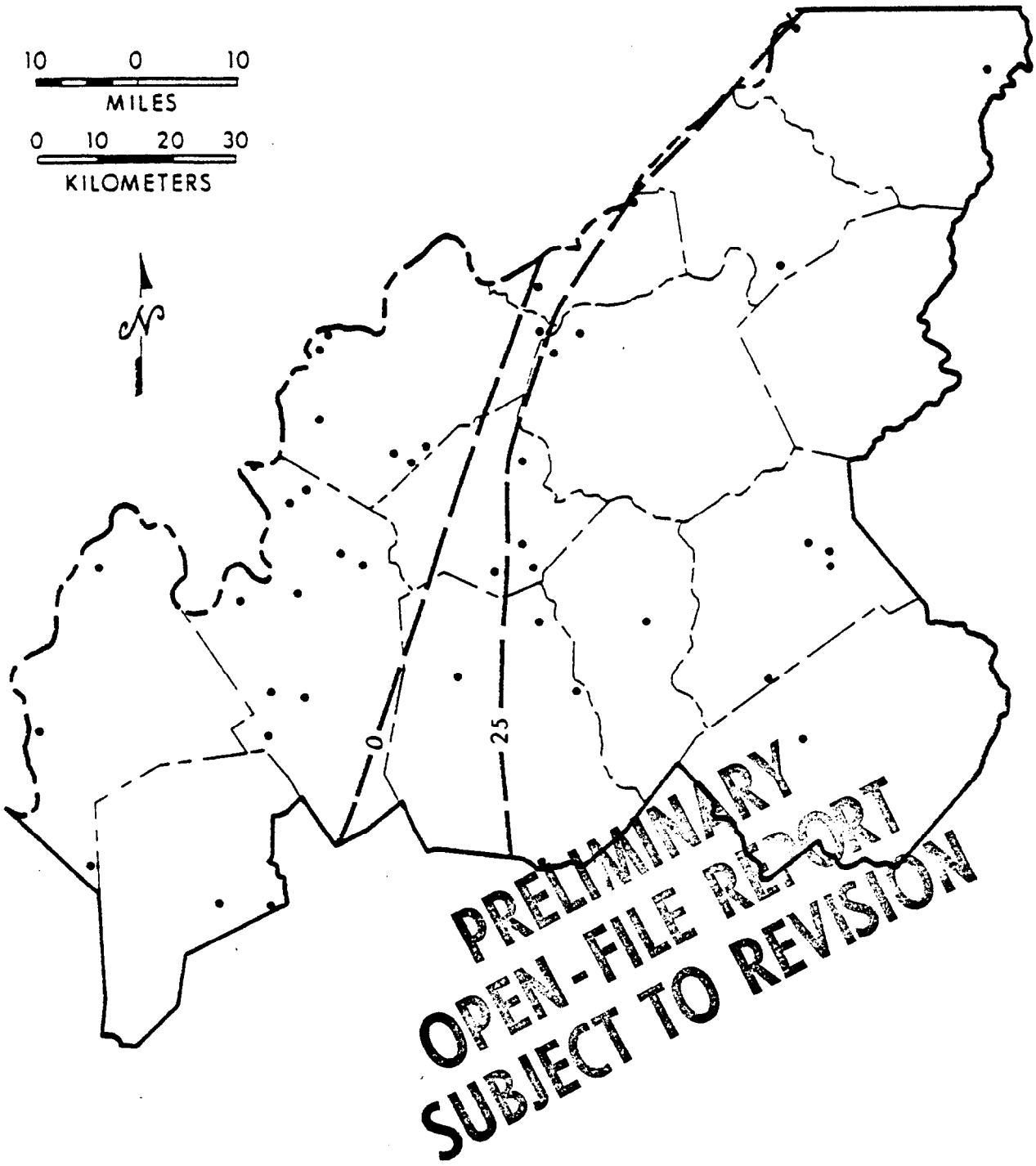

Figure 17. Isopach map of the Geneseo Shale. Contour interval is 25 feet.

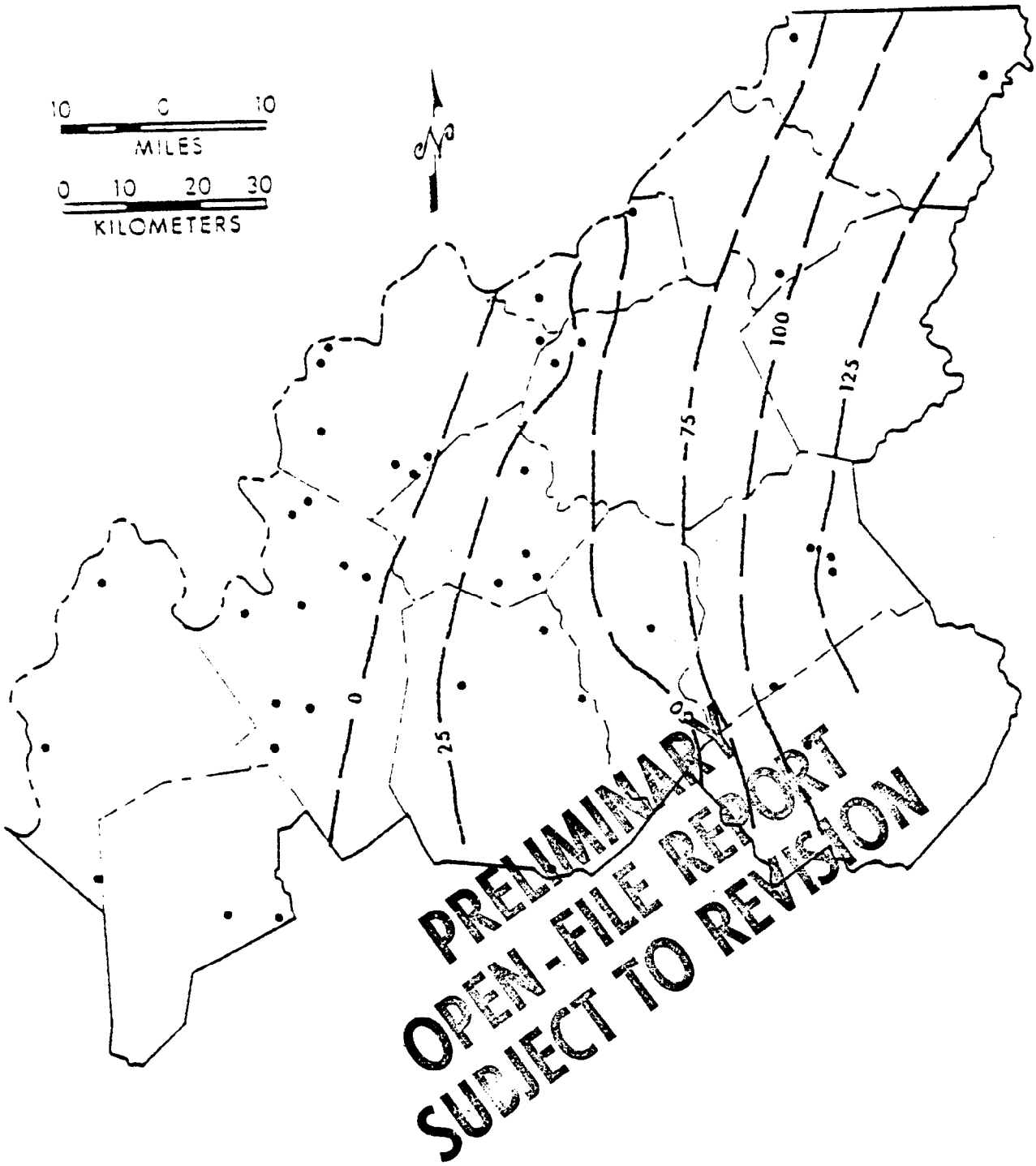

Figure 18. Isopach of the West River Shale. Contour interval is 25 feet.

and Ohio (Wallace, Roen, and deWitt, 1977) showed the Geneseo Shale Member pinching out and a black shale of the Penn Yan becoming the basal member of the Genesee Formation. A tie line across central Ohio and northern West Virginia (Roen, Wallace, and deWitt, 1978) identified the basal black shale as either Penn Yan or Geneseo. A cross section in central Pennsylvania (Piotrowski and Krajewski, 1977) showed the Renwick Shale in the Penn Yan Member onlapping the basal black shale of the Genesee Foramtion which they identify as Burket Shale. They show the Burket Shale extending to the west. The basal black shale of the Genesee Formation in the study area can be correlated with the Burket Shale Member of the Harrell Shale in the eastern outcrop belt and one solution to the nomenclatural problem would be to use the term Burket Shale for this unit in the subsurface. At present, I prefer to retain the name Geneseo Shale for the basal black shale unit until additional data become available to substantiate an alternative identification.

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Sonyea Formation

The type section of the Sonyea Formation is along Keshequa Creek, south of Sonyea, Livingston County, New York and was initially described by Chadwick (1933). In western New York, two members are present: the Middlesex Shale and the Cashaqua Shale. Two other members are recognized to the east: the Pulteney Shale Member and the Rockstream Siltstone Member (Colton and deWitt, 1958).

Two members are recognized in the study area, the Middlesex Shale Member and the Cashaqua Shale Member. The Middlesex Shale rests on the Genesee Formation in the eastern part of the study area and on the Onondaga Limestone in the western part of the area. The

Cashaqua Shale is overlain by the West Falls Formation. The Middlesex Shale Member is composed of black to dark-gray shale and is recognized on gamma-ray logs by its characteristic two pronged peak (Figure 19). It has a higher radioactive response than the adjacent units, but a much lower response than the Geneseo Shale Member of the Genesee Formation. The Cashaqua Shale Member is composed of dark-gray to gray shale and has a lower radioactive response. In the eastern part of the study area there is a slight increase in gamma-ray intensity in the middle of the Cashaqua Shale Member, although the character of the gamma-ray response does not change. The Sonyea Formation is absent in western Mason County, and gradually thickens from a zero edge in eastern Mason County to 100 feet in the central part of the study area, whereas farther to the east it rapidly thickens to 300 feet (Figure 20). The Middlesex Shale Member ranges in thickness from zero to 25 feet, with a slightly thicker sequence present in Roane and Wirt Counties (Figure 21). The Cashaqua Shale Member ranges in thickness from zero to 275 feet across the study area (Figure 22).

The westward change in the rate of thinning of the Sonyea Formation is the result of progressive onlap above the unconformity. The correlations in the western part of the area are complicated by the thinning of units and the increase in the amount of radioactive shale to the west. In Wood, Jackson, and Putnam Counties, the base of an extensive massive zone of black shale in the overlying Rhinestreet Shale Member of the West Falls Formation aids in correlating the bottom part of the section. Three zones can be recognized below the massive zone in the Rhinestreet Shale (Figure 23). The upper (basal Rhinestreet Shale) zone is characterized by an intermediate gamma-ray response with

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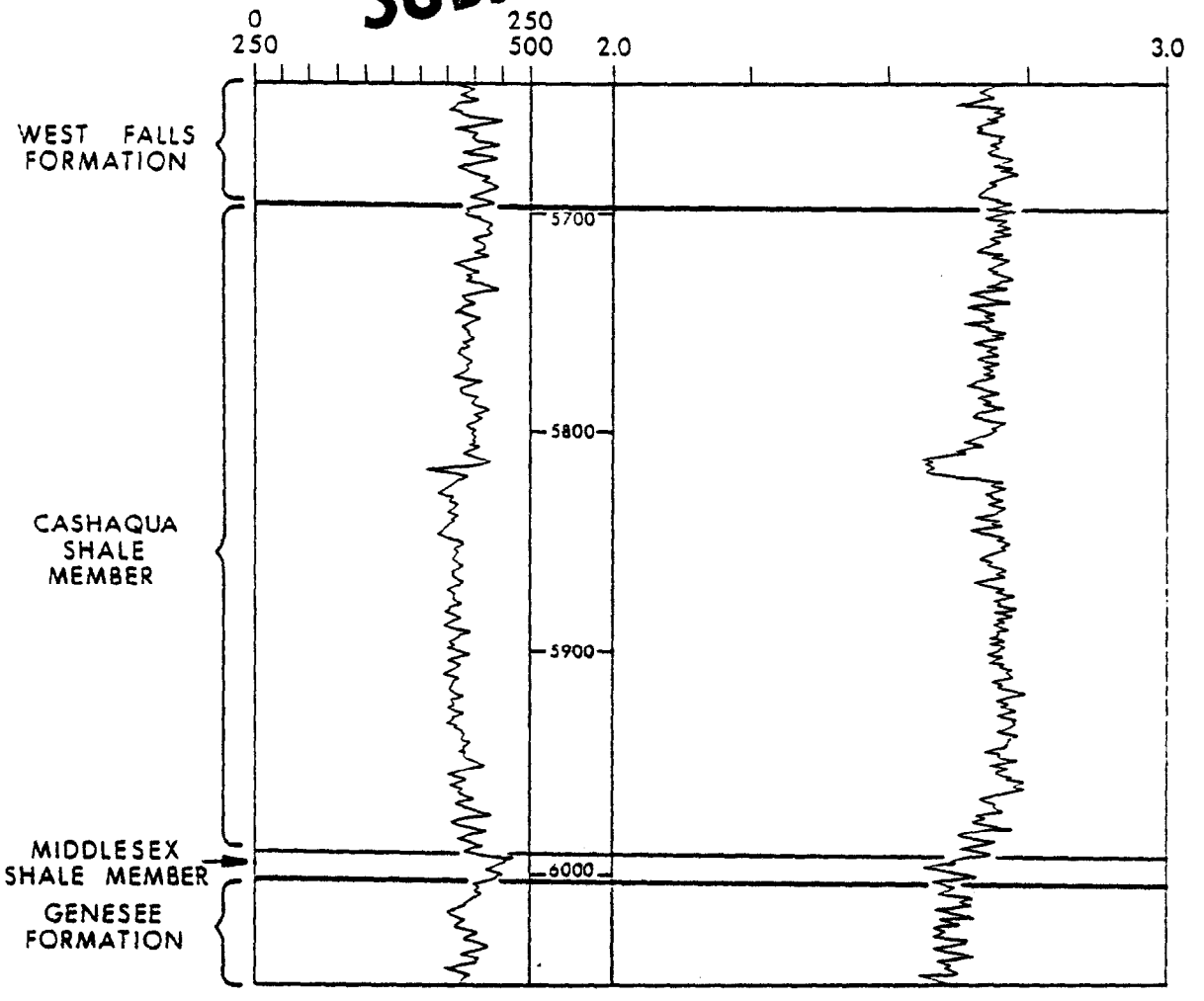

Figure 19. Typical gamma-ray log of the Sonyea Formation (Gilmer 2943).

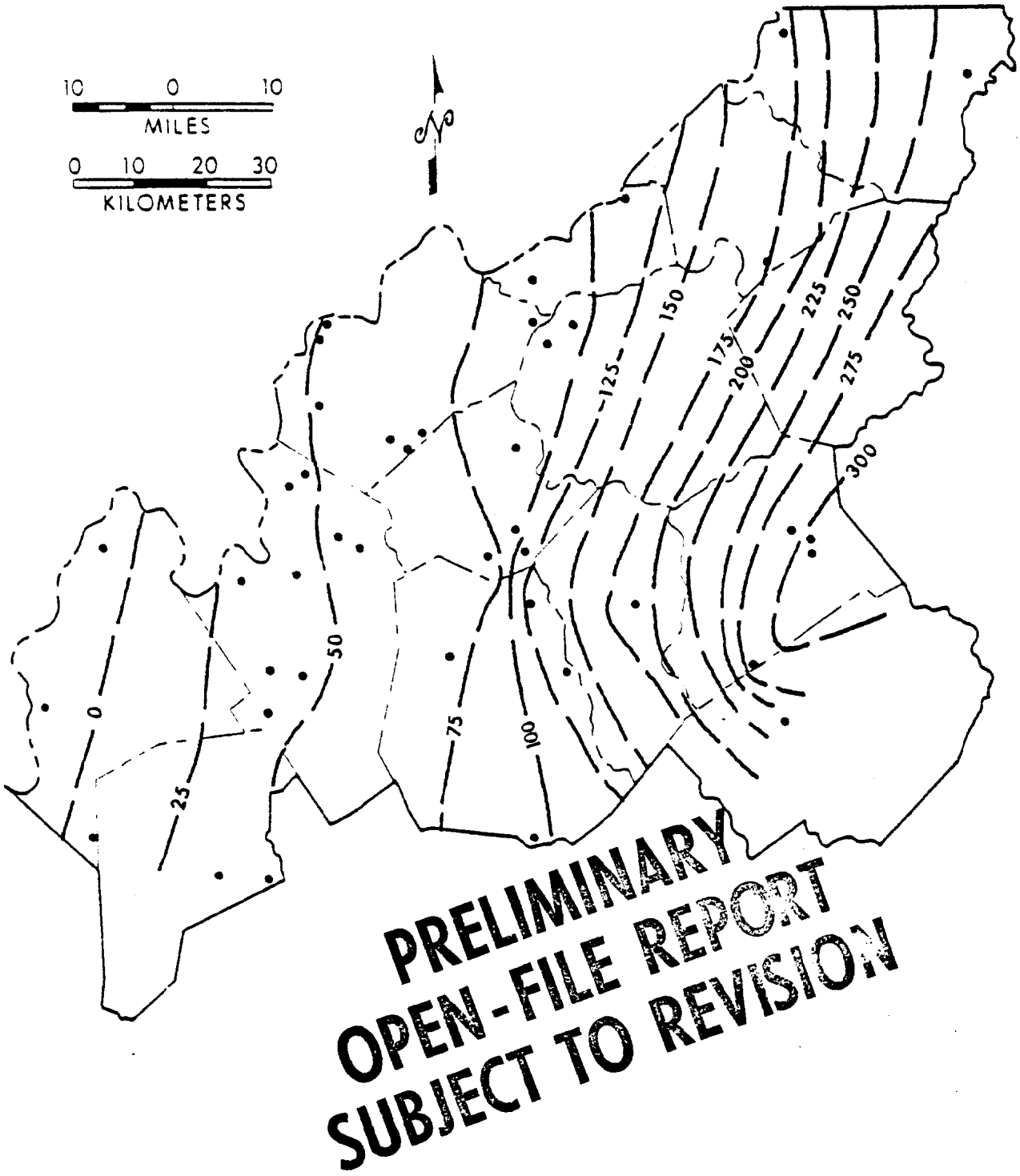

Figure 20. Isopach map of the Sonyea Formation. Contour interval is 25 feet.

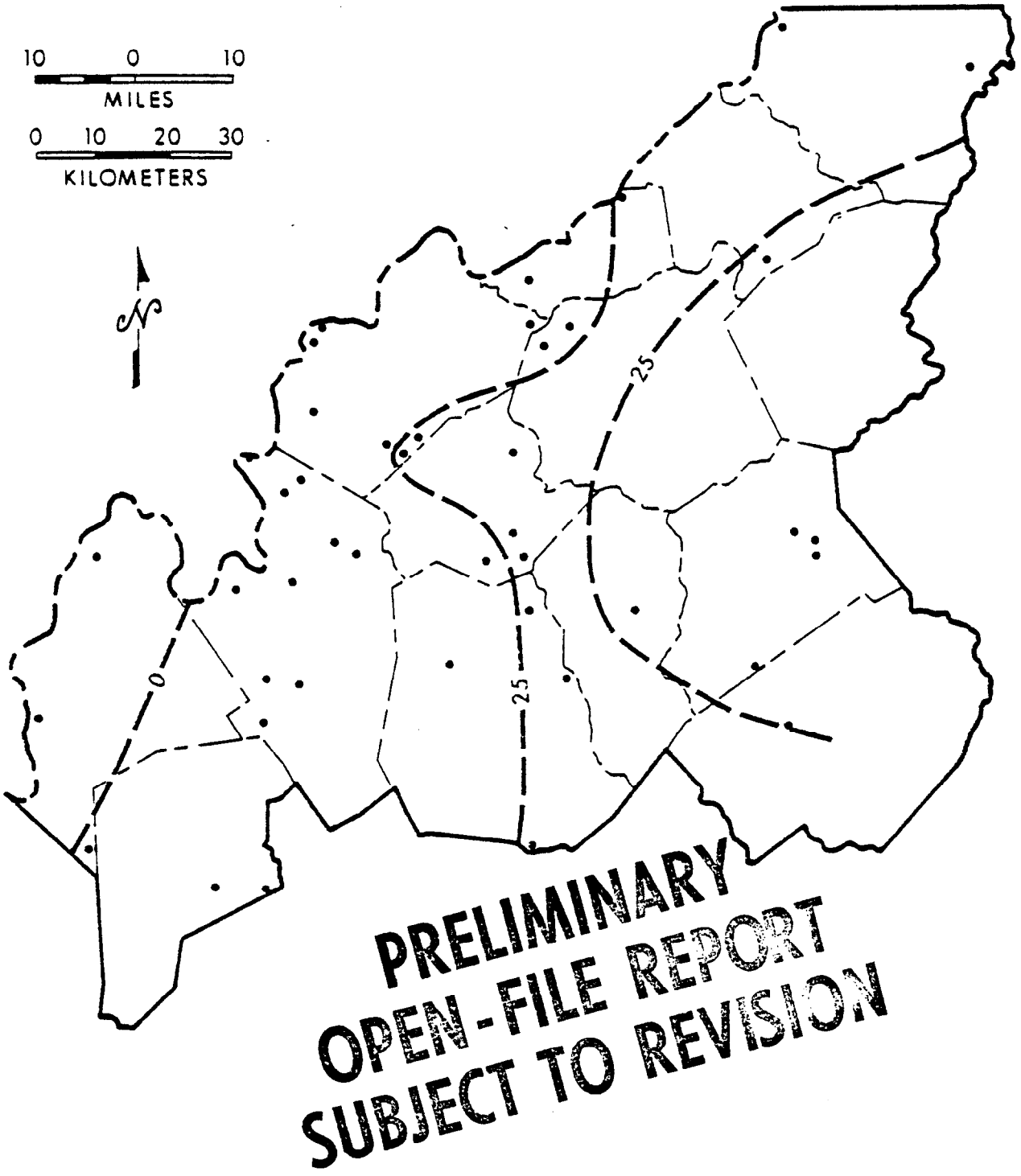

Figure 21. Isopach map of the Middlesex Shale. Contour interval is 25 feet.

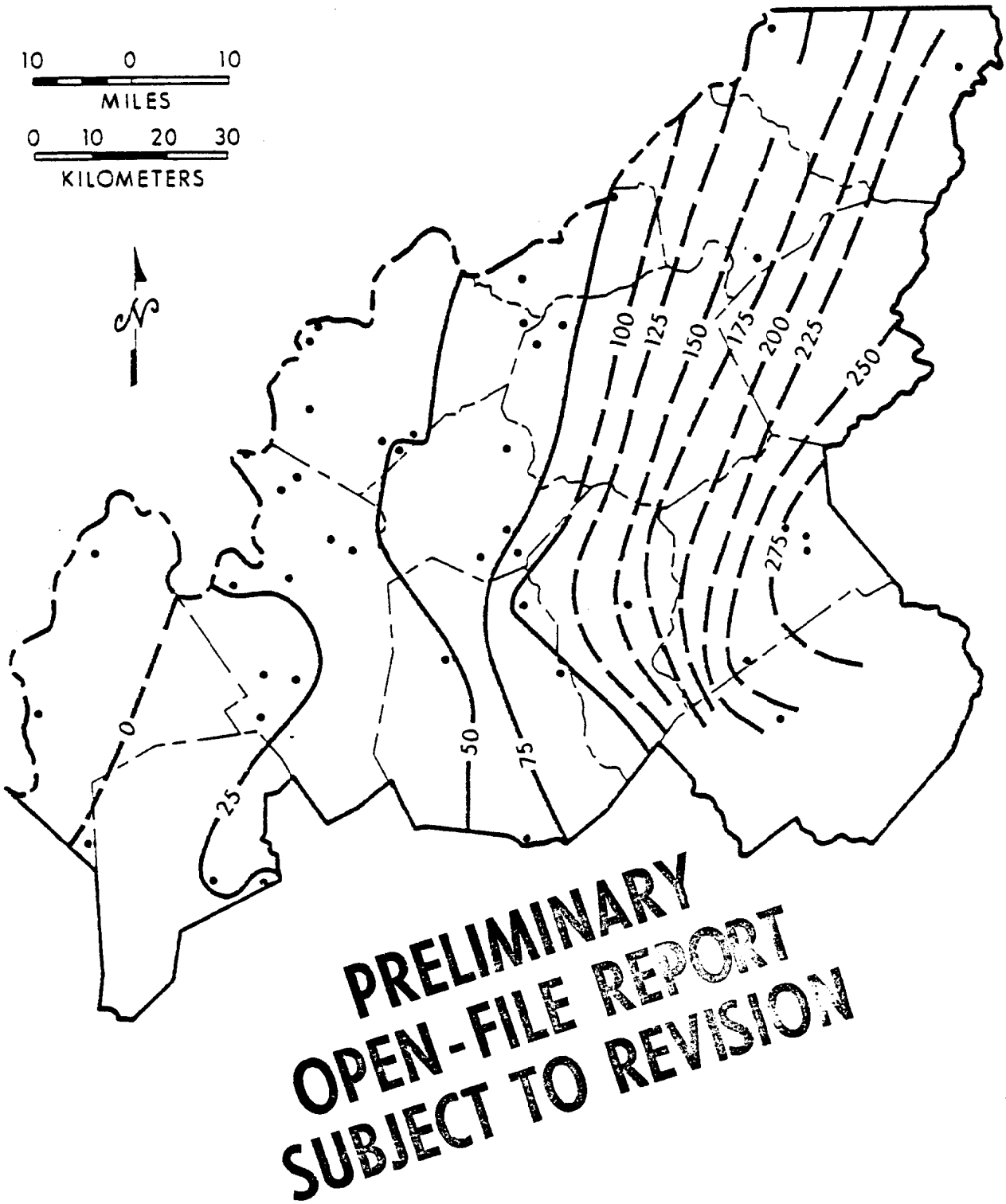

Figure 22. Isopach map of the Cashaqua Shale. Contour interval is 25 feet.

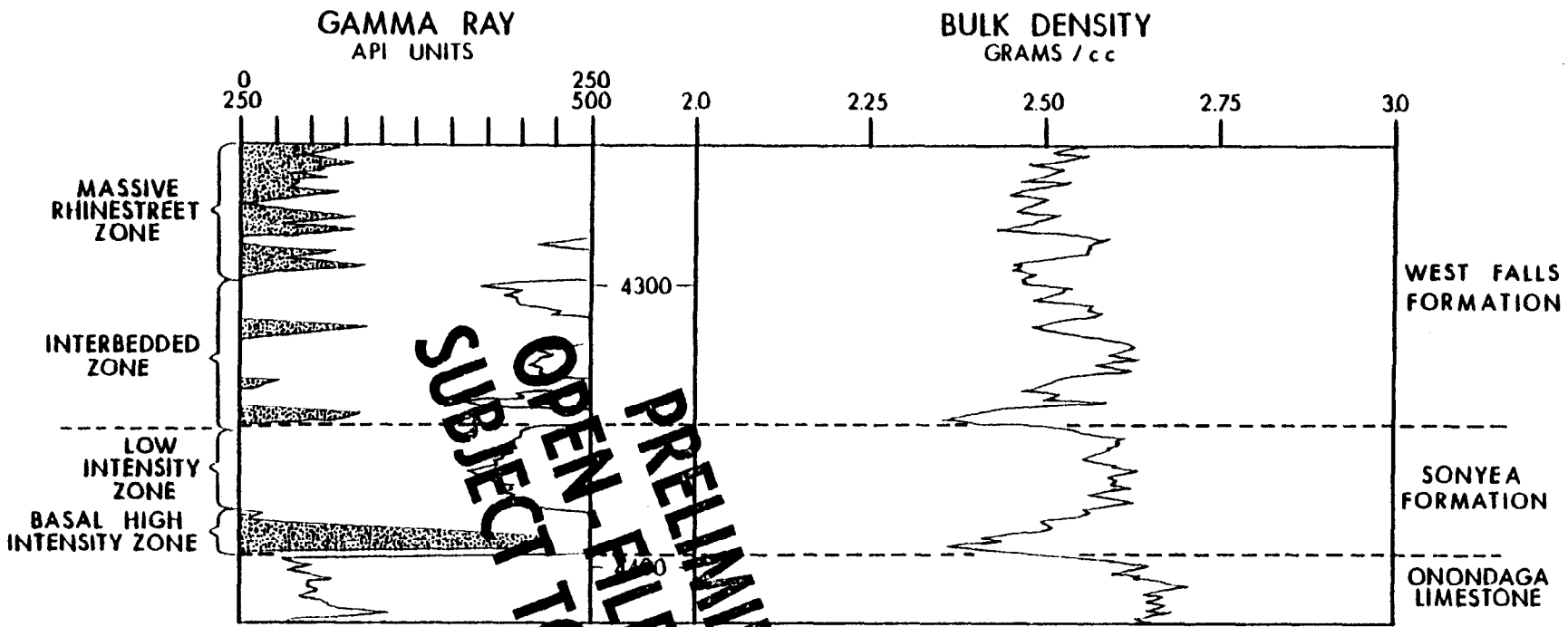

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Figure 23. Typical gamma-ray log of the section from the massive part of the Rhinestreet Shale to the Onondaga Limestone in the western part of the study area (Wood 594).

numerous highly radioactive beds. This is underlain by a zone of lower radioactivity (the Cashaqua Shale Member), which in turn is underlain by a very highly radioactive zone (Middlesex Shale). Well sample studies (Martens, 1945) for Jackson 131 (p. 301), Jackson 58 (p. 319), and Jackson 56 (p. 323), as well as samples examined by me from Wood 72 (Appendix 2), indicate that black shale rests directly on the Onondaga Limestone and is overlain by gray to greenish-gray shale which, in turn, is overlain by very dark gray shale. Previous workers (Schwietering, 1970; Roen, Wallace, and deWitt, 1978) have placed the unconformity at the top of the low radioactive, green-gray shale zone. They correlated the basal part of the section as Marcellus Shale overlain by the Mahantango Formation. I chose to correlate the entire interval as Upper Devonian with the Sonyea Formation resting unconformably on the Onondaga Limestone (see Plates [illegible]).

If the unconformity is in fact on the top of the Onondaga Limestone, this surface might show irregularities in topography because of subaerial erosion or submarine erosion prior to deposition of the Sonyea Formation. In order to test this hypothesis, I examined an area 6 miles square in Jackson County where well control was good. The area is bounded on the north by latitude 38°55' and on the east by longitude 81°45' (Figure 24). The top and thickness of the Onondaga Limestone were obtained from drillers' logs for 104 wells in the area. A structure map constructed on top of the Onondaga Limestone (Figure 25) shows a regional northeast-southwest strike with the Onondaga surface dipping to the southeast, but there are many irregularities in the structure contours. An isopach map constructed for the Onondaga

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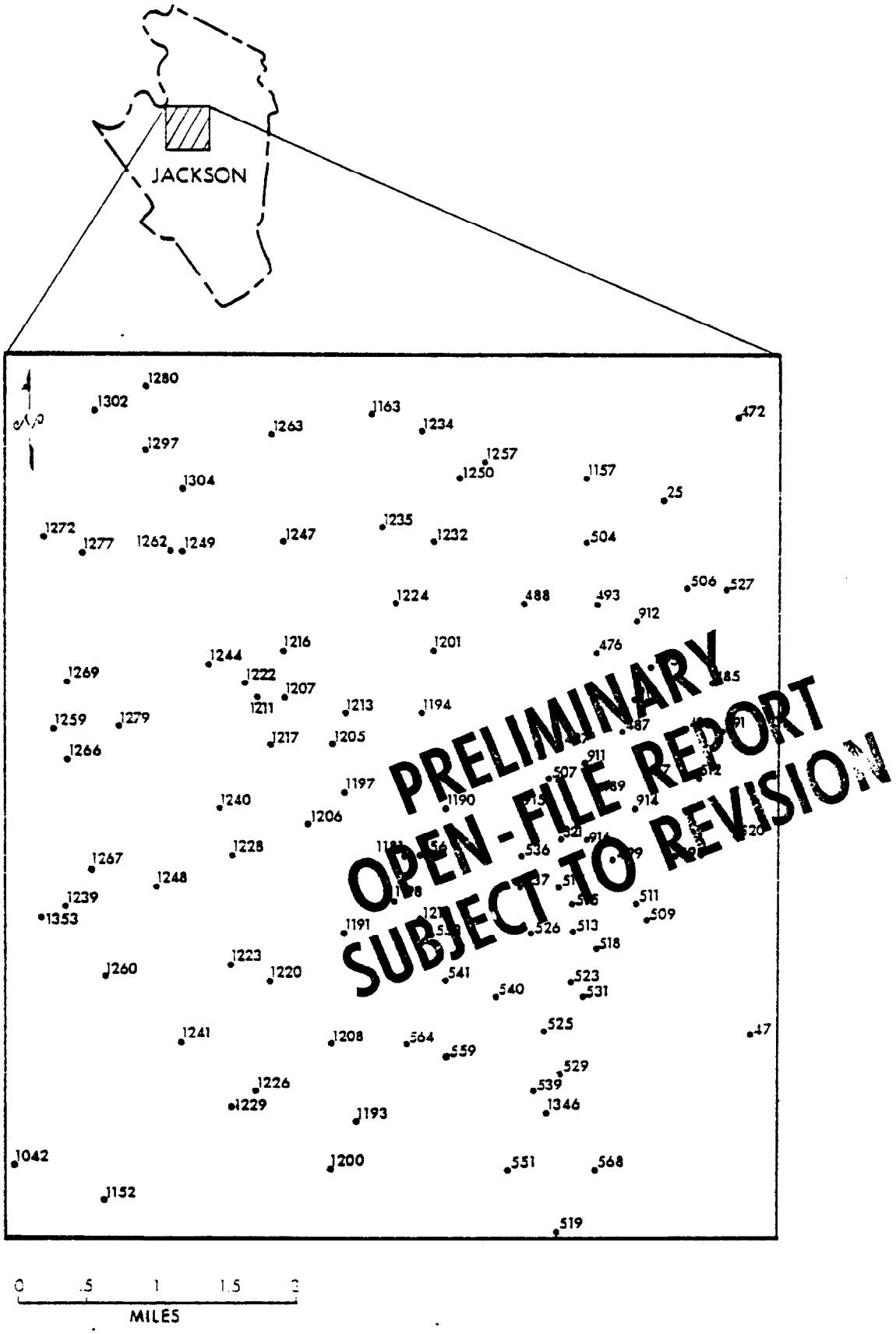

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Figure 24. Location of wells in central Jackson County used for Trend Surface Analysis.

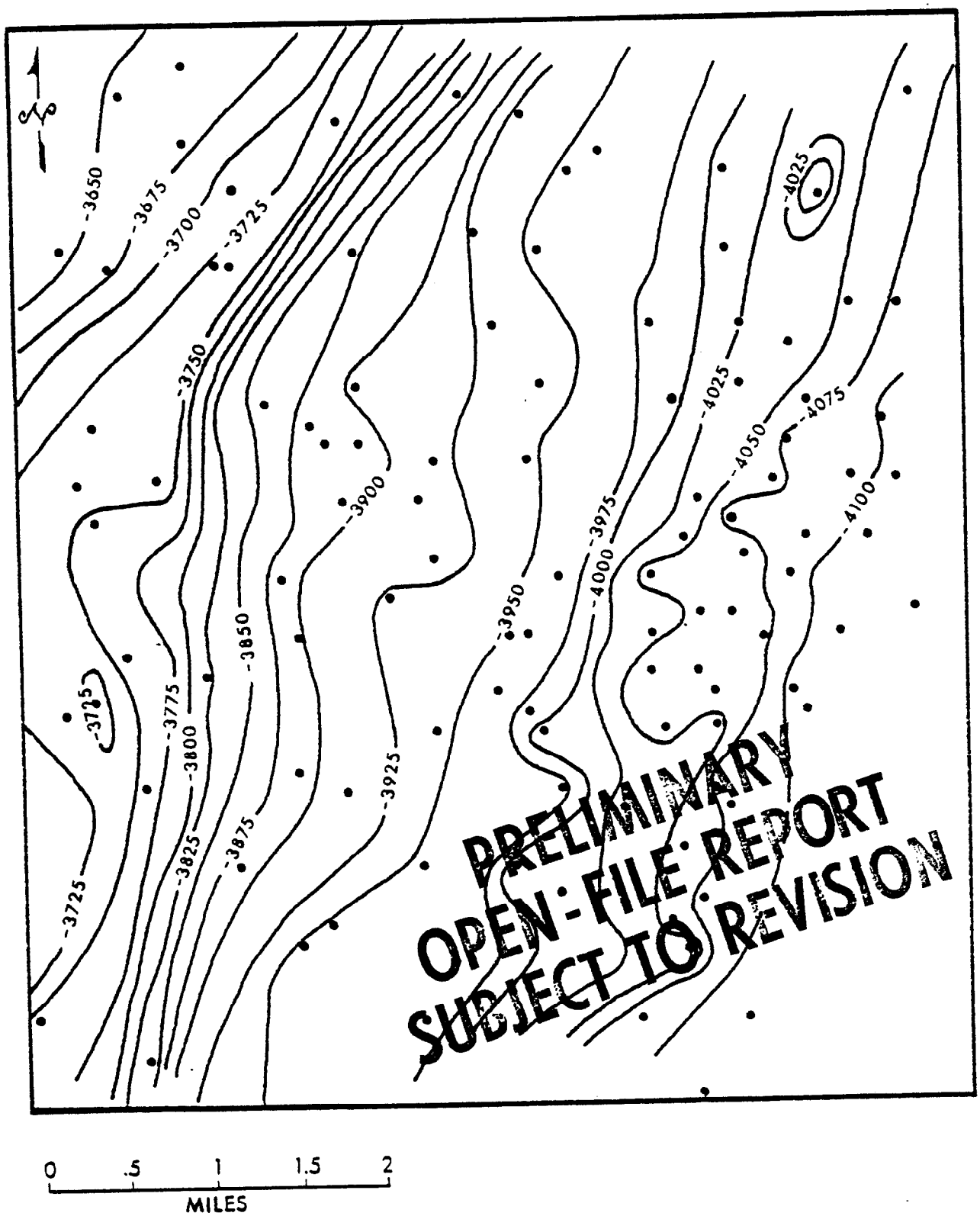

Figure 25. Structure on top of the Onondaga Limestone in central Jackson County. Contour interval is 25 feet.

Limestone (Figure 26) shows a variation in thickness from 76 to 124 feet for the unit, which generally thins to the west. In order to examine the irregularity in the surface of the Onondaga Limestone, a first order trend surface was calculated using SAS (Statistical Analysis System, Barr et al, 1976). This surface (Figure 27) reflects the regional dip with the surface striking northeast-southwest and dipping to the southeast, with 97.45% of the variation in the elevation of the top of the Onondaga explained by this surface. A trend surface calculated for the base of the Onondaga Limestone is identical in trend to that of the top. The residuals from the Onondaga trend surface were plotted and contoured (Figure 28). The fact that the residuals can be contoured indicates that they are probably not random and are related to some geologic control. Prior to construction of the contour map of the residuals the assumption was made that where erosion or solution had occurred, the Onondaga Limestone would be thin and the elevation of the top of the Onondaga would be below the regional surface. Where erosion had not occurred the elevation would be above the regional surface and the Onondaga Limestone would be thick. This assumption was used to infer trends in construction of the contour map of the residuals. This map, with its admitted bias, suggests that the surface of the Onondaga Limestone was subject to erosion. Therefore, the black shale must post-date the unconformity.

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An additional means of confirming the correlation of the basal, black shale as Middlesex would be to determine the age of the shale and the overlying gray-green shale in the sequence above the Onondaga

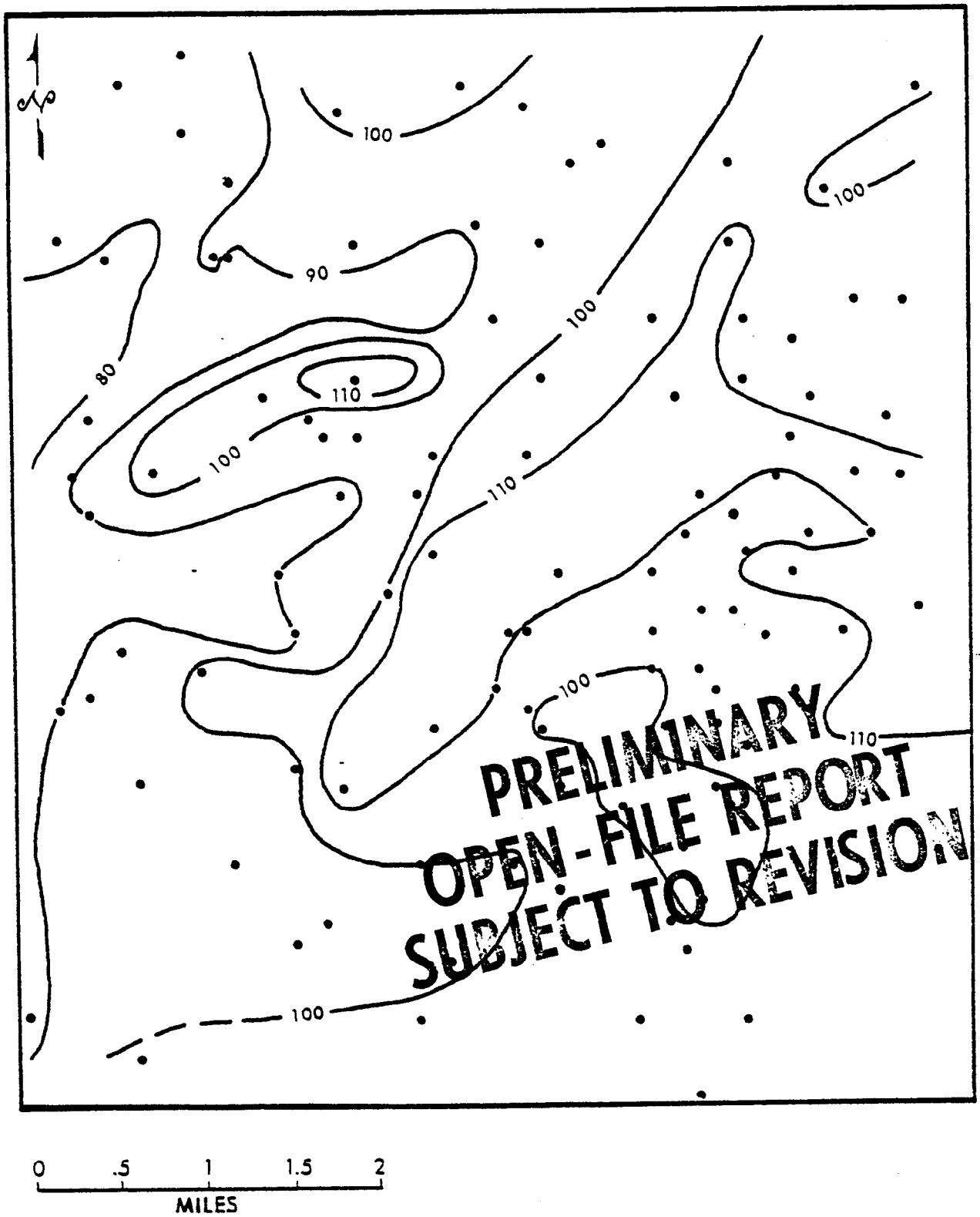

Figure 26. Isopach map of the Onondaga Limestone in central Jackson County. Contour interval is 10 feet.

Figure 27. Trend surface on top of the Onondaga Limestone in central Jackson County. Contour interval is 100 feet.

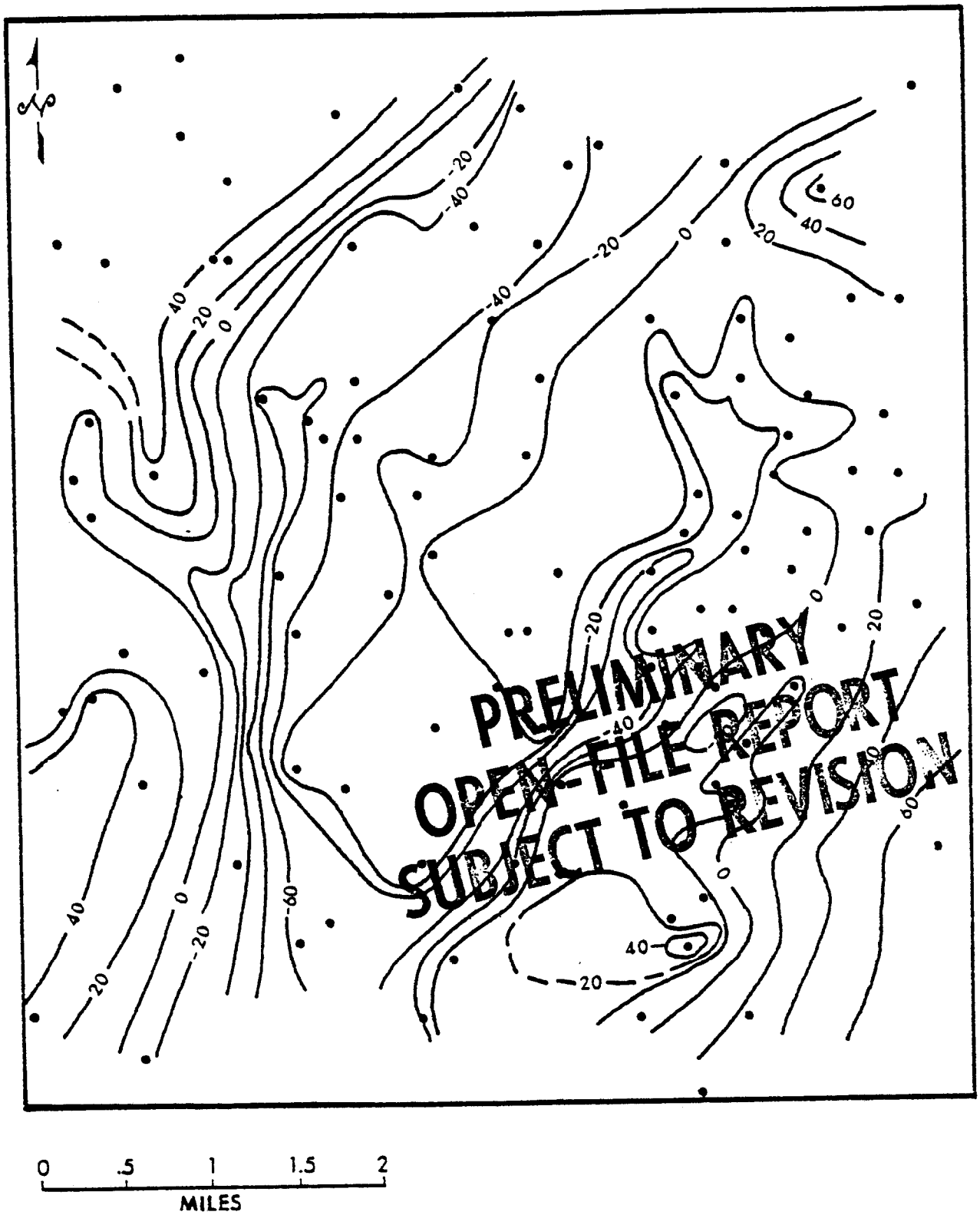

Figure 28. Contour map of the residuals from the trend surface in central Jackson County. Contour interval is 20 feet.

Limestone. At present, the shale cannot be dated because suitable samples are not available from the zone for biostratigraphic study. In southern West Virginia, a core from Lincoln 1637 has a similar basal black shale overlain by lighter colored shale. Duffield (1977) made a biostratigraphic study of the conodonts from this well and found the section to be entirely Upper Devonian in age, except for the basal dark shale. However, the 7 feet of dark shale overlying the Onondaga Limestone were barren, and age determinations could not be made.

West Falls Formation

The type section of the West Falls Formation is located along Cazenovia Creek near West Falls and Aurora, Erie County, New York (Pepper, deWitt and Colton, 1956). In New York seven members are recognized locally: the basal Rhinestreet Shale Member, which is overlain by the Angola Shale Member in the west and the Rhinestreet and overlying Hatch Shale, Grimes Siltstone, Gardeau Shale, West Hill Member and Nunda Sandstone Member in the east.

In the western part of the study area, two members are recognized; the Rhinestreet Shale Member and the Angola Shale Member. The Rhinestreet Shale Member is underlain by the Sonyea Formation, and the Angola Shale is overlain by the Java Formation. The Rhinestreet Shale Member is composed of black shale interbedded with dark gray and gray-green shale. It is recognized on gamma-ray logs by its higher radioactive response than adjacent units (Figure 29). The Rhinestreet Shale Member can be subdivided into three zones in the western part of the area: a basal zone of intermediate radioactive

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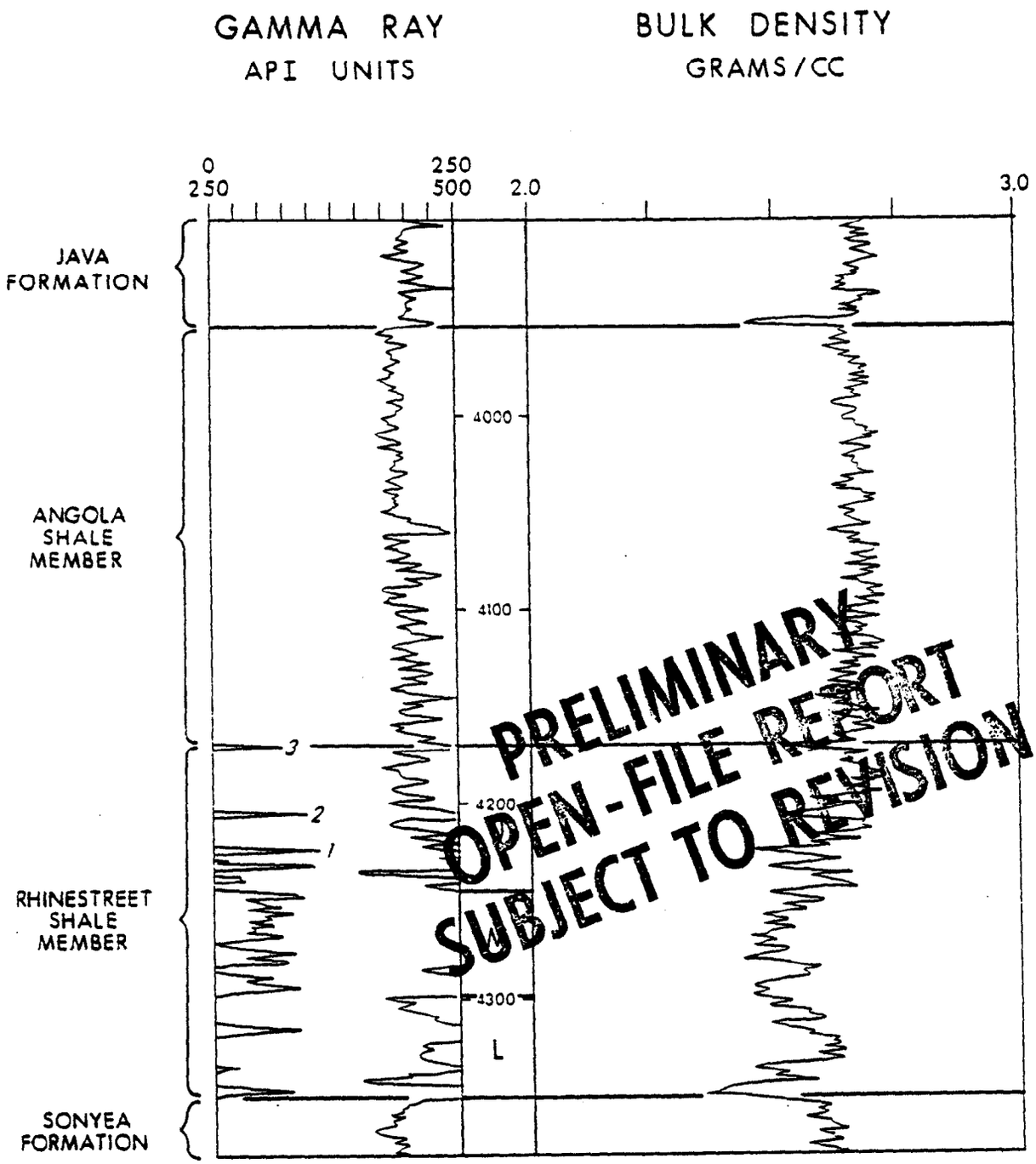

Figure 29. Typical gamma-ray log of the West Falls Formation (Wood 594).

response with numerous high peaks, a middle massive high radioactive zone, and an upper zone of intermediate radioactivity with numerous higher peaks. The gamma-ray log is characterized by the presence of three high peaks near the top of the Rhinestreet. To the east, the Rhinestreet Shale Member changes facies to gray and gray-green shale and its radioactive intensity decreases. The Angola Shale Member is composed of gray to gray-green shale throughout the study area and has a lower radioactive response than the Rhinestreet Shale Member. The West Falls Formation thickens from 200 feet in Mason County to more than 1200 feet at the eastern edge of the study area (Figure 30). The Rhinestreet Shale Member and its eastern nonblack equivalents thicken from 100 feet in Mason County to 950 feet at the eastern border of the area (Figure 31). Black shale is the dominant lithology west of the 400 foot isopach and gray shale is the dominant lithology east of that contour. The Angola Shale Member is more uniform in thickness, increasing from 150 feet to 300 feet across the area (Figure 32).

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Most of the formations in the study area are characterized by a massive black shale zone at the base. The West Falls Formation is unusual because of the presence of 30 to 40 feet of interbedded gray and black shale beneath the massive black shale zone. The decision to place the boundary at the base of the lower interbedded unit and not at the base of the massive zone was made by comparison to gamma-ray logs from New York (Van Tyne et al, 1978). This places the base of the Rhinestreet Shale Member at the bottom of the stratigraphically lowest highly radioactive zone above the Cashaqua Shale Member of the

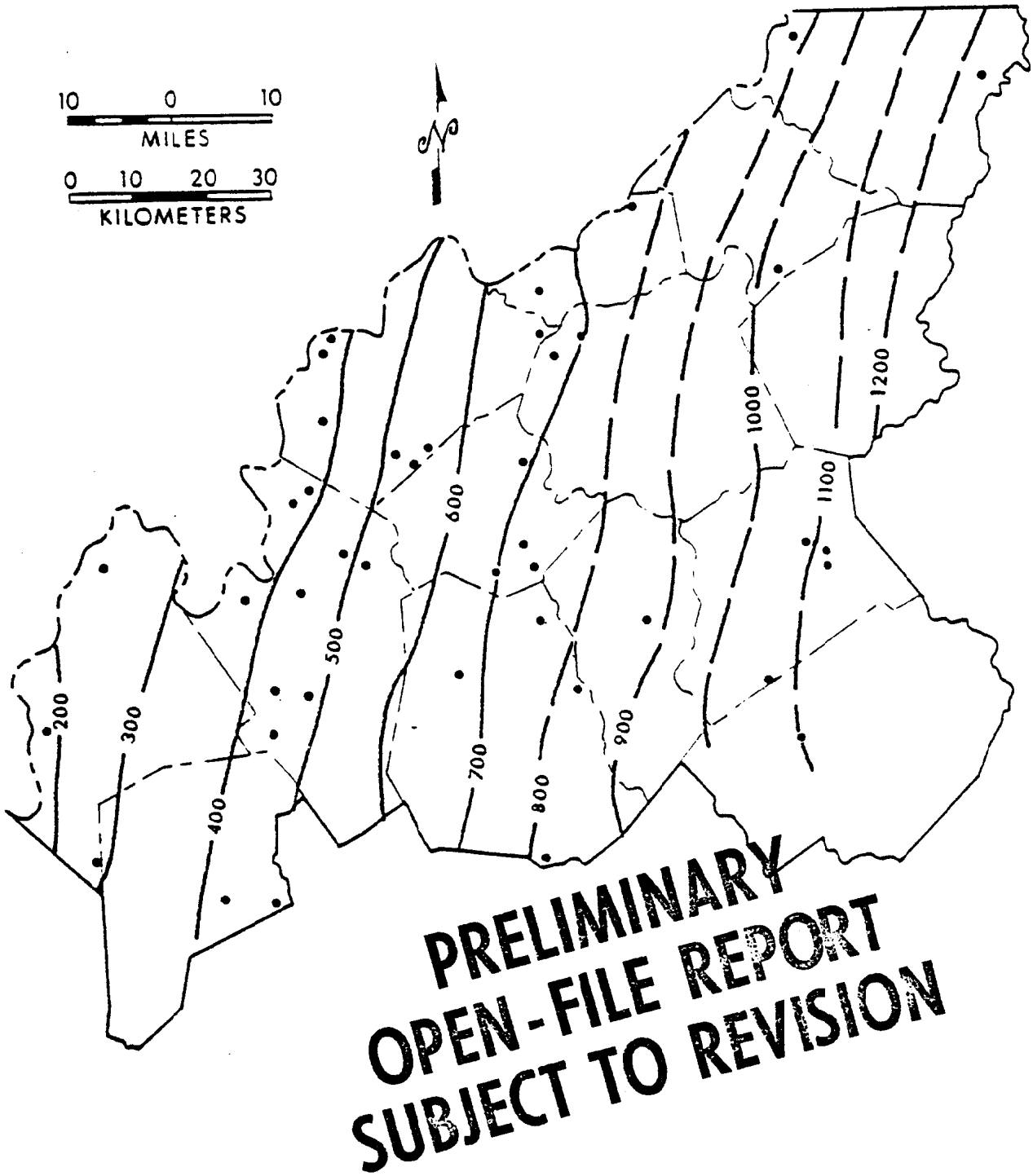

Figure 30. Isopach map of the West Falls Formation. Contour interval is 100 feet.

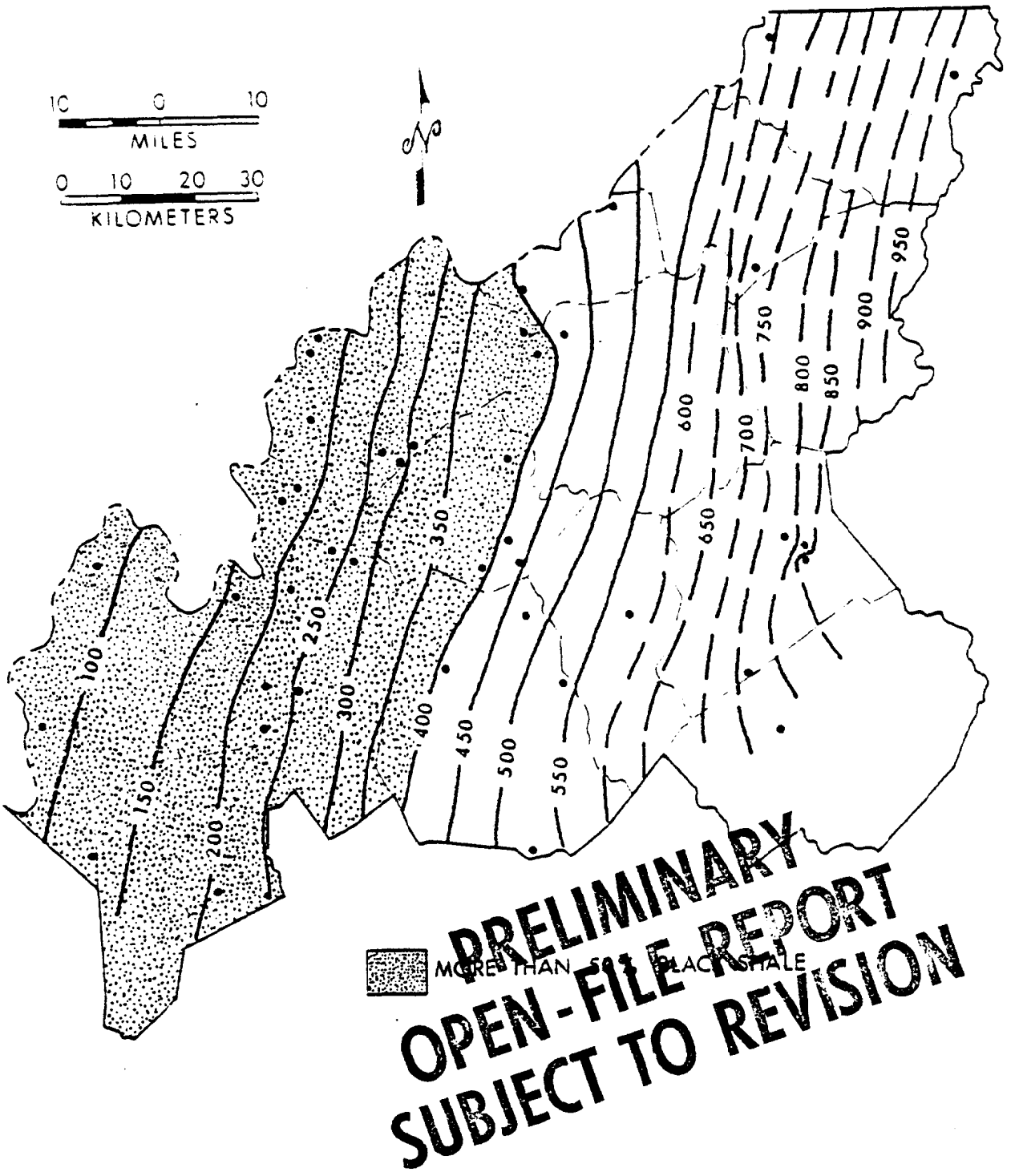

Figure 31. Isopach map of the Rhinestreet Shale. Contour interval is 50 feet.

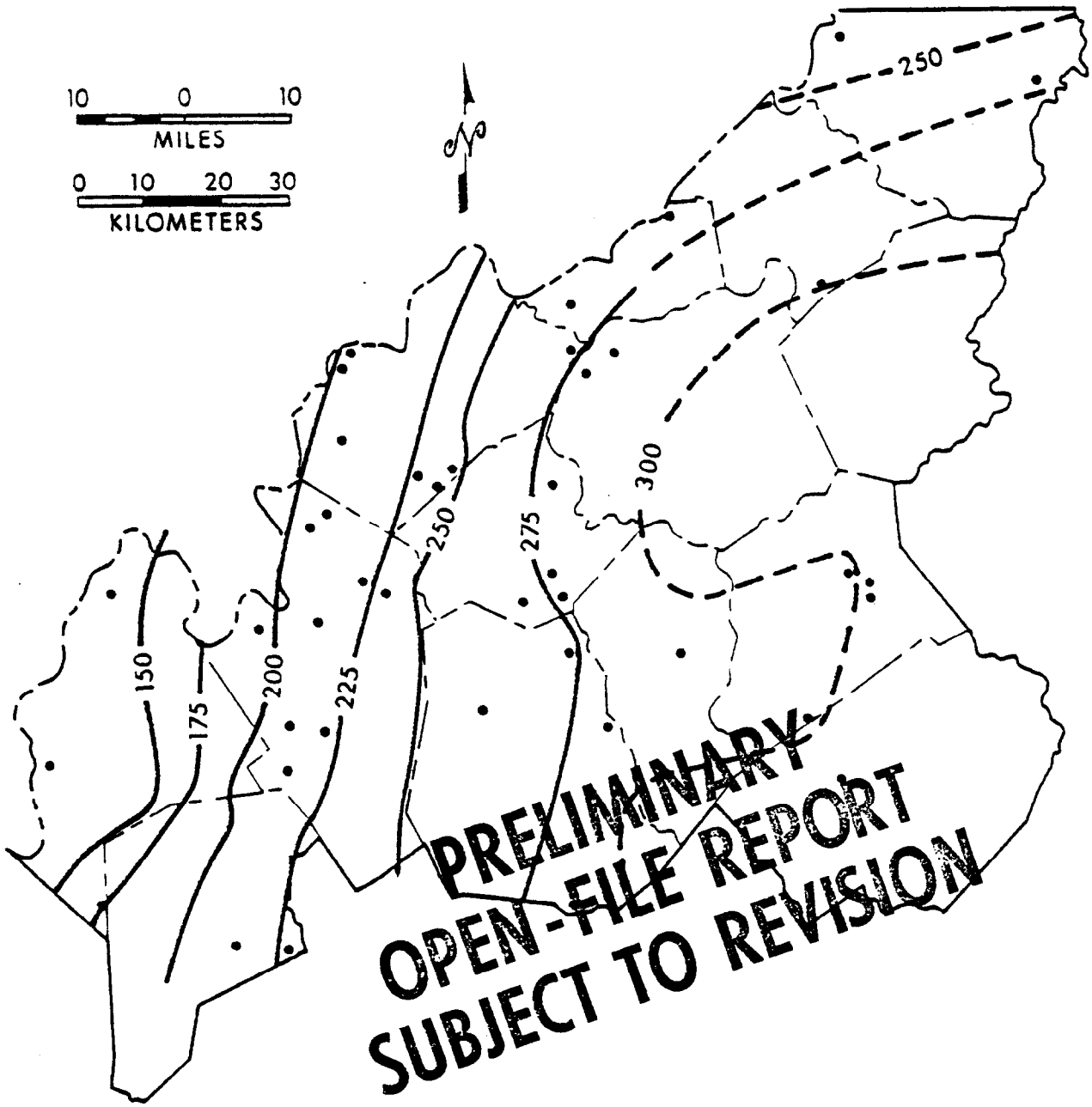

Figure 32. Isopach of the Angola Shale. Contour interval is 25 feet.

Sonyea Formation.

Java Formation

The Java Formation was named by deWitt (1960) for exposures in Java Township, Wyoming County, New York. In New York, three members are recognized: the basal black Pipe Creek Shale, the Hanover Shale, and the Wiscoy Sandstone.

In the study area, the formation is not subdivided because the Pipe Creek Shale is present only as a thin marker at the base of the Java Formation. The Pipe Creek marker is eight inches thick in the core from Mason 146 and is occasionally reported on drillers' logs and sample studies as a brown shale. It is recognized on gamma-ray logs as a peak of intermediate intensity and on the density logs by its very low density. The Java Formation is underlain by the West Falls Formation and is overlain by the Ohio Shale. The Java Formation is composed of gray shale and siltstone, and is recognized on gamma ray logs by its low radioactivity compared to the apparent radioactive shale of the Ohio Shale (Figure 33). The Java Formation ranges in thickness from 125 feet in the western part of the area to 250 feet in thickness in the east (Figure 34).

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Ohio Shale

The Ohio Shale was named by Andrews (1870) from exposures in southern Ohio and is composed of black to dark gray shale, rich in organic detritus. In Ohio and in Cabell County, West Virginia, two members are recognized: the Cleveland and the Huron. The dark shale of the Huron Member is separated into upper and lower tongues by an intervening gray shale.

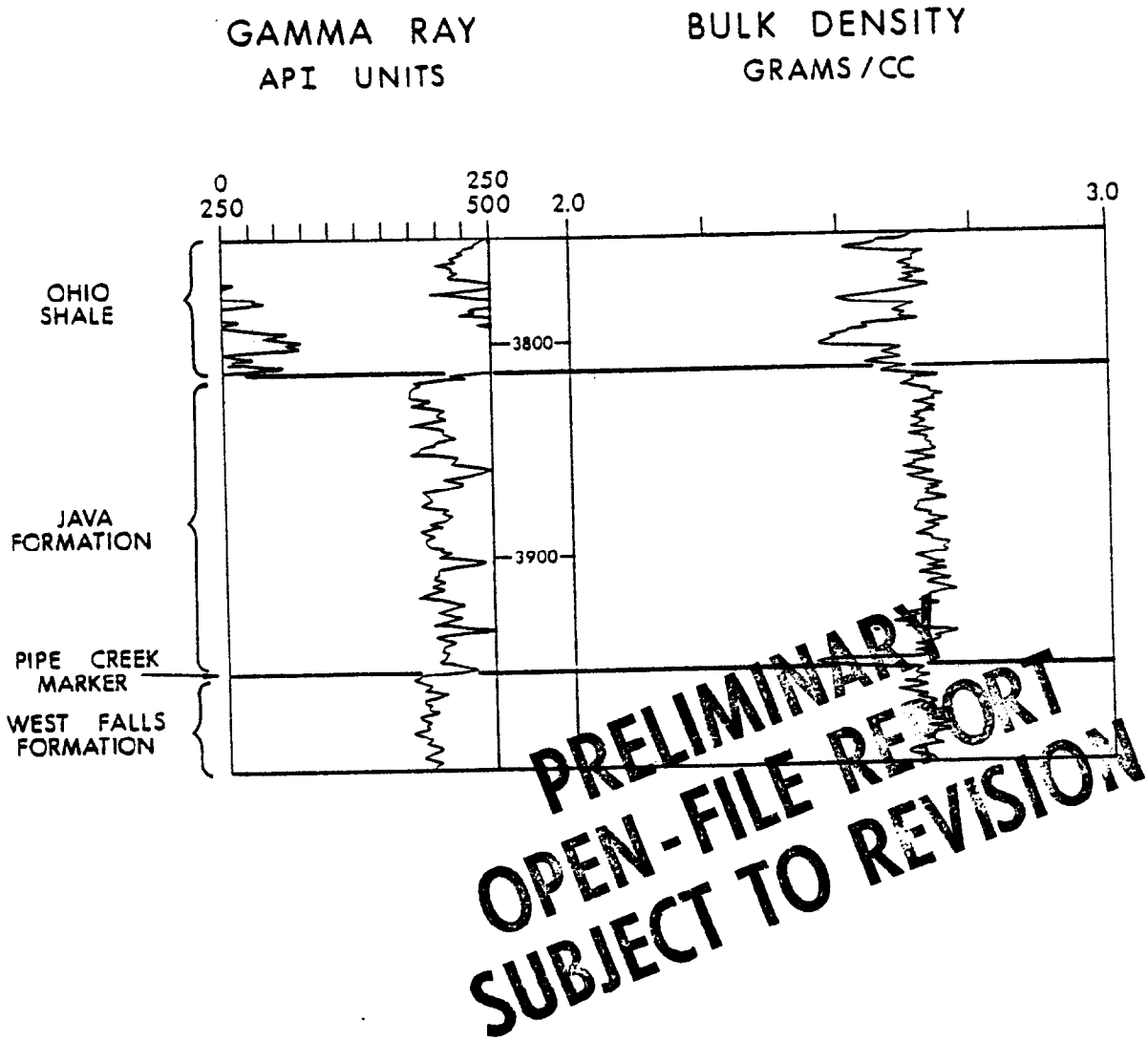

Figure 33. Typical gamma-ray log of the Java Formation (Wood 594).

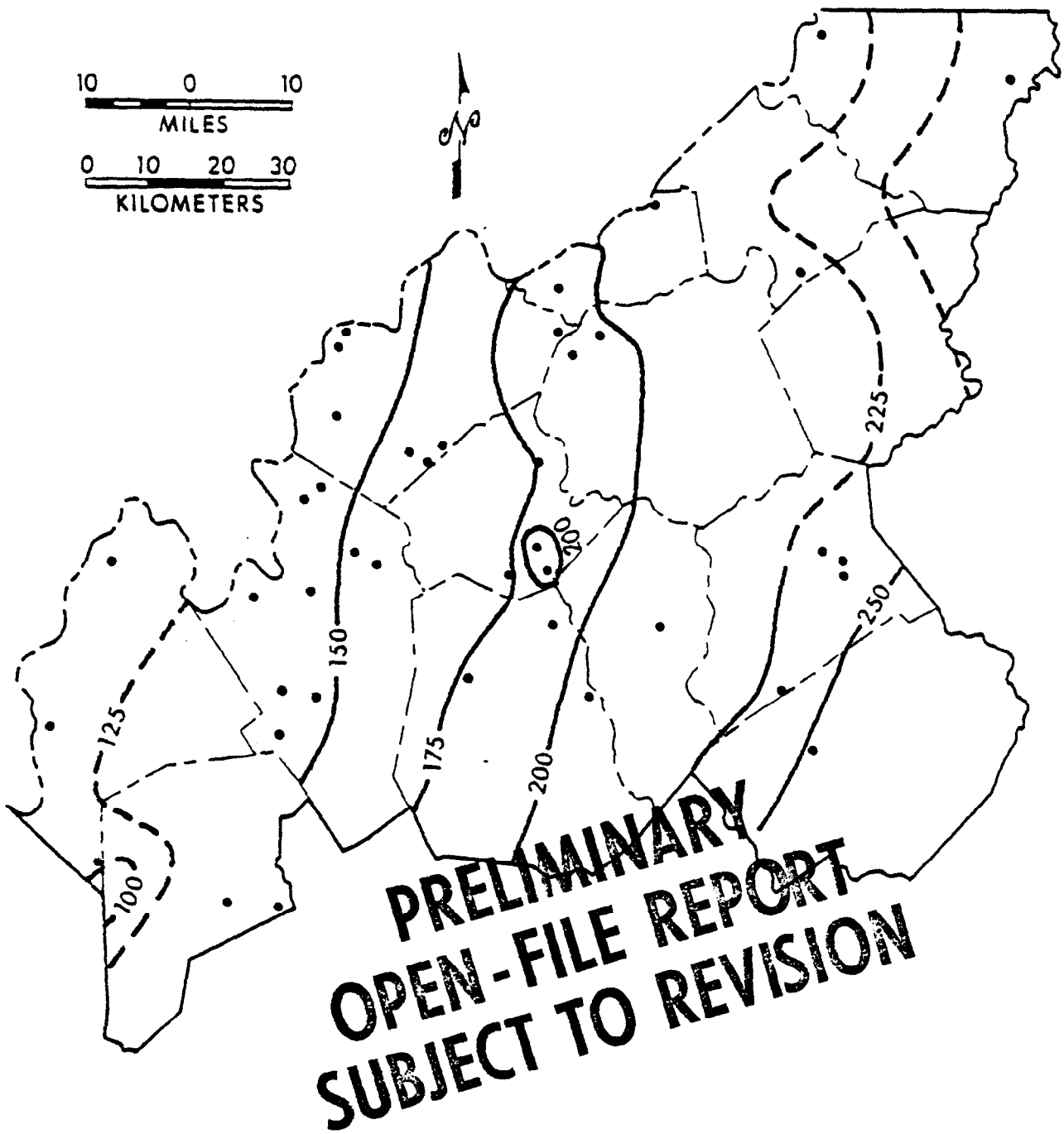

Figure 34. Isopach map of the Java Formation. Contour interval is 25 feet.

In the study area only the lower part of the Huron Member is recognized, and it is separated into an upper and a lower tongue by an eastward-thickening tongue of gray shale. The Ohio Shale overlies the Java Formation and underlies undivided Upper Devonian rocks. The Ohio Shale is composed of black shale, rich in organic matter, with some interbedded dark-gray shale. It is recognized on gamma-ray logs as a zone of higher radioactive intensity than adjacent units (Figure 35). Like the Rhinestreet Shale Member of the West Falls Formation, the Huron Member of the Ohio Shale undergoes a facies change from black and dark gray shale in the west to gray shale in the east. The iospach map (Figure 36) shows the thickness of the black shale in the west and the laterally equivalent gray shale in the east. The Huron Member of the Ohio Shale and its lateral equivalents range in thickness from 100 feet in Mason County to 1500 feet on the eastern side of the study area. Black shale is the dominant lithology west of the 700 foot isopach line and gray shale predominates to the east.

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The Huron Member of the Ohio Shale is the main gas-producing zone in the Middle and Upper Devonian clastic sequence in Jackson and Putnam Counties. Because of its economic importance, its stratigraphic relationships have been studied in more detail than those of the other units. In extreme western Mason County, the Huron Member of the Ohio Shale is a massive black shale rich in organic detritus. To the east, the Huron Member interfingers with gray and gray-green shale with a lower radioactive response. East of central Roane County, the Huron Member loses most of its distinctive radioactive character (see

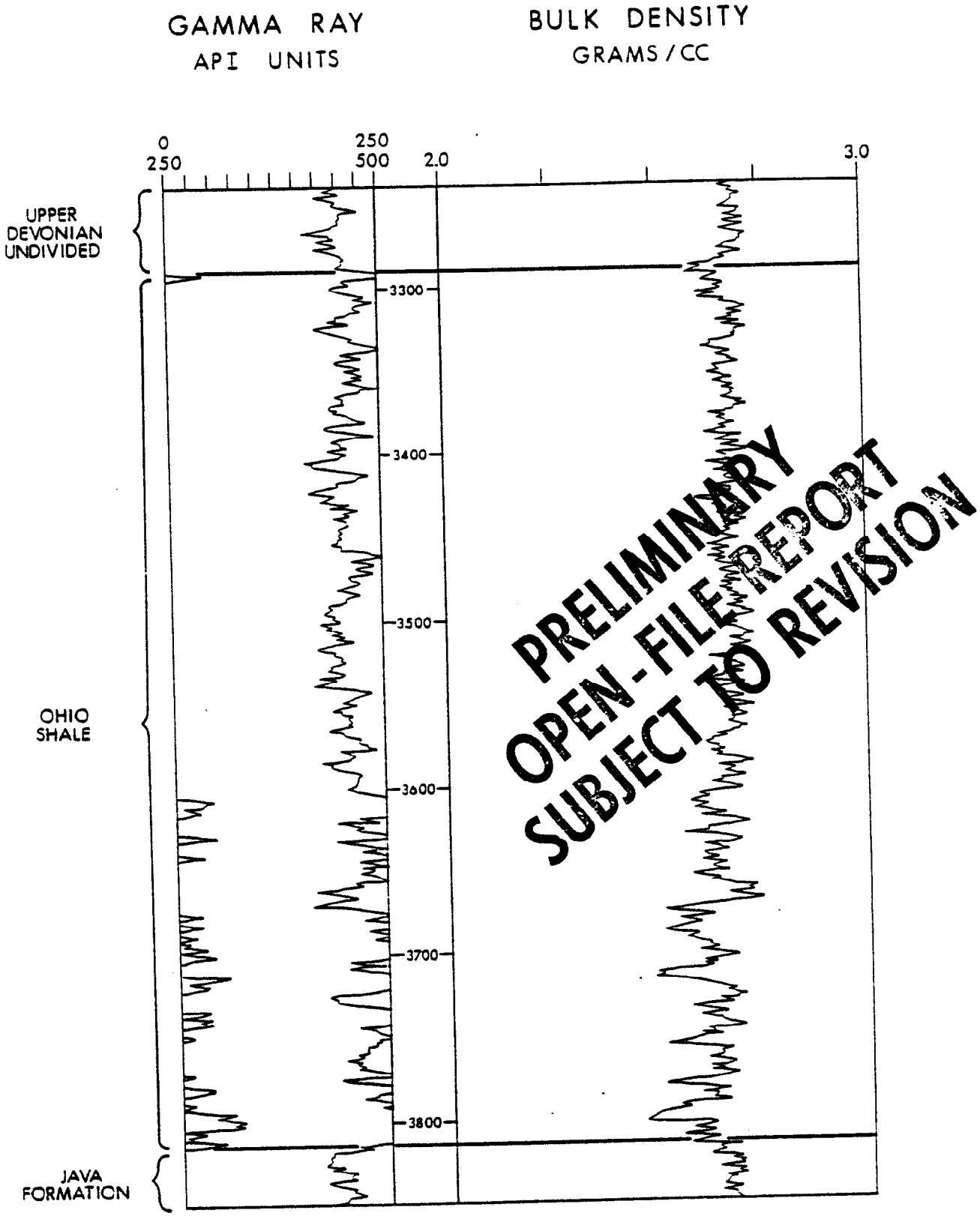

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Figure 35. Typical gamma-ray log of the Ohio Shale (Wood 594).

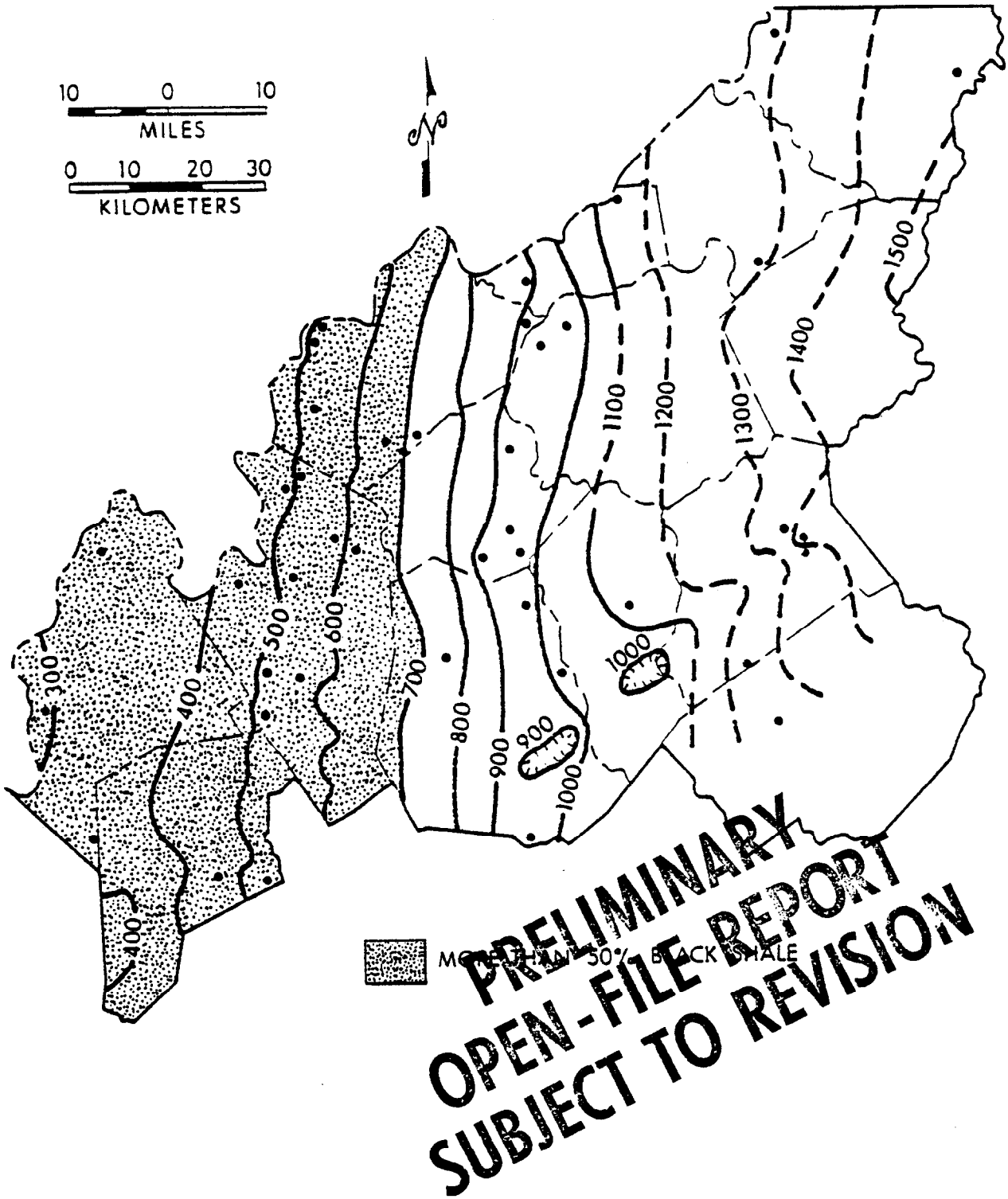

Figure 36. Isopach map of the Ohio Shale and lateral equivalents. Contour interval is 100 feet.

Plate 2), although it may still be recognized by its brown color in drillers' logs as far east as Calhoun County, and in sample studies farther east. Ideally, the name Huron Member of the Ohio Shale should be restricted to the darker shale intertonguing from the west and another name should be used for the tongues of gray shale from the east, but I chose to consider the interval as one unit, the Huron Member and lateral equivalents. It includes all of the sequence from the base of the lowermost dark gray to black shale above the Java Formation to the top of the uppermost dark gray to black shale.

The stratigraphy of the Huron Member is characterized by interfingering of gray and black shale and was studied in greater detail using both drillers' logs and gamma-ray logs. The drillers' logs have been found to be the most useful tool for studying the interval, but must be used with care, because frequently the drillers called the whole interval "brown" shale and did not record any intercalated beds of gray shale. There are, however, enough logs that indicate "brown" and "non-brown" shale intervals to make them useful. Within the study area the Huron can be subdivided into upper and lower tongues of "brown" shale and a medial tongue of gray shale. The upper tongue is 60 to 100 feet thick and extends as far east as Calhoun County. The lower tongue is thicker than the upper tongue and also is recognized as far east as Calhoun County on drillers' logs. A cross section based on drillers' logs shows that the "brown" shales thicken slightly to the west (Figure 37) whereas the intertonguing gray shale units thin and pinch out to the west. This pinching out of the gray shale accounts for the thinning of the overall interval

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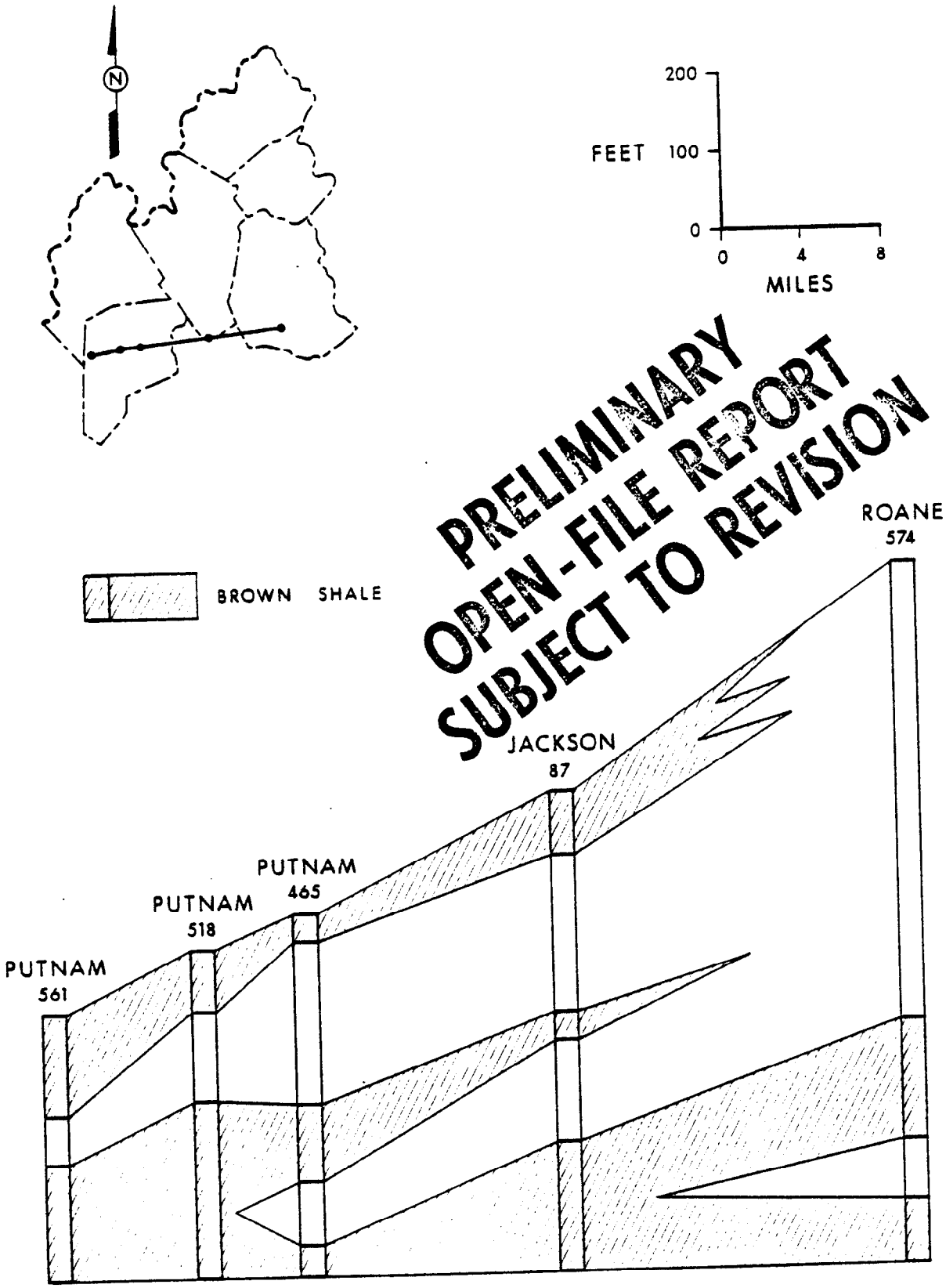

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Figure 37. Drillers' log cross section of the Huron in Putnam, Jackson, and Roane Counties.

to the west. Figure 37 also suggests that the base of the Huron may be lapping onto the underlying Java Formation. This appearent, though slight, disconformity was first recognized on drillers' log cross sections and was further documented by gamma-ray log cross sections (Figure 38). This disconformity is very subtle and only a minimal amount of section is missing at the base of the Huron Member. The disconformity may represent non-deposition or a gradual shift of facies at the contact.

Upper Devonian Undivided

Because of the lack of adequate markers (i.e., black shale beds) the interval between the top of the Huron Member of the Ohio Shale and the base of the Berea Sandstone has not been subdivided in the study area. The undivided rocks of the Upper Devonian are composed of gray shale, silty shale and siltstone. They have a low to intermediate radioactive response (Figure 39) with the shale units generally having a higher response than the siltstone units. The undivided Upper Devonian ranges in thickness from 900 to 1200 feet across the study area (Figure 40).

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Although this sequence is undivided, some units can be recognized within the interval. A siltstone bed 10 to 40 feet thick has been recognized approximately 300 feet below the Berea Sandstone. This siltstone can be traced laterally through most of the western part of the study area. Stewart (1979) examined well cuttings from several wells in the Cottageville gas field in Jackson County and was able to subdivide the undivided clastic interval into three units, on the basis on changes in the proportion of siltstone. This subdivision could not be carried south to Putnam County (Templin, 1979).

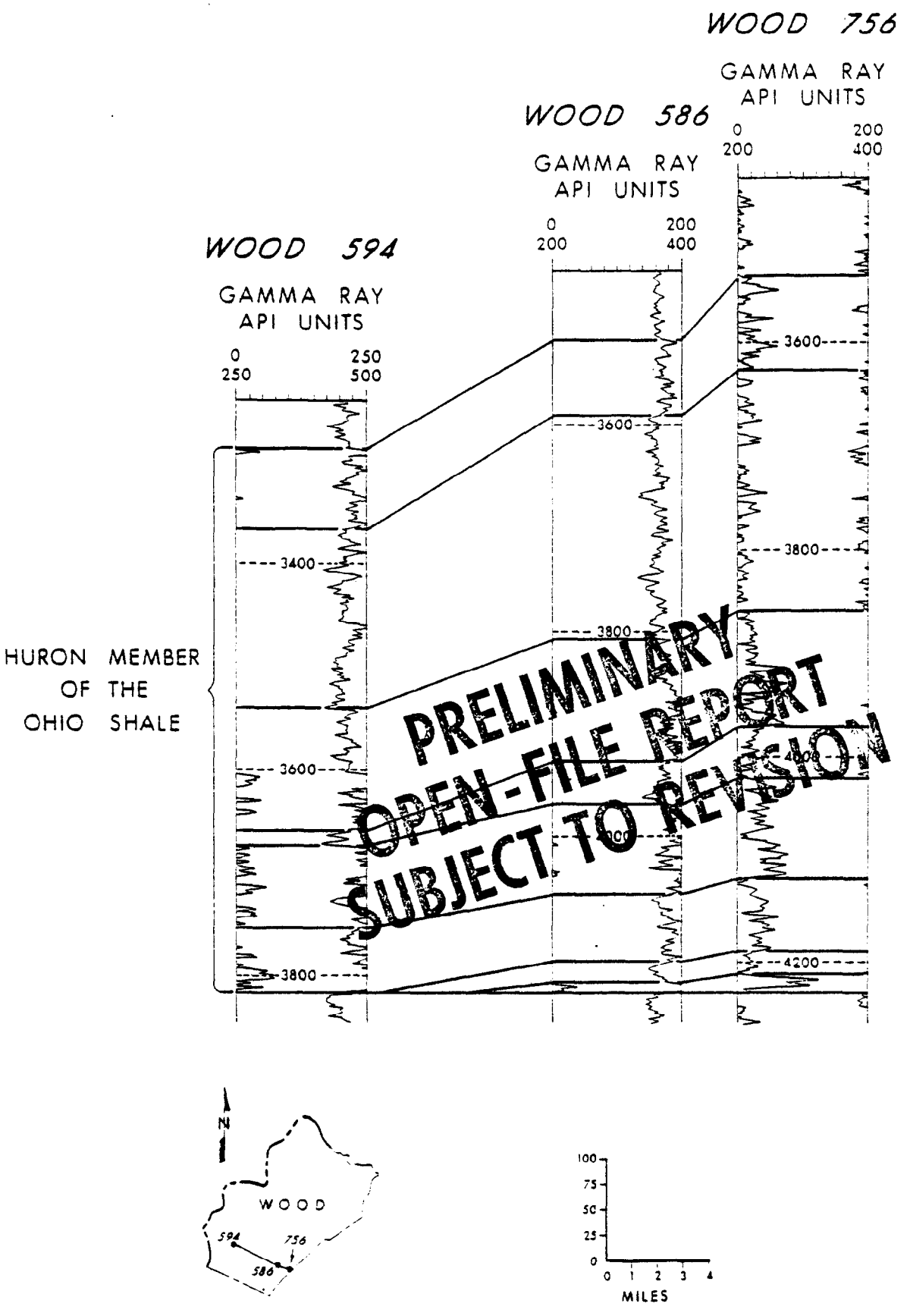

Figure 38. Gamma-ray log cross section of the Huron in Wood County.

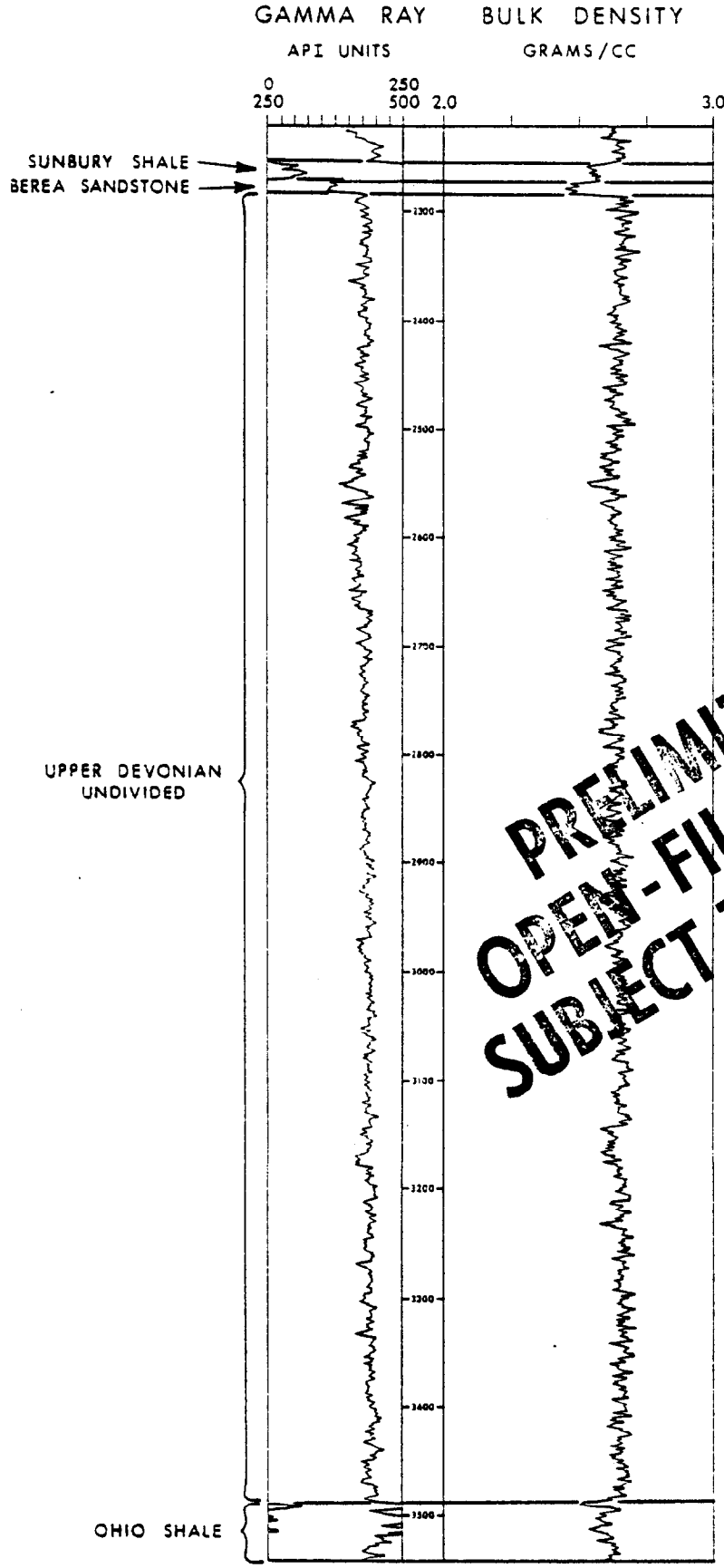

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Figure 39. Typical gamma-ray log of the Upper Devonian undivided (Putnam 741).

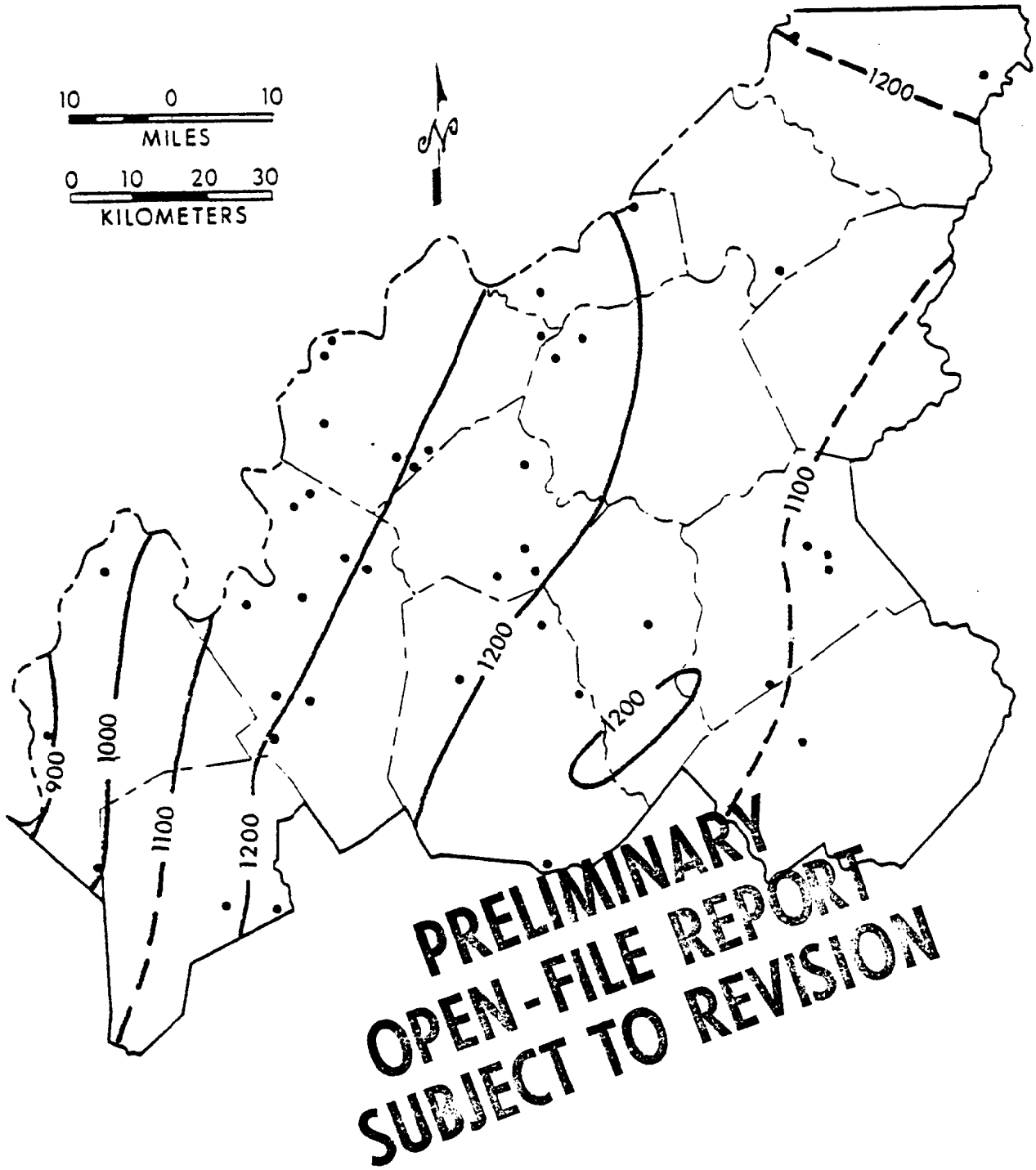

Figure 40. Isopach map of the Upper Devonian undivided. Contour interval is 100 feet.

In Ohio and southern West Virginia, where both the Huron and the Cleveland Shale Members of the Ohio Shale can be recognized, the gray-green shale which separates the two members is called the Chagrin Shale. The undivided Upper Devonian sequence in the study area is in part equivalent to the Chagrin Shale, but because neither the upper part of the Huron Member nor the Cleveland Member of the Ohio Shale can be recognized, the Chagrin Shale cannot be differentiated from gray-green shale equivalent to the Huron and Cleveland.

Eastern Facies

In the eastern and northern part of the study area, black, highly-radioactive shale is not recognized above the Middlesex Shale Member of the Sonyea Formation. Although the units between the Sonyea and the base of the undivided Upper Devonian sequence have been correlated throughout the area, they are, in fact, different lithologically from the units recognized to the west. Correlation has been accomplished primarily by the use of markers and the overall character of the logs. In the east, the section is composed of gray shale, siltstone, fine-grained sandstone, and, in the upper portion of the section, red beds. Included within this section are approximately twenty named, gas-producing sands. However, many of these informal "sands" are in fact siltstones. The detailed stratigraphy of these units is beyond the scope of this study, but the general relationships of the sands and the shales have been examined. The detailed stratigraphy of the sands is complicated by several factors, mainly the fact that the sands tend to be thin and discontinuous, and furthermore that the tops of units on drillers' logs are frequently inaccurate and inconsistent.

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At a recent meeting of West Virginia Geological Survey personnel working on correlation of the sands, the severity of the problem was clearly illustrated. Correlations by the group showed that the interval called "Benson" sand in Lewis County is nearly 500 feet lower, stratigraphically, than the interval called "Benson" in Upshur County. The sands are recognized only in the subsurface and no type log or type section has been defined for some of the named sands. For the purpose of this paper, the nomenclature used for the sands is taken from a well log (Lewis 1864) with some of the sands identified (Patchen, 1977b).

Within the study area, the sand units were correlated within the framework provided by correlation of the shale to the west (Figure 41). The Benson correlates with the lower portion of the Huron Member of the Ohio Shale. This correlation was suggested by previous workers (Lafferty, 1941; and Martin and Nuckols, 1976). Neal (1979) correlated the Fifth sand with the uppermost part of the gray shale underlying the upper part of the Huron Member of the Ohio Shale in southern West Virginia. The Fifth sand cannot be carried as far west in the study area and the upper part of the Huron Member is not recognized, but the horizons do correlate. Neal (1979) also correlated the Gordon sand with the middle of the Chagrin Shale in southern West Virginia. In northern West Virginia, the Gordon sand correlates with the siltstone recognized 300 feet below the Berea in the western counties. Below the Benson is an interval of silt and sand which has been called the basal Chemung siltstone interval (Patchen, 1977b). This interval can be correlated generally with the gray and green shale of the Angola

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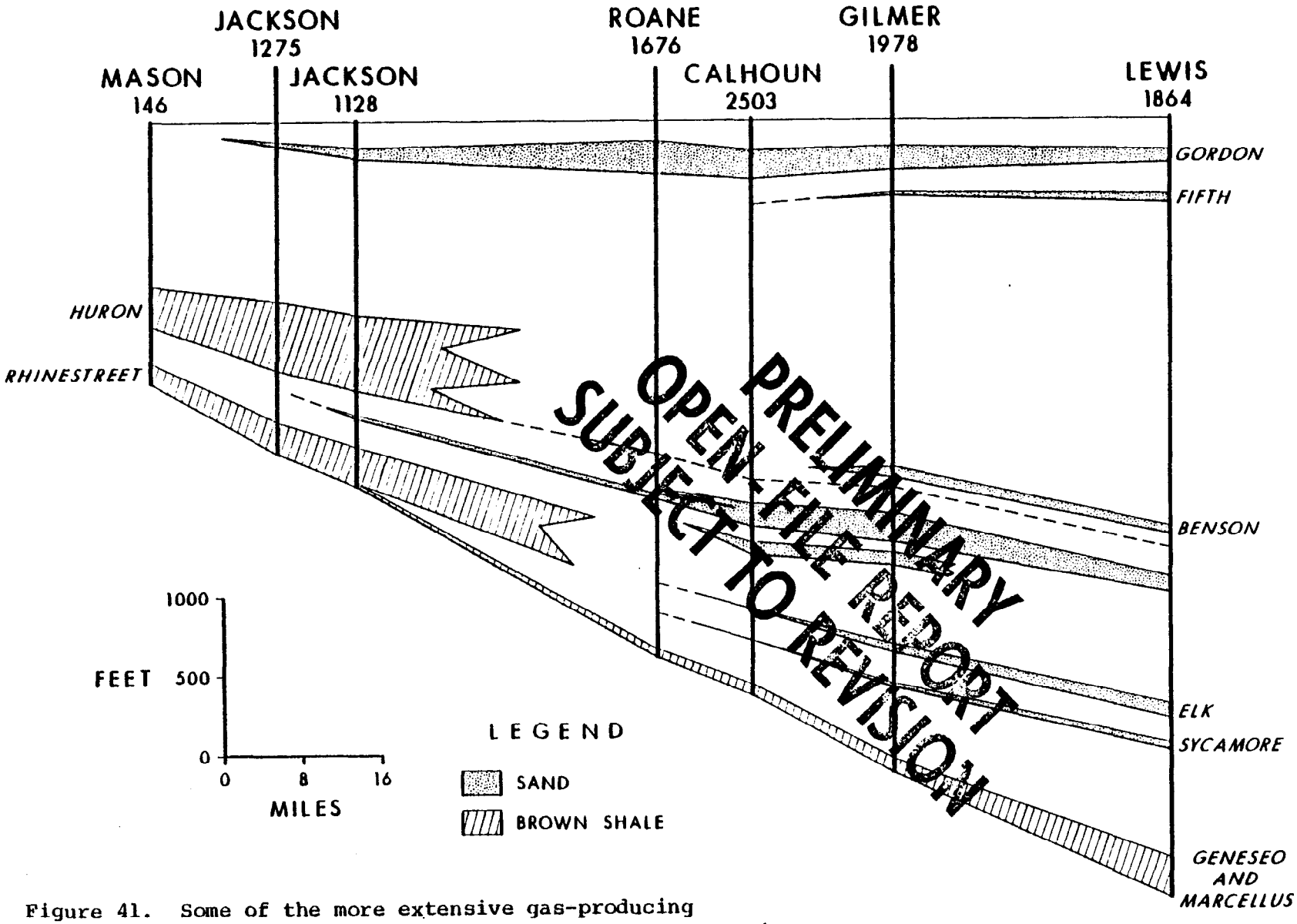

Figure 41. Some of the more extensive gas-producing sands in the study area in relation to the Rhinestreet and Huron black shales.

Shale Member of the West Falls Formation and the Java Formation in the western counties.

The lack of adequate gamma-ray log control makes mapping the distribution of the sands virtually impossible, but several things can be noted from the cross sections (Figures 41 and 42). Cheema (1977) documented changes in the shape of the radioactive signatures of the "Benson" across the area he studied. He attributed the changes in the shape of the gamma-ray response to changes in lithology which were controlled by depositional environment. In the study area, several of the older sands show a change in gamma-ray character from east to west (Figure 42). Below the Benson, each younger sand steps out slightly farther to the west than the preceding sand. In sands younger than the Benson, no distinct patterns can be seen. These sands are more discontinuous, and the overall interval is much coarser-grained.

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Summary

The gamma-ray log cross sections (Plates 2, 3 and 4) illustrate the regional relationships between the stratigraphic units. The formations are characterized by a basal high-radioactive shale overlain by less-radioactive shale. The units all thicken to the north and east. The two thickest radioactive shale units, the Rhinestreet Shale Member of the West Falls Formation and the Huron Member of the Ohio Shale, change facies in the central part of the study area from highly-radioactive shale to less-radioactive shale. In the eastern part of the study area, the section does not contain any highly radioactive shale above the Middlesex Shale Member of the Sonyea Formation,

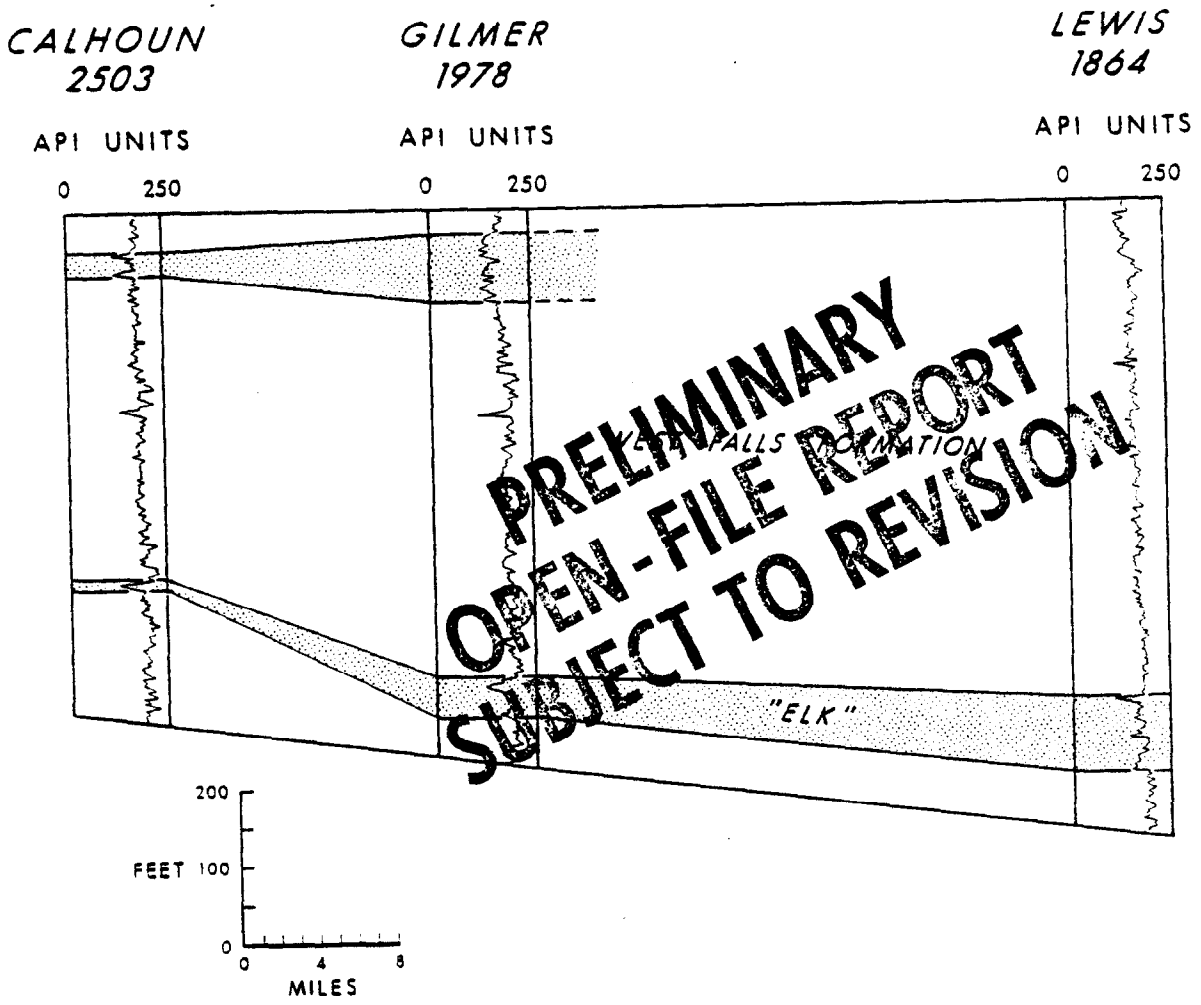

Figure 42. Gamma-ray log correlation of some of the sands in the West Falls Formation.

although many sandstone and siltstone beds are present above this stratigraphic interval.

STRUCTURE

The structure within the study area is characterized by broad open plunging folds, trending generally northeast-southwest (Figure 43). The Burning Springs Anticline, the most prominent feature in the area, has much greater than average structural relief and trends at an angle to the other folds in the area. The other important structural feature in the area is the Rome Trough (Figure 2) which is not evident at the surface. These general features are seen on structural contour maps on the top of the Onondaga Limestone (Figure 44, modified after Cardwell, 1974) and on the base of the Huron Member of the Ohio Shale (Plate 5).

The Burning Springs Anticline trends north-south along the Wood-Ritchie County border plunging out to the south in Wirt County and to the north near the Ohio River. The Sandhill deep well (Wood 351) was drilled on the crest of the structure in 1951 and penetrated a normal section except for the lower Devonian carbonates. The Onondaga and Helderberg Limestones were repreated three times and the sequence is about 1500 feet thicker than normal. Cardwell (1974) noted that the structural relief on the Onondaga Limestone in the Sandhill well is about 1500 feet, or equal to the thickening of the Onondaga and Helderberg section. Stratigraphic studies of the Middle and Upper Devonian clastic sequence in the area of the Burning Springs Anticline show a normal thickness of the interval except in Wood 518

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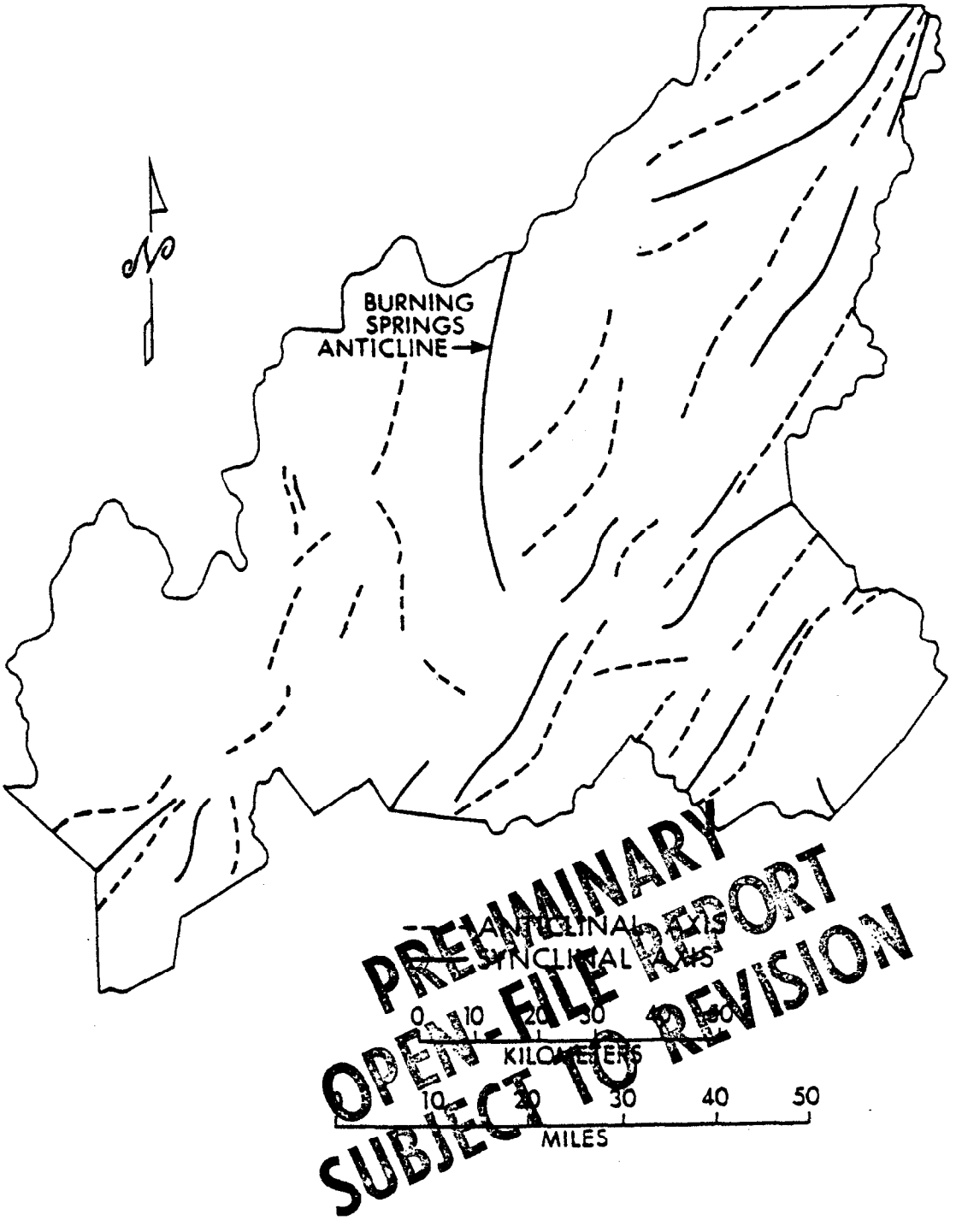

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Figure 43. Fold axes in the study area, from Cardwell, Erwin, and Woodward (1968).

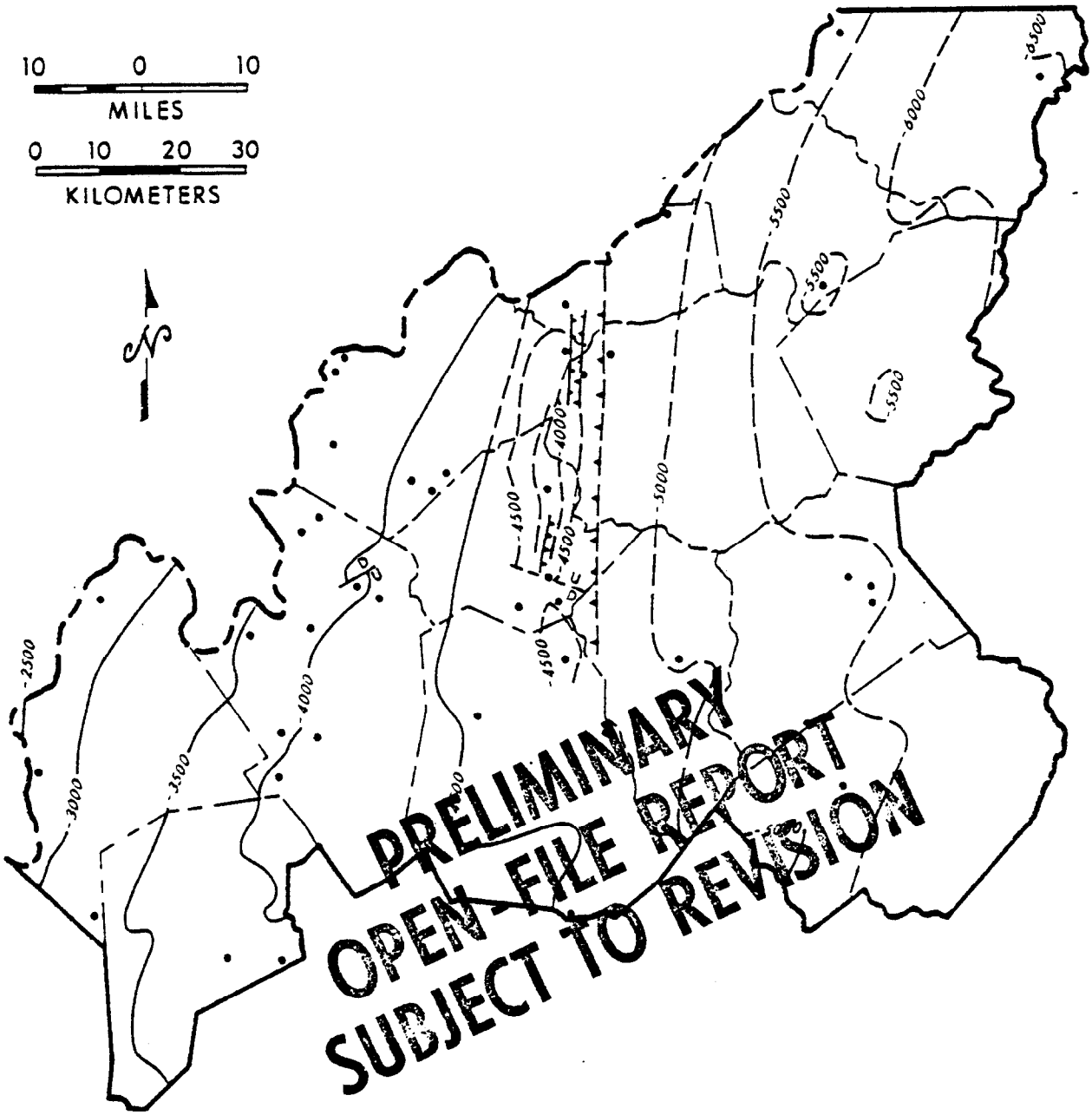

Figure 44. Structure on the Onondaga Limestone. Contour interval is 500 feet. Modified after Cardwell (1974).

to the west of the crest of the structure and Ritchie 1256 to the east. Thickening also is seen in the base of the section in wells in southern Wirt County and northern Roane County. A structural cross section of the anticline (Figure 45) shows a dip of 23 from Wood 351 to Wood 518, and 14 from Wood 351 to Ritchie 1256 at the base of the Huron. If the thickness of the units in these two wells is corrected for dip, they are comparable to those in adjacent wells off the structure. The basal black shale unit in Wood 518 has been repeated by thrust faulting.

In Wirt County, at the southern end of the structure, the anticline plunges out very sharply. Cardwell (1974) recognized a fault in the Onondaga Limestone in Wirt 548 and has inferred a fault trending east to west across the structure. Cardwell's interpretation of the Burning Springs Anticline involves three thrust faults and may be unnecessarily complicated. On the basis of the present study a simpler model is suggested. The Burning Springs Anticline is thought to be a detached structure with imbricate thrusts ramping up into the Middle Devonian carbonates. One or more of these thrust faults broke through into the basal black shale and continued as a bedding plane thrust, the extent of which is not known (Figure 46). The east-west fault shown by Cardwell in Wirt County is probably a tear fault marking the end of the transported block. The ramping would increase the dips on the side of the structure opposite the ramps as is observed on the west side of the anticline. Harris (1970) suggests a similar model for thrust faults in the southern Appalachians. The age of faulting must be post-Devonian because the sturcture did not

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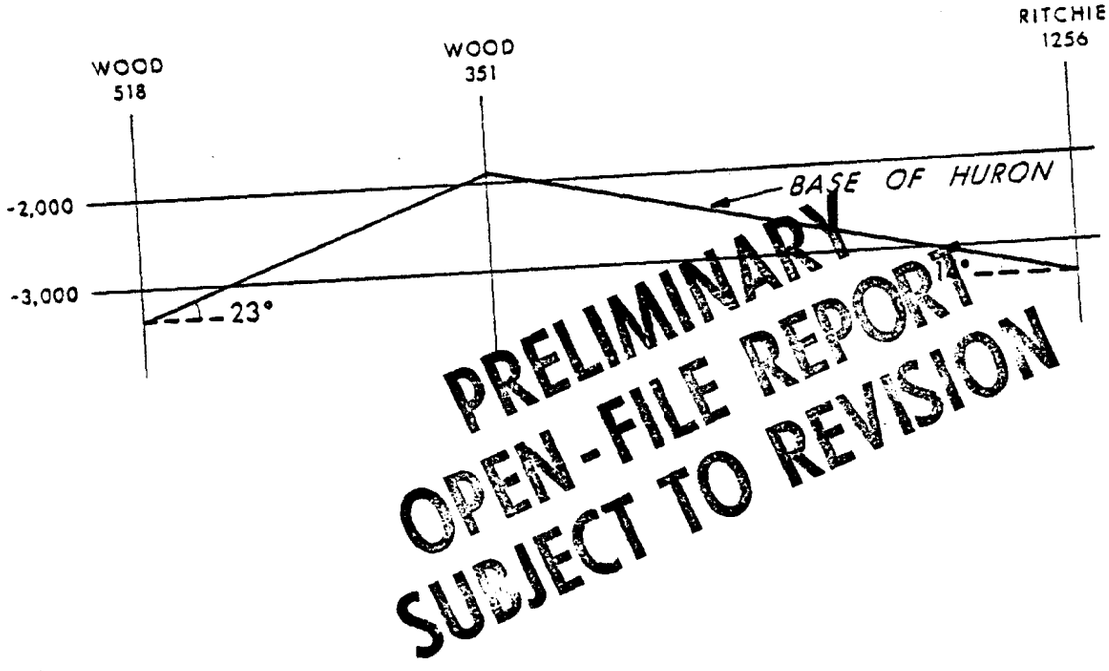

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Figure 45. Structural cross section of the Burning Springs Anticline.

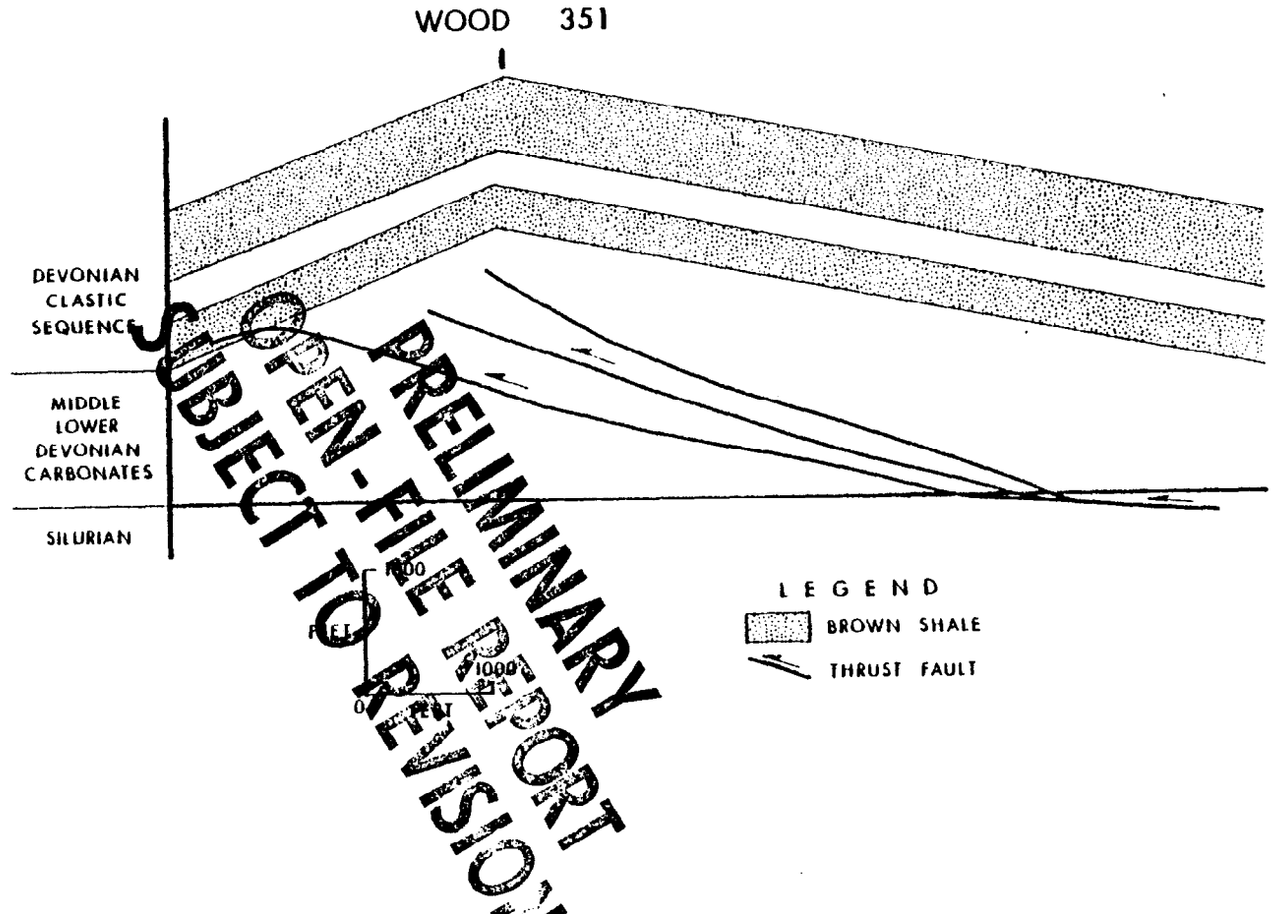

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Figure 46. Proposed model for the Burning Springs Anticline.

affect sedimentation during the Devonian.

The Rome Trough is a basement structure that is Late Precambrian to Early Paleozoic in age. The graben-type structure has been interpreted as an aulocogen (Harris, 1978), presumably a failed rift arm possibly related to the Late Precambrian opening of the Proto-Atlantic Ocean. In Kentucky, the trough trends roughly east to west and the borders are marked by the Kentucky River Fault System. In southern West Virginia, the Rome Trough curves and trends to the northeast, and its position throughout the state is marked by both basement faults and thickening of Cambrian and Ordovician units within it. In the southern part of the state, the borders of the trough are marked by anticlines at the top of the Onondaga and in the Devonian shale (Neal, 1979). The Warfield Anticline, marking the eastern edge of the Rome Trough, plunges out in Kanawha County, and in the study area the eastern edge of the trough cannot be recognized at the surface. The western edge of the trough trends through Putnam, Jackson and Wood Counties and only subtle changes in structure and stratigraphy point to the presence of the structure.

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In Mason, western Jackson, and western Wood Counties, the structure on the base of the Huron (Plate 5) dips steadily to the east. In central Jackson County and near the western border of Wood County, the slope changes and the -3500 foot contour changes trend and general character. In Mason County, the Midway Anticline falls at the edge of this change in dip and character. It is suggested that this change in dip and the change in trend of the contours mark the edge of the Rome Trough. Slightly farther to the east, there are

changes in sedimentation. The black shales in the Huron Member of the Ohio Shale and the Rhinestreet Shale Member of the West Falls Formation change facies to less radioactive gray shale. The isopach map of the Huron Member of the Ohio Shale (Figure 36) shows a change in the rate of thickening in eastern Jackson County. All of these changes marking the edge of the Rome Trough are very subtle, yet the influence of the border of the trough can be recognized. The facies changes suggest that the trough had a subtle control on the basin configuration, perhaps only as simple as a slight differential in compaction of the sediments within the trough and outside.

In the eastern part of the study area, a relationship is seen between structure and sedimentation. Unfortunately, data are very sparse and at best the recognized trends are general and conjectural. Structural contours drawn on top of the Onondaga Limestone and at the base of the Huron show an anticline and a syncline trending approximately northeast. Both of the structures also change to the northeast. A structure map constructed on the top of the Mississippian Greenbrier Limestone (Haught, 1955a), where there are more data, shows these two structures and many smaller folds. Isopach maps of the Ohio Shale (Figure 36), West Falls Formation (Figure 30), Sonyea Formation (Figure 20), and Genesee Formation (Figure 16), show a change in the trend of the contours in the area with the units thicker in the syncline.

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INORGANIC GEOCHEMISTRY

Samples of well cuttings from 10 wells in the southwestern part

of the study area (Figure 47) were analyzed by the Geochemistry Section of the West Virginia Geological Survey. Samples were taken at 50-foot intervals, where possible, and each sample represents an average of 10 feet of section. However, some sample intervals do range from 5 to 20 feet in thickness. In addition, samples from the Mason County core (Mason 146) representing 0.1 foot intervals and spaced from 1 to 20 feet apart were analyzed. Elemental analyses were performed by X-ray spectroscopy using pelletized powders according to the method outlined by Nuhfer et al (1979). Results were expressed as oxide percentages such that the concentration of the oxides of silicon, aluminum, iron, magnesium, calcium, sodium, titanium, phosphorous and manganese sum to 100%. Sulfur was expressed as a percentage of the total rock.

The distribution of 4 elements (silicon, aluminum, titanium, and sulfur) has been examed in detail in the study area. Silicon and aluminum were studied because they are the two dominant constituents of the shale. In addition, examination of silicon and aluminum concentrations yields information about the relationship of quartz and the clay minerals, the dominant mineralogic constituents of the shale. Titanium was chosen for study because it is usually associated with the detrital fraction of the rock (Vine and Tourtelot, 1970) and should be useful in determining the distribution of the allocthonous portion of the sediment. Sulfur is generally associated with the organic carbon (Leventhal, 1978).

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To examine variations in geochemistry with lithology, the section was subdivided into three units: the Huron Member of the Ohio Shale;

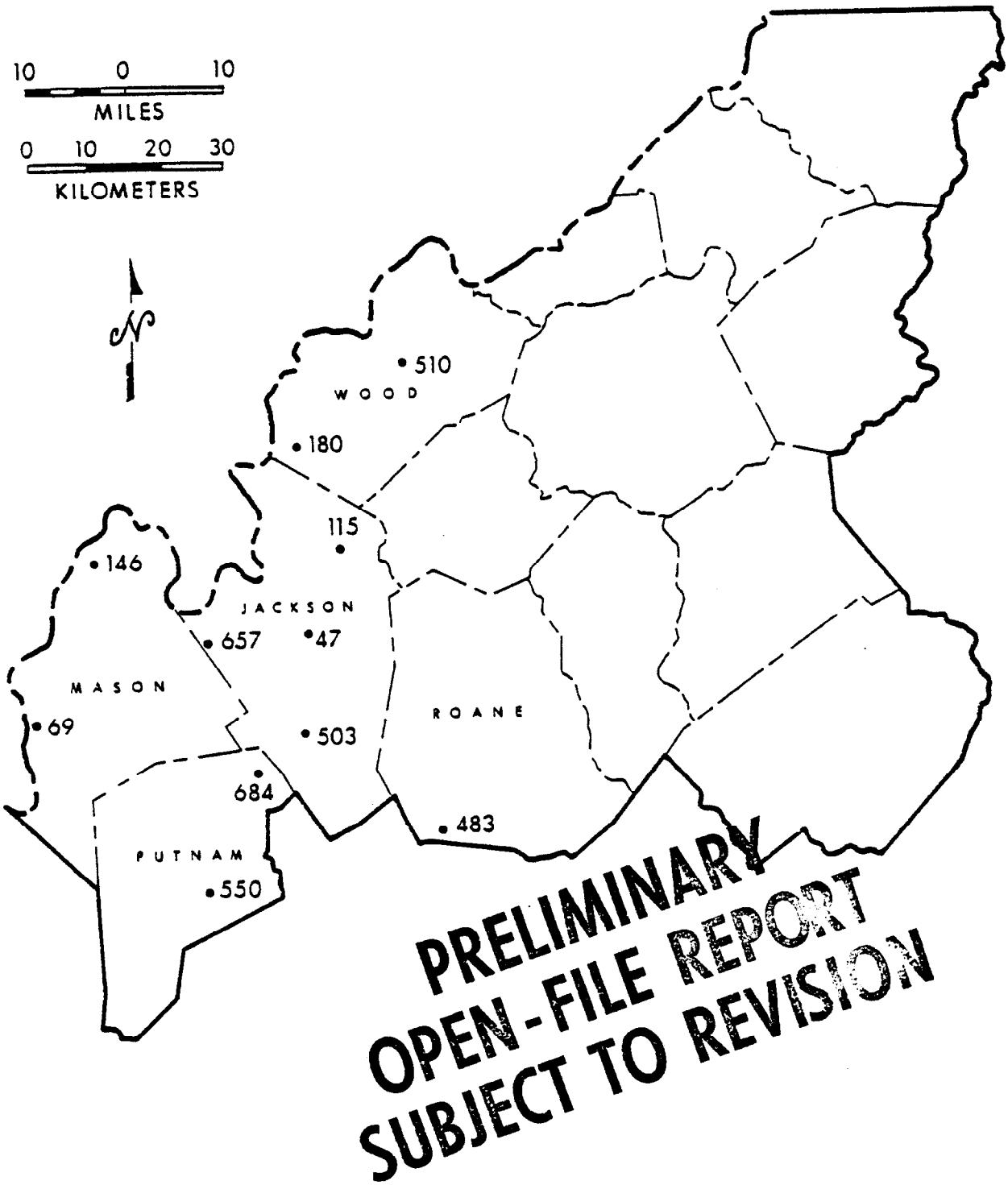

Figure 47. Location of geochemical samples. Numbers are state permit numbers.

the Big White Slate, which is equivalent to the Java Formation and the Angola Shale Member of the West Falls Formation; and, for the purposes of the geochemical study, the Rhinestreet Shale, which includes all of the shale between the top of the Rhinestreet Shale Member of the West Falls Formation and the top of the Onondaga Limestone. These broad stratigraphic subdivisions were necessary because most of the well cuttings are from cable-tool wells and the only source of stratigraphic information were drillers' logs and sample studies in which it is not possible to recognize the refined stratigraphy obtained from gamma-ray logs.

The variation in the concentration of the elements was examined both vertically and geographically. The vertical distribution was made by examination of plots of concentration against depth. The geographic distribution of the concentration was studied by mapping the mean of the concentration of each oxide for each stratigraphic interval. The non-parametric Kolomogorov-Smirnov Goodness of Fit test (Siegel, 1956) was used to determine if the variation of the means across the study area was significant. The nonparametric test was employed because of the small sample size.

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In the study area, silicon ranges from 5% to 70%, and in Wood 510 and Roane 483, the northern and eastern-most wells studied, the concentration of silicon increases up-section. Otherwise no vertical trends are seen for silicon. Neal (1979, Fig. A2 and A15) found that silicon increases up-section in southern West Virginia. This trend is most conspicuous in the eastern portion of Neal's area and is most evident in the undivided shale sequence above the Huron.

The trend was probably not recognized in the study area because the samples are from the western portion of the area and the undivided Upper Devonian sequence was not sampled. The complete Huron interval was examined in only five wells (Mason 146, Jackson 657, Jackson 503, Jackson 47 and Roane 483). In these wells, the silicon shows a high in the west, with a saddle in the middle, and a low to the east (Figure 48A). In the Big White Slate, there is no significant variation across the area, although a slight increase is seen to the west (Figure 48B). The silicon concentration in the Rhinestreet interval IFigure 48C) shows a high in the center of the area decreasing to the southwest and to the east.

Aluminum generally exhibits a negative correlation with silicon. Because these two constituents generally compose 90% of the sample, as the concentration of one increases, the concentration of the other decreases. Aluminum shows no trends through time in any of the wells. The geographic distribution of aluminum is generally opposite that of silicon (Figure 49).

In general, titanium increases in concentration up section. All of the wells exhibit an increase in the concentration of titanium through the Rhinestreet. The trend continues up through the Big White Slate, but is not as conspicuous. In all of the wells, except Wood 510 and Roane 483, titanium concentration decreases at the base of the Huron and the concentration is variable with the Huron. In Wood 510 and Roane 483, a slow increase in titanium is seen all the way up the samples section. In the Huron, the titanium concentration increases to the east (Figure 50A). There is no significant change in

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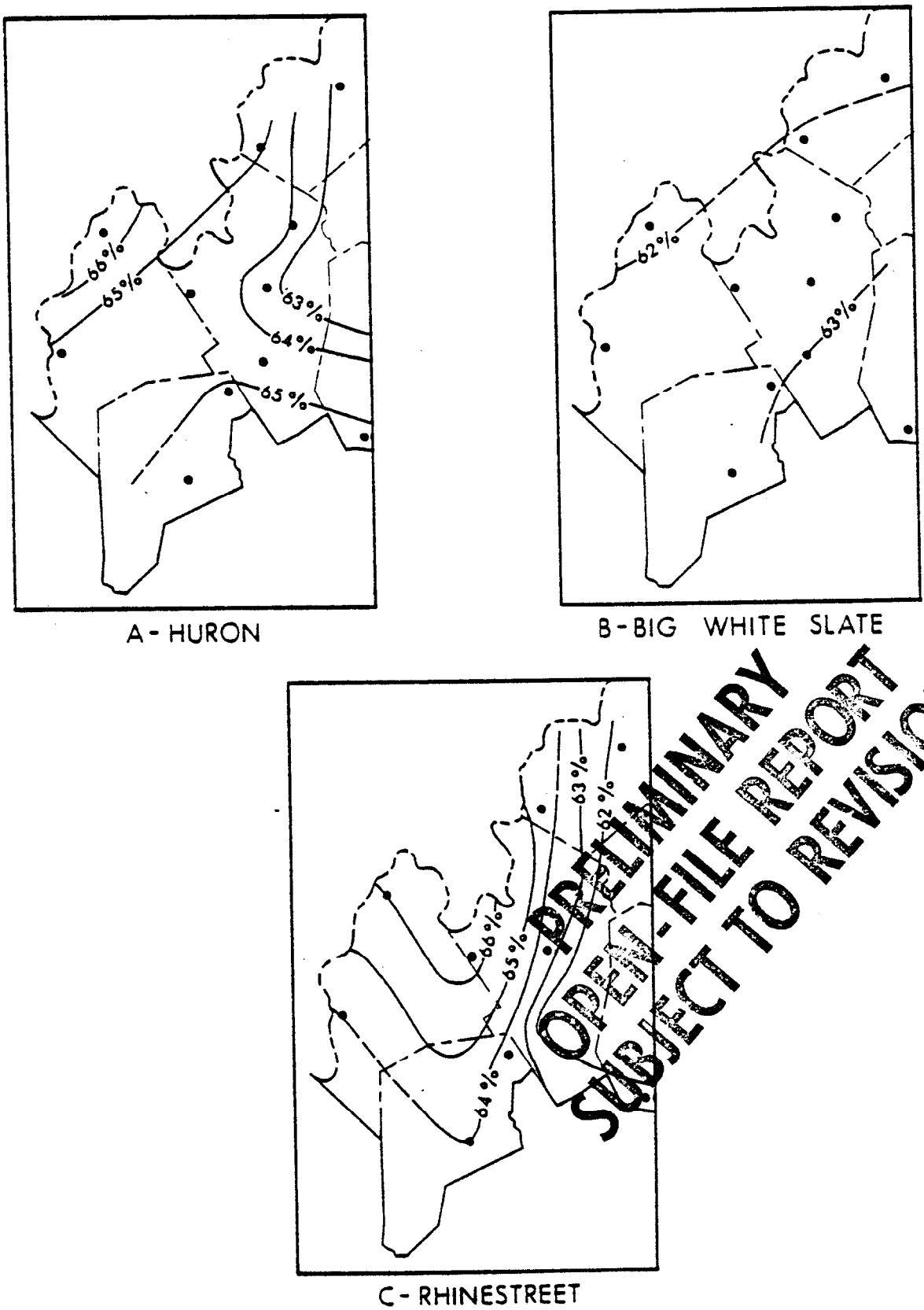

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Figure 48. Distribution of silicon (as SiO_2) in the western part of the study area.

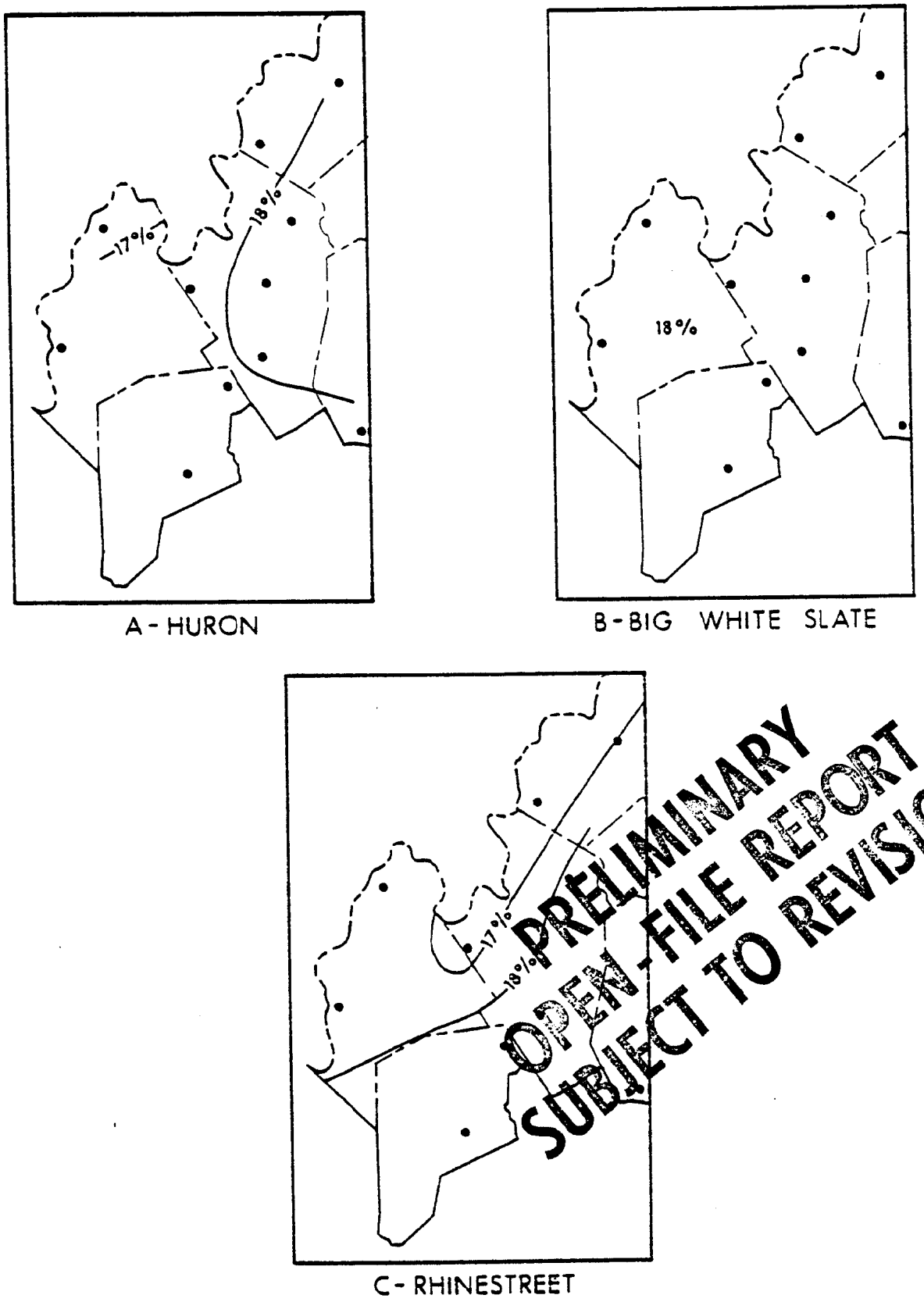

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Figure 49. Distribution of aluminum (as Al_2O_3) in the western part of the study area.

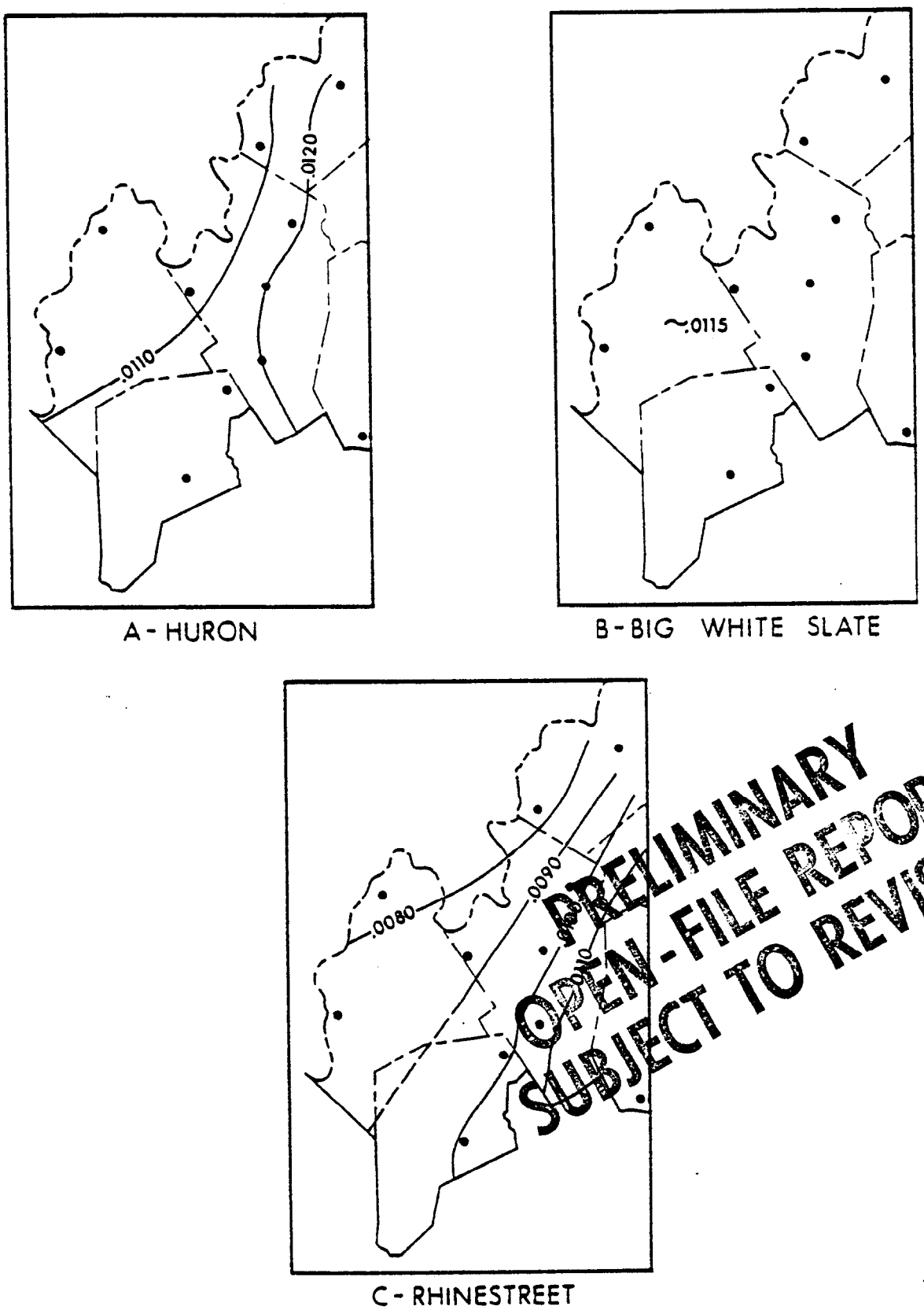

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Figure 50. Distribution of titanium (as TiO_2) in the western part of the study area.

titanium concentration in the Big White Slate, but the concentration increases to the southeast in the Rhinestreet (Figure 50C).

Sulfur is the only element that shows a significant change at lithologic boundaries, being higher in both the Huron and Rhinestreet units. The geographic distribution of sulfur was not examined.

Examination of cores and gamma-ray logs shows that the shale of the Huron and Rhinestreet intervals is not homogeneous, but is composed of brown to black shale interbedded with gray-green shale. The units vary from paper-thin laminae to beds several feet thick. The variability of silicon in well cutting samples suggests that the chemistry of the units may vary with color. To examine the variation of chemistry with the color of the shale, a more detailed study was made of samples from the Mason County core (Mason 146). The core was described in 5 to 10 foot intervals, the color of the shale was determined using the Rock-Color chart (Goddard et al, 1948), and a visual estimate of the percentage of shale of each color was recorded in the description (West Virginia Geological and Economic Survey, in preparation). Concretions and siltstone beds also were noted in the description. The concentrations of silicon, aluminum, and titanium, and the color and intensity of the dominant shale were plotted against depth for the Rhinestreet Shale member of the West Falls Formation and the Huron Member of the Ohio Shale (Figures 51 and 52). Trends are not apparent in the concentrations of the elements in the Huron Member of the Ohio Shale. In the Rhinestreet Shale Member of the West Falls Formation, silicon and aluminum show no conspicuous trends, but titanium increases up-section. Titanium and aluminum show covariability in both the Huron

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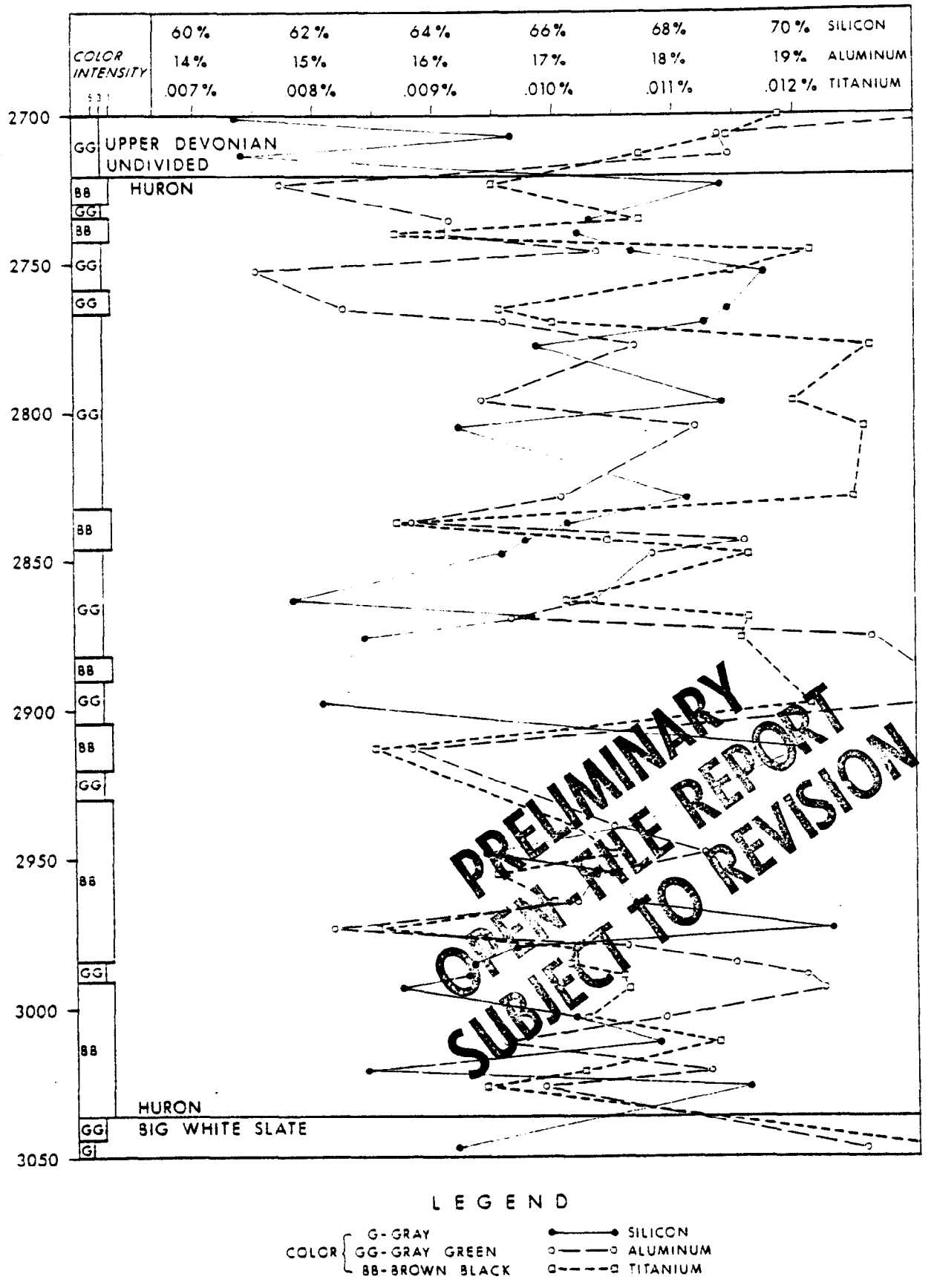

Figure 51. Vertical distribution of silicon, aluminum, and titanium (as oxides) in the Mason 146 core.

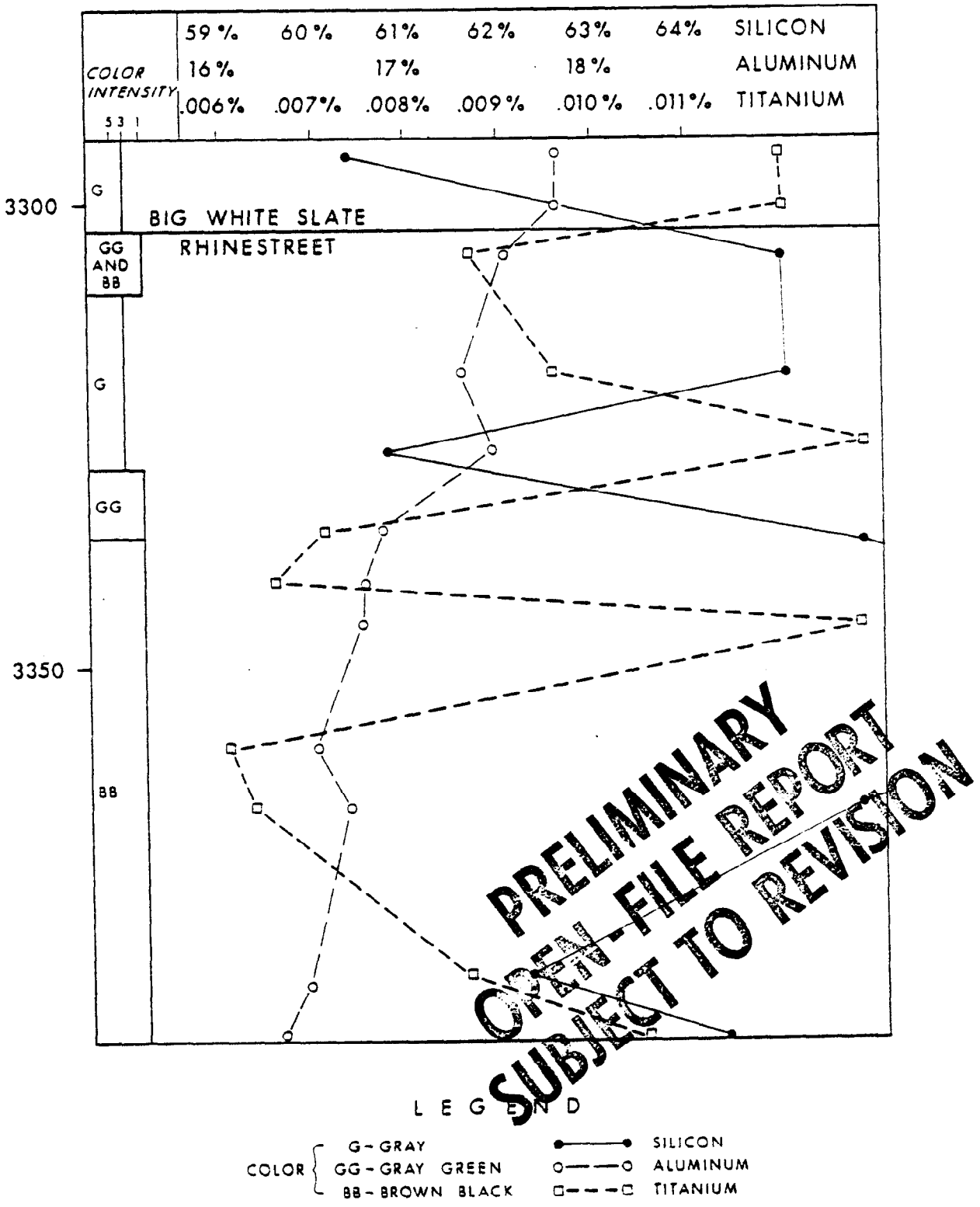

Figure 52. Vertical distribution of silicon, aluminum, and titanium (as oxides) in the Rhinestreet in the Mason 146 core.

and Rhinestreet and both elements show a negative correlation with silicon.

To test for variation of composition with lithology, all of the samples (9) from core intervals that were dominantly (greater than 85%) dark brown-gray (5YR 2/1) and all of the samples (7) from core intervals that were dominantly (greater than 80%) olive-gray (5Y 4/1) were compared. The difference in the means of the two groups was compared using the Kolmogorov-Smirnov Goodness of Fit test under the null hypothesis that the concentration of silicon (aluminum, titanium) is the same for the samples from the brown-gray shale and the olive-gray shale. Using a class size of 1% for silicon, the null hypothesis was rejected at an α level of 0.01. Using a class of 1% for the aluminum, the null hypothesis could not be rejected, but a class size of 0.05% allowed the null hypothesis to be rejected at an α level of 0.05. The null hypothesis was rejected at an α of 0.01 for a class size of 0.0005% for titanium. The concentration of silicon is higher in the dark shale and the concentration of titanium and aluminum is higher in the olive gray shale.

Comparison of the concentration of silicon and aluminum between 10 randomly selected samples from the Big White Slate and the brown-gray shale of the Huron Member indicates that they are statistically different. The aluminum and silicon concentrations of the olive-gray shale are not significantly different from those of the bluish-gray shale of the Big White Slate.

The differences seen between the brown-gray shale and the Big White Slate are not apparent in the analysis of well cuttings, because

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of the mixing of the two lithologies that make up the Huron. The mixed samples mask the distinct character of each, and the average sample of the Huron is representative of neither type of lithology. To see if the variations could be recognized in the analysis from well cuttings, the color of the prepared powdered XRF samples was determined and compared to the concentrations. The color of the XRF pellets may not be true to the original color of the shale, but the tint has been preserved and the relative color intensity between samples is maintained. Significant correlation was not seen between the color of the samples and the composition of the shale from Jackson 47, Wood 510 and Mason 69.

In summary, chemical analysis of well cuttings can be used for a very broad-brush regional picture of the changes in the area, but because of the variation in the data it is imperative that data and contours be viewed critically. Well cuttings are suitable only for general regional trends, because the 5 to 20 feet composited for analysis commonly include differing lithologies of gray-green shale, gray-brown shale, siltstone and concretions. The actual composition of the Huron is not accurately determined in these samples, because they are a mix of two chemically-distinct shales.

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The titanium concentration for both the Huron and Rhinestreet intervals shows a gradual increase to the east, which fits with presently accepted models of sedimentation in the basin with a sediment source to the east. The increase of titanium vertically through the Rhinestreet and the Big White Slate indicates a general increase in detrital components with time. The correlation of titanium

with aluminum indicates that the clay minerals were the detrital component. The negative correlation of silicon and titanium suggests that some of the silicon may be the result of authigenic growth of quartz in the dark shale.

GAS PRODUCTION

Gas is produced from the Middle and Upper Devonian clastic sequence throughout the western part of the study area. Most of the production is from the Huron Member of the Ohio Shale (Plate 6) with additional production from the Rhinestreet Shale Member of the West Falls Formation (Plate 7). The Devonian shale is the main producing interval in two fields in the study area: the Midway-Extra Field in Putnam County and the Cottageville-Mount Alto Field in Jackson and Mason Counties.

Schaefer (1979) made a detailed study in the Midway-Extra field and found that the lower part of the Huron Member of the Ohio Shale is the major producing zone in the field. He noted that low-density zones rich in organic matter are the most productive intervals within the Huron. Production also is structurally controlled, coming primarily from the flank of the Midway anticline. Schaefer stated that "The relationship between production and structure suggests that the gas production is from a fracture system developed by stresses during or after folding (p. 59)."

Nuckols (1979) studied the Cottageville-Mount Alto Field located in Jackson County and adjacent eastern Mason County. The Cottageville Field also produces from low-density zones rich in organic matter within the Huron Member of the Ohio Shale. Production

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is structurally controlled in the Cottageville Field as well. A monoclinal flexure trends across the field, and Nuckols suggested that this flexure may have caused more intense fracturing of the Huron Member in the field area.

Gas production from the Devonian shale is in part stratigraphically controlled. Both Schaefer and Nuckols noted that production is primarily from the low-density zones, rich in organic matter, within the Huron Member of the Ohio Shale. The Huron is potentially productive throughout the western part of the study area, where dark, organic-rich shale is present. To the east, the Huron changes facies to gray-green shale which is non-productive. The facies change coincides approximately with the 700 foot isopach contour in Figure 36. Although some black shale is present to the east in the Huron interval, it is probably not thick enough or extensive enough to be productive. Plate 6 shows production from the Huron Member of the Ohio Shale; production is scattered in Putnam, Mason, Jackson, and Wood Counties. On the basis of regional stratigraphy, these counties are considered favorable targets for exploration.

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The Rhinestreet Shale Member of the West Falls Formation also is characterized by a dark, low-density shale zone rich in organic matter and should be considered an exploration target. Gas production from the Rhinestreet Shale is scattered throughout the western part of the study area (Plate 7). Generally, the Rhinestreet Shale is untested in the Midway-Extra and Cottageville Fields, because most of the older wells were not drilled below the base of the Huron. However, recent wells on the northeast edge of the Midway-Extra Field have

produced gas from the Rhinestreet Shale. At present, it is uncertain if production reported from Calhoun and Ritchie Counties is from dark shale of the Rhinestreet Shale or from siltstone beds within the shale sequence.

A third exploration target is the dark shales of the Genesee Formation and Marcellus Shale in the eastern part of the study area. Recent wells in Gilmer County (Plate 7) are producing from these intervals.

Production in the Midway-Extra and Cottageville Fields is from fractured reservoirs related to structure. Exploration for Devonian shale gas should focus on structural anomalies that might indicate the presence of fractures. Because of the low relief of the structures, detailed structural maps are necessary. Nuckols (1979) mapped the Cottageville Field using a contour interval of 20 feet and was thus able to recognize structural controls in the field which had not previously been identified. In the western part of the study area, the top of the Berea Sandstone can be used as a datum for structural maps. The Berea Sandstone and the overlying Sunbury Shale can be recognized in drillers' logs and more control is available in these units than deeper horizons. Nuckols demonstrated that the structure present in the Cottageville Field could be recognized at the top of the Berea Sandstone.

In the western part of the study area, the Lower Devonian Oriskany Sandstone produces from several fields (Plate 6). In these areas, because the Oriskany Sandstone was the principal target, gas in the brown shale was generally overlooked. Furthermore, production from the Oriskany Sandstone is stratigraphically controlled (Cardwell, 1974). Therefore, these areas should be re-examined for possible

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structural anomalies that would allow production from the shale. Recent developments in Jackson County included production from the Huron Member of the Ohio Shale along the western edge of the Oriskany producing trend.

DISCUSSION

Devonian clastic rocks are today preserved along the length of the Appalachian Mountains from New York to Alabama, and as far west as Iowa. In the eastern part of the Appalachian basin coarser-grained rocks (sandstone and siltstone) predominate. To the west, finer-grained clastic rocks are dominant and thick sequences of black shale, rich in organic matter, are present along with gray and greenish-gray shale. The study area is situated at the transition between the coarse-grained and fine-grained clastic rocks in the basin. The rocks can be subdivided into two facies in the study area: an eastern facies composed of siltstone and gray shale, and a western facies composed of fine-grained clastic rocks that are often rich in organic matter.

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The rocks present in the western part of the study area are composed of gray, gray-green, and black shale, with some siltstone beds. Traditional classification schemes for clastic, fine-grained rocks are based on fissility (Pettijohn, 1957). Fissile rocks are classified as shale, and non-fissile rocks as mudstone or mudrock. Many of the fine-grained clastic rocks of the study area are non-fissile and should be termed mudrock, but historically the Devonian clastic rocks in West Virginia have been called shale and that usage has been followed here.

In western West Virginia, drillers have long recognized two dominant lithologies in the interval from the top of the Huron to the top of the Onondaga: "brown" shale and "white slate". The "brown" shale intervals correlate with the highly radioactive Rhinestreet Shale and the Huron Member of the Ohio Shale. The "white slate" correlates with the gray shale of the Angola Shale and the Java Formation.

The "brown" shale intervals of the Rhinestreet Shale and the Huron Member are not uniform in character. Lithologies range from laminated dark-colored shale to massive gray-green shale, all of which are silty. The dark-colored shale is dark-gray to brown-black in color and in the study area contains as much as 10% organic carbon (Leventhal, 1978; Zielinski et al., 1978; West Virginia Geological and Economic Survey, 1979). The dark-colored shale is laminated and where laminae are less than 2 mm thick, they are continuous and have sharp boundaries (Nuhfer, Vinopal, and Klanderman, 1979). As laminae increase in thickness, they are less continuous and have more diffuse boundaries. The darkest-colored shale (brown-black) commonly has the thinnest laminae. Pyrite is common in the dark-colored shale as disseminated grains, nodules, and laminae. Burrowing is rare in shale with very thin laminae, but becomes more common as laminae thicken.

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The dark-colored shale is interbedded with gray-green shale, which is either banded or massive. The banded shale is characterized by alternating light and dark-colored bands greater than a centimeter in thickness with sharp boundaries (Nuhfer, Vinopal, and Klanderman,

1979). The massive shale may show vestiges of lamination, but it has generally been destroyed by bioturbation (Nuhfer, Vinopal, and Klanderman, 1979). The massive shale is generally lower in organic content than the banded and dark-colored shales, but no clearcut relationship exists between lithology and organic content (West Virginia Geological and Economic Survey, 1979).

The contacts between the gray-green shale and the dark-gray shale are generally gradational as in the Wetzel 645 core (Appendix 1) where cycles of gray-green shale grading upward into dark-gray shale are dominant. The cycles range in thickness from 2 to 12 inches and have a sharp contact between the top of the dark shale and the overlying gray-green shale (see Appendix 1, 6112.9 to 6127.3 feet). Bioturbation decreases toward the top of each cycle and the concentration of organic matter increases upward (Figure 5B). Gradational changes from dark to light to dark-colored shale and light to dark-colored shale are occasionally noted (see Appendix 1, 6127.3 to 6157.9 feet; Nuhfer, Vinopal, and Klanderman, 1979, Figure 4C and 4D). The brown-black shale is usually present ranging in thickness from laminae to beds several inches thick with sharp upper and lower boundaries.

Dark-colored shale is not evenly distributed in the Huron Member and the Rhinestreet Shale. The Rhinestreet Shale can be subdivided into 3 units: a lower zone composed of interbedded gray-green shale and dark-gray to brown-black shale; a middle zone dominated by dark-colored shale; and an upper zone of interbedded light and dark-colored shale. In the Rhinestreet Shale in the Wetzel 645 core, the proportion of dark-colored shale increases down-section in 5 to 10 foot intervals.

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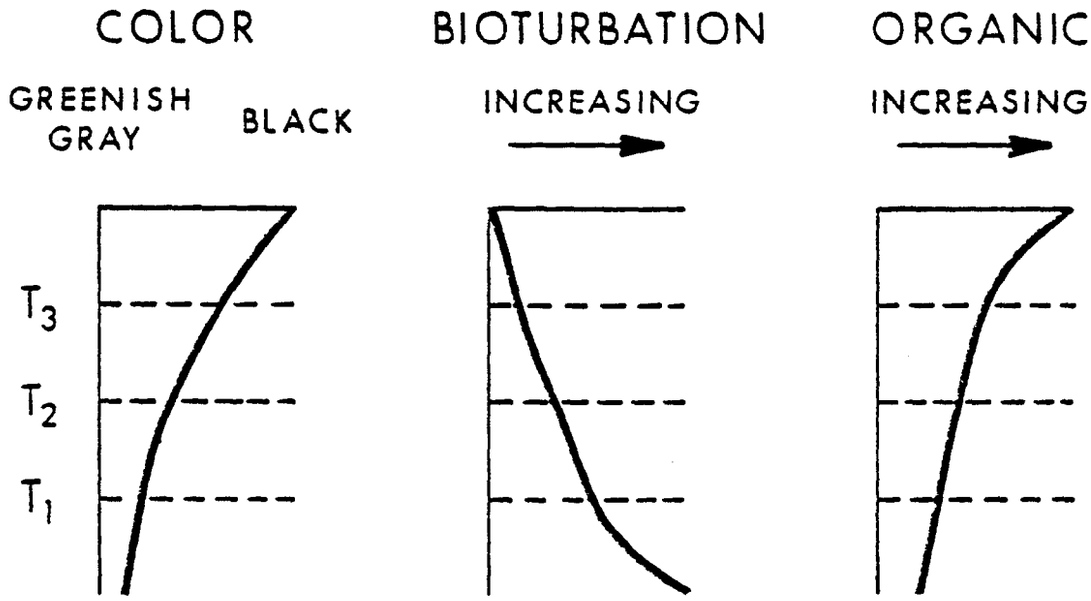

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Figure 53. Schematic representation of variation observed in small cycles in the Wetzel 645 core.

The dark-colored shale beds are more frequent at the base of each interval. The gradual increase in dark shale beds toward the base is repeated through the Rhinestreet Shale.

The Huron Member of the Ohio Shale in the study area can be divided into an upper and lower tongue of "brown" shale separated by a tongue of gray-green shale that pinches out to the west. Similar younger tongues of "brown" shale (the upper part of the Huron Member and the Cleveland Shale Member of the Ohio Shale) are recognized to the west of the study area. In the lower tongue of the Huron in the study area the porportion of dark shale increases toward the base of the section.

Occasional beds of siltstone are present in the "brown" shale intervals but they are most common in the upper part of the section. Most of the siltstone beds show small-scale cross-bedding, and rip-up clasts, load casts, and soft sediment deformation also have been observed in siltstone beds (Nuhfer, Finpal, and Klanderman, 1979). The siltstone beds usually have sharp basal contacts and gradational upper boundaries. Calcareous concretions are common in the "brown" shale intervals.

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The Java Formation and the Angola Shale Member of the West Falls Formation are composed of banded and massive gray shale with some gray-green shale. The shale is silty, pyritic, and frequently burrowed. Siderite concretions are present in this interval. The boundaries between the gray shale intervals and the "brown" shale intervals are sharp.

The fauna in the shale is dominated by ostracods, conodonts,

styliolininds, and cephalopods which have been interpreted as planktonic and nektonic forms that lived in surface waters (Rich, 1951; deWitt and Colton, 1978). However, the shale is not devoid of benthic forms because Duffield (1978) reported the presence of pyritized micromorphs of brachiopods, gastropods, and cephalopods from the Lincoln 1637 core. Klanderman (1980, personal communication) examined concretions from the Wetzel 645 and Mason 146 cores, and found numerous, small, fragile fossils including gastropods, bivalves, and echinoderm plates preserved in the concretions. Also, linguloid brachiopods are locally abundant in the shale (Conant and Swanson, 1961). Bioturbation is present throughout the shale in the study area, although it is most common in the gray and gray-green shale and less abundant in the darker-colored shale. In the Wetzel 645 and Mason 146 cores, burrows are evident as dark traces in gray-green shale subjacent to dark shale beds. Two burrowing patterns can be recognized: large burrows, 1/2 to 2 inches in length and 1.4 inch wide; and small burrows, 1/4 to 1/8 of an inch long. Dark burrow traces in gray shale underlying dark shale also were observed in outcrop at the base of the Dunkirk Shale along Lake Erie at Dunkirk, New York.

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The eastern facies of the Devonian clastic sequence is composed of shale, siltstone, and some fine-grained sandstone. I have not examined the eastern facies in detail but several intervals in it have been studied in central West Virginia (Cheema, 1977; Horsey, 1978; Tepperman, 1978). Martens (1939) described samples from the lower 3100 feet of the clastic section in Doddridge 71. Gray-green and gray to dark-gray, sandy, silty shale are the dominant lithologies in this well and Martens also recognized some brown to dark-brown

shale in the interval. In the upper part of the section that he described, very fine-grained, gray to gray-green, silty and shaly sandstone beds were present. Cheema (1977) described cores from the "Benson" interval as being composed of interbedded light brown-gray, massive, fine-grained sandstone; gray to light brown-gray siltstone; and dark gray to black shale. Argillaceous siltstone and shale were the dominant lithologies in the "Benson" interval. Tepperman (1978) examined well-cuttings of sandstone intervals in the upper part of the section and described them as generally clean, very fine-grained, and quartzitic, although in some areas they were more argillaceous and micaceous.

DEPOSITIONAL MODEL

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Many models have been proposed for the environment of deposition of the Middle and Upper Devonian clastic sequence. These models can be grouped as deep water with water depths interpreted as in excess of 500 feet (Rich, 1951; McIver, 1961; Byers, 1977; and Claeser, 1979) and shallow water with water depths interpreted as less than 300 feet (Grabau, 1906; Conant and Swanson, 1961; Hallam, 1967).

Deep water models propose the deposition of coarse-grained clastics on a shallow shelf in the eastern part of the basin, gray shale on an intermediate slope, and black shale in deep water to the west in the basin (Figure 54). The deep water model does not take into consideration the known stratigraphic relationships of the western margin of the basin and suggests that the deep basin extends to the west. It is known that to the west the Devonian clastic sequence onlaps a major unconformity. In Tennessee, black

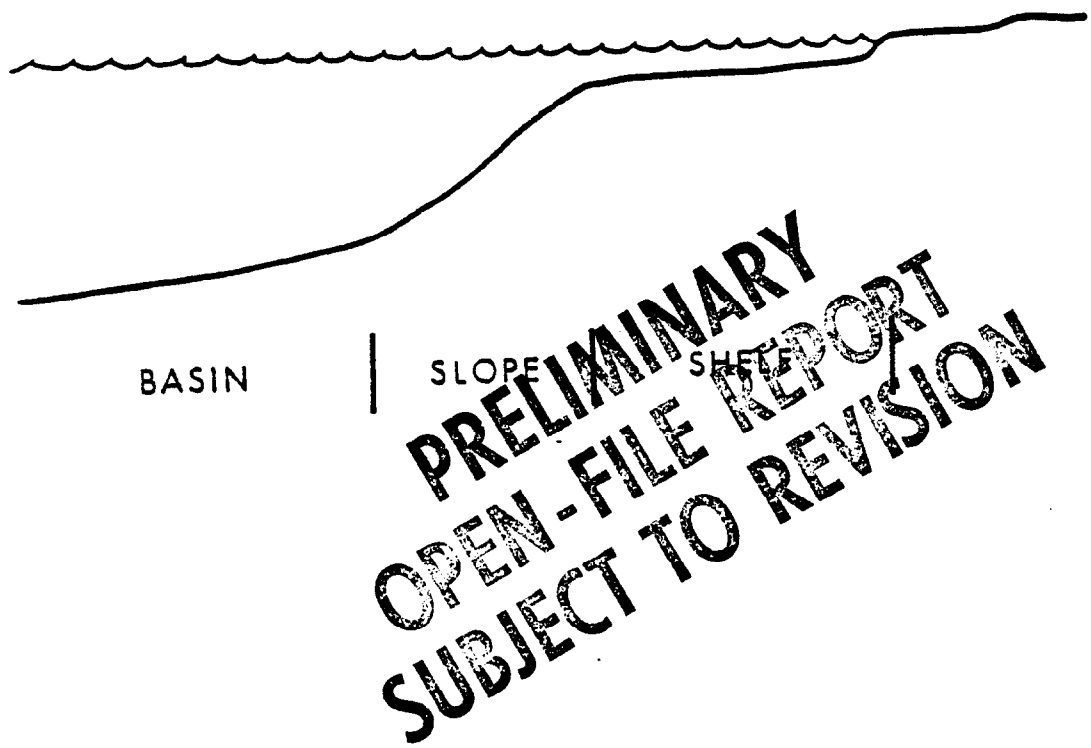

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Figure 54. Basin configuration proposed by deep-water models.

shale rests directly on the unconformity and has been interpreted by Conant and Swanson (1961) to represent shallow water black shale deposition. In Ohio, the Cincinnati Arch was emergent during deposition of the lower part of the Devonian clastic sequence, but during the Upper Devonian, the Ohio Shale was deposited across the arch (Schwietering, (1970).

The lamination of the shale and the absence of sedimentary structures have been interpreted as evidence that the shale was deposited in quiet water below wave base. Sedimentary structures are not entirely absent as small-scale cross-bedding and small cut and fill structures have been observed (see Appendix 1, 6130.93 and 6138.2). The presence of the lamination has been interpreted by some workers to be evidence of gentle current action (Conant and Swanson, 1961; Nuhfer, Vinopal, and Klanderman, 1979). The small scale of the current features suggests that gentle currents may have been present, but the shale was deposited in a low-energy environment below disturbance by waves. Many workers have used 600 feet, the depth of the shelf break on modern continental shelves, as the base of effective wave action (McIver, 1970). Other models have used shallower depths such as 200 feet (Rich, 1951), but Dietz and Menard (1951) reported that the limit of vigorous wave abrasion is less than 30 feet on modern continental shelves. Shaw (1964) and Irwin (1965) advanced the hypothesis that in shallow epeiric seas, tidal energy would be dissipated by frictional effects on the bottom. A theoretical model presented by Keulegan and Krumbein (1949) demonstrated that in a shallow sea with a bottom slop of less than 1 in 600, waves

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will be modified in shape and energy and will arrive at the shore without breaking and with minimum energy. Thus, the interpretation of a low-energy environment does not require deep water. Low energy may occur in relatively shallow water on a broad, gently sloping shelf, or in a restricted environment such as a lagoon.

The absence of a benthic fauna has been cited as evidence of deposition of the shale under anoxic conditions (Rich, 1951; Sutton, Bowen, and McAlester, 1970; Byers, 1977). Byers presented a mdoel for euxinic basins relating biofacies to oxygen levels which he suggested were controlled by depth. Aerobic water will support a shelly benthic fauna with infaunal bioturbation, whereas dysaerobic water (dissolved oxygen levels less than 2 ml/l) will have infaunal bioturbation but lack a shelly benthic fauna. Euxinic conditions are characterized by the absence of both a shelly benthic fauna and infaunal bioturbation. Fossils are not abundant in the Devonian clastic sequence but they are present and bioturbation is relatively common. Baird (1976) suggested that the low diversity of species in the shale may have developed because bottom muds were too soft or thixotropic to support a shelly benthos. Wells (1947) suggested that the low abundance of fossils in the Olentangy Shale in Ohio was the result of fine sediment stifling the biota. The presence of fossils in the concretions and pyritized forms in teh shale suggests that the apparent absence of fossils also may have been the result of nonpreservation of calcareous forms.

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The abundant organic matter preserved in the black shale has been cited as evidence that it was deposited in a reducing environment

(Rich, 1951; Byers, 1977). Smirnow (1958) stated that even in anoxic water the preservation of organic matter "depended on the presence of reducing conditions in the sediment and on the velocity of sedimentation and rapid burial of organic matter (p. 994)." As organic particles settle through the oxygenated water column they will be oxidized and decomposed by bacterial action. If the particle settles rapidly it will reach the sea floor before these processes are completed. The chances of preservation are increased by adsorption of organic matter on clastic grains as they will be protected against consumption and will settle more rapidly (Tissot and Welte, 1978). Tissot and Welte suggested that shallow water is more favorable for the accumulation of organic matter than deep water, because the organic matter would not be exposed to oxygenated water for as much time during settling. Rapid burial of organic matter is then necessary to insure its preservation because organic matter in the uppermost part of the sediment will be subject to decomposition by scavengers and bacteria. In a reducing environment, anaerobic bacteria are as effective at decomposing organic matter as aerobic bacteria are in an oxidizing environment, given sufficient time prior to burial (Smirnow, 1958). In normal marine waters the oxidation/reduction boundary coincides with the sediment/water interface (Krumbein and Garrels, 1952). Thus, the presence of reducing conditions in the sediment will inhibit further decomposition of the organic matter after sufficient burial to protect the organic matter from scavengers.

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The accumulation of organic matter can be a cause of reducing

conditions and not an effect (Tourtelot, 1979). The presence of abundant organic matter will deplete oxygen during oxidation and may in fact create anoxic conditions more favorable for the preservation of the organic matter.

During the Middle and Upper Deovnian, highlands on the eastern margin of the North American continent shed vast quantities of sediment to the west, where they were deposited in the Appalachian basin. Sand, silt, and mud were deposited on alluvial plains, in deltas, and in shallow marine environments adjacent to the source areas (McIver, 1961; Walker and Harms, 1971). West of the nearshore environment, silt with interbedded mud and some sand was deposited on a gentle prodelta slope (Cheema, 1977; Horsey, 1978). Farther west, gray-green and black muds were deposited across the craton. The study area is situated at a point transitional between the rocks deposited on the prodelta slope and those deposited on the craton (Figure 55).

The source of clastics during the Devonian was the highlands to the east. Paleocurrent studies based on sedimentary structures show a general east to west trend across the basin (Kepferle et al, 1978). Emergent lands to the west were low-lying carbonate terranes and probably contributed little clastic detritus to the basin (Schwietering, 1970). The increase in concentration of titanium to the east (Figure 50) supports the interpretation that the clastics were derived from the east. The high correlation of titanium with aluminum in the western part of the study area suggests that the clay minerals were the primary detrital components in the west. The low correlation of titanium with silicon suggests that the silicon was derived, in part, from some other source.

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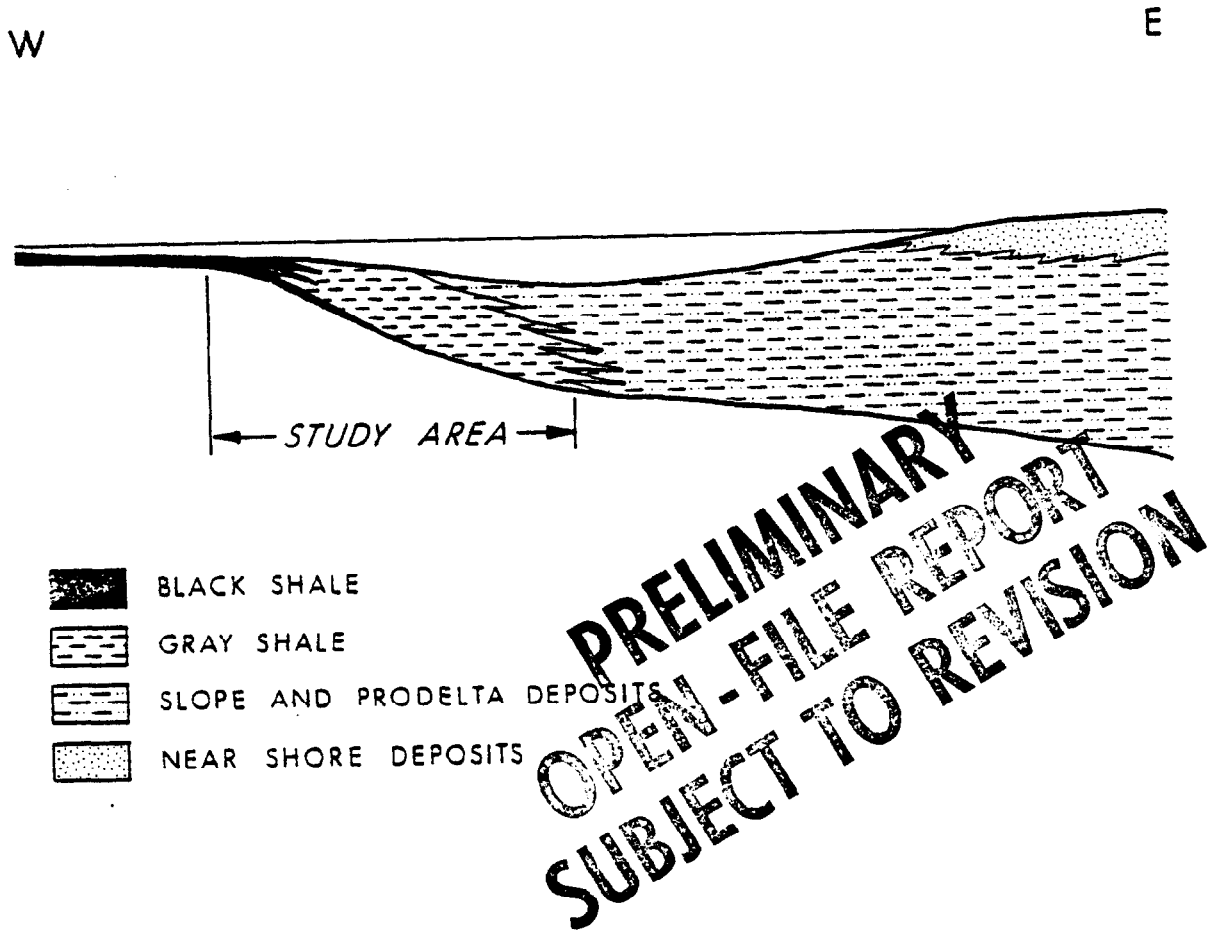

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Figure 55. Schematic diagram of the basin during the deposition of the Upper Devonian clastic sequence.

I believe that the Devonian clastic sequence was deposited in a basin that was deepest in the east and shallower to the west on the craton. I do not believe that the deep water was a requirement for the development of the black shale facies in the western part of the area.

The thick sequence in the eastern part of the study area was accomodated by subsidence during deposition. The facies change from gray to "grown" shale in the Huron Member of the Ohio Shale is interpreted to mark the western edge of the subsidence. This facies change marks the western edge of the Rome Trough and it is reasonable that the western limit of subsidence coincided with this basement feature. The Rome Trough subsided actively from the Cambrian through the Silurian and was the site of deposition of thick sequences at that time (Harris, 1978).

Several sand units present in the Rhinestreet Shale in Calhoun County and eastern Roane County may represent ponding in the deeper part of the basin; however, log control is not adequate to confirm this hypothesis.

Cheema (1977) studied the "Benson" interval in central West Virginia and interpreted it as having been deposited as a turbidite from a single source in that area. He suggested that the Benson was deposited at the toe of the prodelta slope in a maximum water depth of 300 feet. Horsey (1978) proposed similar conditions for the deposition of the Speechley-Balltown interval in the same area. Tepperman (1978) studied the Gordon sand in Gilmer and Braxton Counties and interpreted it as a nearshore-bar complex.

The nature of the kerogen in the shale is considered an indicator

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of the source of the organic matter. Amorphous, herbaceous, and algal kerogen is most likely derived from marine sources whereas woody or coaly kerogen is probably terrestrial in origin. Zielinski et al (1978) reported that the kerogen from the shale in the Mason 146 core showed abrupt variation from amorphous to woody types with minor amounts of coaly kerogen being ubiquitous throughout the sequence.

Clastic detritus and terrestrial organic matter were derived from the east and, because of the low density and small grain size, the clay particles and organic matter were carried across the basin and deposited further west than the coarse-grained clastics. Organic matter also was derived from planktonic marine sources. Variations in concentrations of organic matter from marine sources were probably the result of changes in productivity of the phytoplankton or algal blooms in the surface waters.

The "brown" shale intervals of the Huron Member of the Ohio Shale and the Rhinestreet Shale Member of the West Falls Formation correlate with thick clastic sections in the eastern part of the study area (Plate 2). The gray shale intervals do not change dramatically in thickness across the study area; thus, I believe that the Huron Member and Rhinestreet Shale represent times of increased deposition across the area. The increased deposition of clastics in the eastern part of the area was accompanied by an increase in the amount of organic and fine-grained clastic detritus being carried across the basin and deposited in the western part of the area.

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At the site of deposition in the western part of the area, preservation of organic matter may have been affected by the oxygen levels in the water, which in turn may have been controlled by the abundance

of organic matter. I believe that cycles of greenish-gray shale grading to dark-gray shale (Figure 53) represent periods of increasing depletion of oxygen in the water immediately overlying the depositional surface. Deposition began in moderately oxygenated water where burrowing organisms were present and much of the organic matter was decomposed. As deposition continued, the decomposition of the organic matter depleted the oxygen supply, burrowing organisms decreased and more organic matter was preserved. The stagnation ended abruptly when the waters were reoxygenated, and the cycle began again with greenish-gray shale.

I have recognized two types of boundary relationships in black shale beds: the gradational boundaries described above, and beds with sharp upper and lower contacts. These may have been the result of deposition of organic matter from different sources. The black shale beds with sharp boundaries may be the result of deposition of marine organic matter during periods of algal blooms in the surface waters. Thin, regionally extensive beds such as the Pipe Creek Shale marker in the Java Formation may have resulted from this source. The remainder of the organic matter was derived from terrestrial sources and changes in the amount of organic matter entering the depositional environment probably controlled its preservation. During times of increased sedimentation, more organic matter entered the depositional environment. At these times of high organic influx, oxygen may have been more readily depleted and more organics may have been preserved. Because sedimentation rates were higher, burial would have been more rapid and the chances of preservation increased.

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Preservation of lesser amounts of organic matter may have resulted from lower organic productivity in the source area, or a decrease in the supply of detritus, organic and clastic, to the depositional basin. The lower amount of organic matter meant that decomposition was more complete, and the decrease of clastic supply meant that burial was slower, and thus, less organic matter was preserved.

I think that during the earliest part of the Late Devonian, the western craton was emergent, and that the oldest black shales were deposited in very shallow water as sea-level rose, submerging the craton. In the Lincoln 1637 core in southern West Virginia, black shale rests directly on a lag deposit at the unconformity (see Figure 9A, Nuhfer, Vinopal, and Klanderman, 1978). The irregularities in the isopach maps of the Geneseo Shale (Figure 18) and the Middlesex Shale (Figure 21) were the result of deposition as the sea transgressed this surface. Erosional products from the surface were probably reworked and redeposited during deposition of the clastics above the unconformity. Because the surface had been planed by erosion, it probably was low-lying and poorly drained and did not contribute much clastic detritus to the shale. Slightly higher than average concentrations of silicon are noted in the shale above the unconformity (see Figure 52) and may reflect the incorporation of residual chert from the limestone in the shale. Large quantities of chert may not have been present as lag deposits because silica may have been leached during weathering. In some parts of the modern tropics, silica is entirely leached during weathering (Krauskopf,

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1967); the equatorial position of the Devonian basin (Van der Voo, French, and French, 1979) may have allowed climatic conditions favorable for the leaching of silicon.

Younger black shales were deposited as the sea transgressed the craton. These were deposited in slightly deeper water, although still no more than several hundred feet in depth. I think the presence of younger black shale tongues to the west reflects the migration westward of the depositional patterns with time. The upper part of the Huron and the Cleveland Members of the Ohio Shale reflect periods of increased organic accumulation, but do not extend into the study area because the coarser clastic facies were being deposited farther west than during the deposition of the lower part of the Huron.

Thin siltstone units in the upper part of the Huron in the study area may represent turbidite deposition. The sharp basal contact and gradational upper boundaries are typical of turbidite deposition. I suggest that western progradation of facies and perhaps a cessation of subsidence to the east, meant that turbidites were not trapped to the east and could spread across the area.

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GEOLOGIC HISTORY

The deposition of the Middle and Upper Devonian clastic sequence in the study area began with the deposition of the Hamilton Group. Deposition of clastics rich in organic matter began in an area that had previously been the site of carbonate deposition. Dennison and Head (1975) suggested that the change from carbonate deposition to fine-grained clastic deposition was the result of a rise in sea

level. I suggest that the deposition of the fine-grained clastic sediments may have been the result of a large flood of clastics into the basin from the east. Clastic deposition had occurred farther to the east during the Onesquethaw (Dennison, 1961) and the influx of clastics in the Hamilton Group may reflect a pulse of clastic deposition that migrated westward with time. Isopach maps of the Hamilton Group (Schwietering, Neal, and Dowse, 1978) suggest that the depocenter of the basin was located east of the study area. Hamilton deposition was followed by regression in the study area, indicated by the disconformity at the top of the Hamilton Group. However, this disconformity is not recognized to the east (Schwietering, Neal, and Dowse, 1978), indicating that the erosion resulting from the regression did not extend into the center of the depositional basin. The original western limit of deposition of the Hamilton Group is not known. Figure 56, a paleogeographic map of the unconformity surface, illustrates that progressively older units were exposed to the west. South and west of the study area rocks as old as Ordovician were exposed under the unconformity (Neal, 1979).

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This regression was followed by a transgression and the Tully Limestone was deposited in the eastern part of the study area. The deposition of limestone suggests a decrease of clastic influx at this time. In the study area, the deposition of the Tully Limestone was followed by a second regression prior to deposition of the Upper Devonian clastics. The western limit of Tully deposition in the study area is not known, because the unconformities above and below the Tully merge and are represented by a single unconformity in the western part of the area.

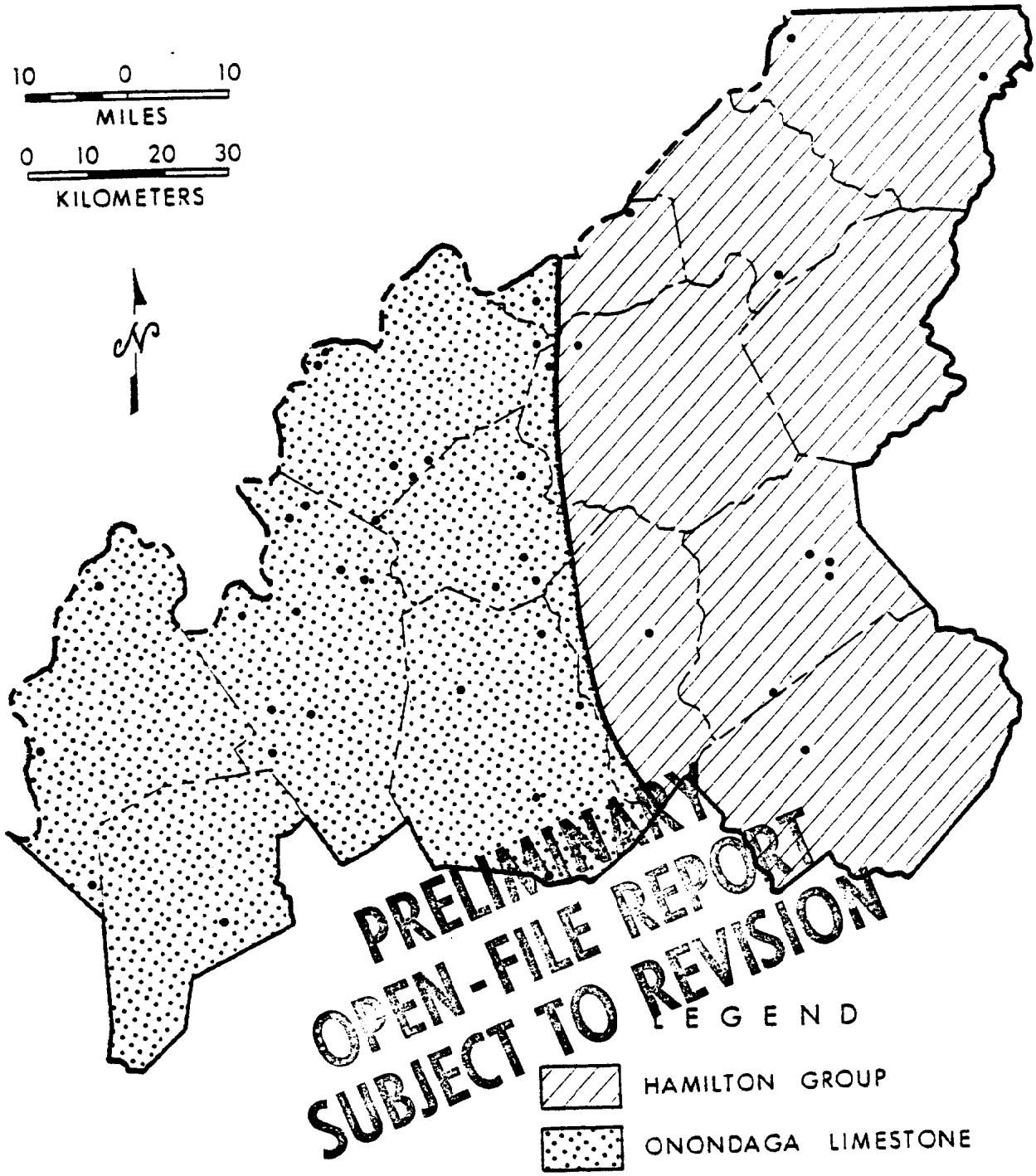

Figure 56. Paleogeographic map of the unconformity in the study area.

The same relationship is seen in New York (Rickard, 1975), although Tully age equivalents are recognized farther west (Collinson, 1967).

The Upper Devonian clastic rocks mark the return of clastic deposition to the area. The Genesee, Sonyea, and West Falls Formations onlapped the unconformity (Figure 57). Deposition of progressively younger units to the west reflects the transgression of the sea westward, slowly submerging the craton. I believe that the western limits of the Sonyea and Genesee Formations represent probable shorelines at those times. During Rhinestreet deposition, the sea transgressed the whole study area. The transgression of the sea across the area through the early Late Devonian is indicative of a slow rise in sea level, which probably kept pace with sedimentation in the western part of the area. The "brown" shales of the Rhinestreet and Huron reflect periods of increased deposition in the study area, whereas the intervening gray shales marked a time of decreased deposition. The Huron Member of the Ohio Shale denotes the last period of brown shale deposition in the study area. The undivided Upper Devonian sequence reflects the filling of the basin with clastic detritus. The Gordon sand may represent the migration of the eastern near-shore facies to the west as the basin filled. Redbeds of the Catskill Formation, interpreted as terrestrial deposits (McIver, 1961) or shallow marine deposits (Dally, 1956), had spread about halfway across the study area by the end of the Devonian (Figure 58). The Early Mississippian Berea Sandstone was deposited in the Gay-Fink Channel in the eastern part of the study area, and as a shallow marine sheet-sand in the western part of the study

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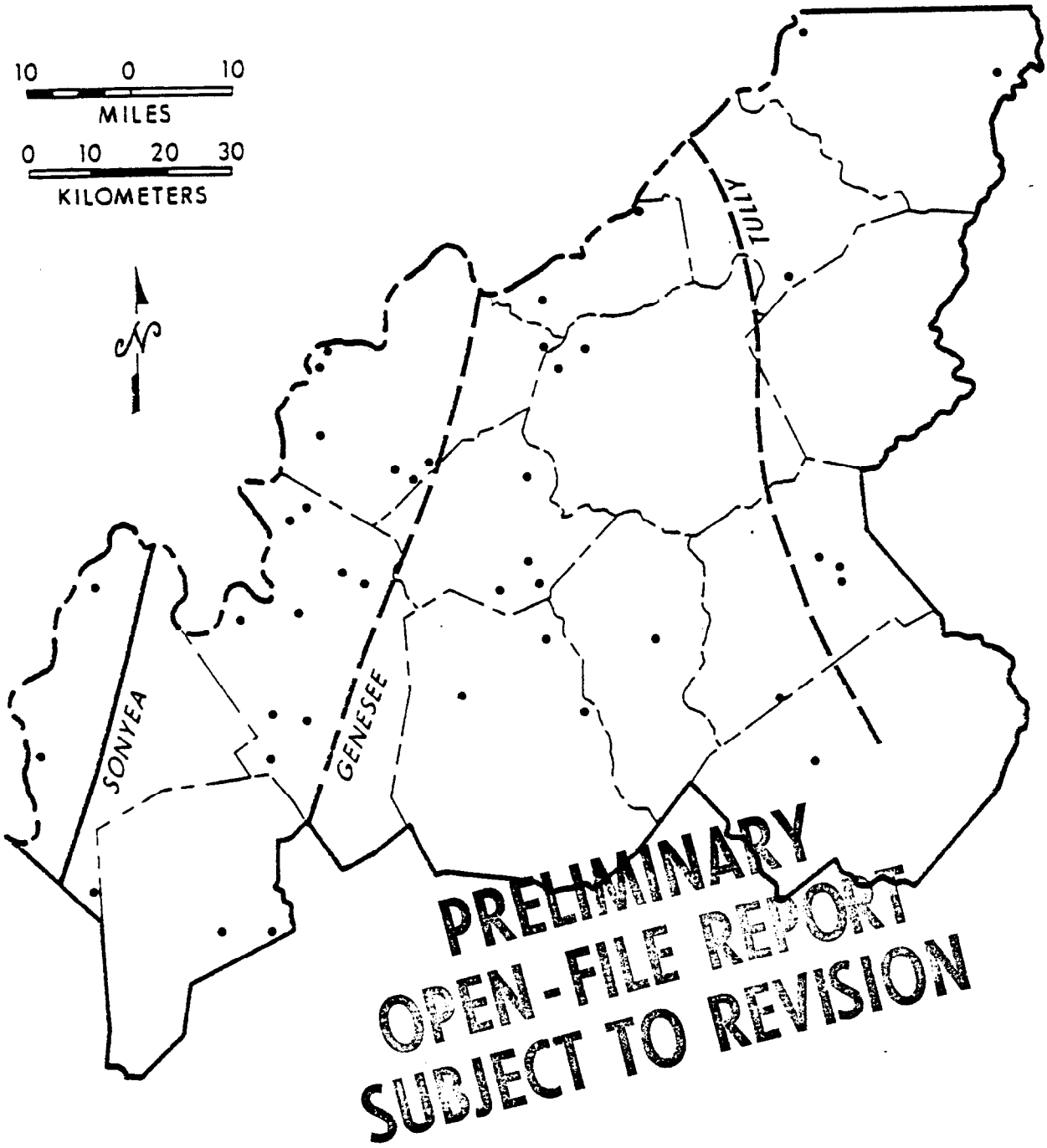

Figure 57. Western limits of the Tully Limestone, Genesee Formation, and Sonyea Formation in the study area.

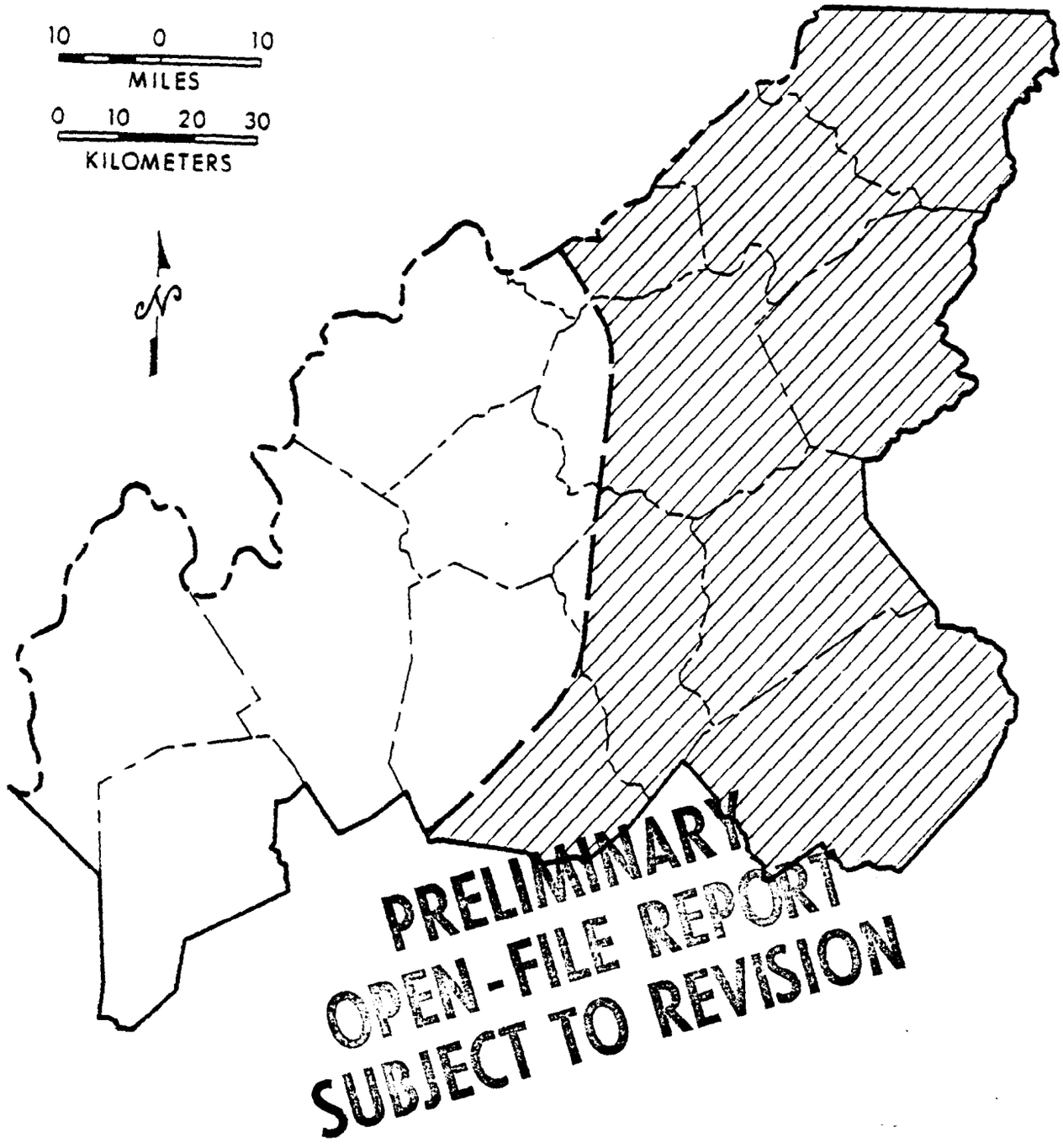

Figure 58. Distribution of red beds in the Upper Devonian in the study area.

area (Larese, 1974).

SUMMARY

The Middle and Upper Devonian clastic sequence which had been previously undivided in the study area has been subdivided into formational units. The subdivision of the sequence has been made possible by the recognition of regionally extensive black shale marker units. Each formational unit is composed of a basal black shale overlain by gray shale. Isopach maps have been constructed for each formation and its members in the study area. The regional relationships between units have been established by the construction of three cross sections in the study area.

The Huron Member of the Ohio Shale and the Rhinestreet Shale Member of the West Falls Foramtion are stratigraphically favorable for gas exploration in the western counties of the study area. Production is from the "brown" shale intervals in Jackson, Mason, Putnam, and Wood Counties. The production is from fractured reservoirs in the shale. Exploration for gas in the shale should focus on the areas of thick "brown" shale in the western part of the area and should include pinpointing structures that would produce fractures for a gas reservoir. Recent developments include the production of gas from the older black shales in the eastern part of the study area.

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A model has been proposed for the deposition of the Middle and Upper Devonian clastic sequence. The model suggests that the basin was deeper in the east and shallowed to the west. Coarse-

grained clastics were deposited as turbidites in the east and fine-grained clastics were deposited on the craton to the west. Although the water depth is interpreted as being shallow, water depth was not a critical factor in the development of the thick "brown" shale sequences in the western part of the area. It is thought that the development of thick "brown" shale units was the result of increased accumulation of organic matter. The high organic influx created conditions for the preservation of the organic matter by depletion of oxygen in the environment, and more rapid burial took place during times of increased sedimentation. During periods of slower sedimentation, less organic matter was present, and it was more completely decomposed before it was buried in the sediment.

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APPENDIX 1
Description of core from Wetzel 645

H. Emch and A. Pyles No. 1
Wetzel 645
Located 4.89 mi S of 39°45' and 3.82 mi W of 80°45', New Martinsville Quadrangle, Proctor District, Wetzel County, West Virginia.
Elevation 1344 G.L.; 1355 K.B.
Drilled by Mobay Chemical Corporation to a depth of 700 feet.
Completed 10/21/78; 500 MCF from the Oriskany Sandstone (6860-6870)

A continuous core was recovered from 6102.1 feet to 6635.6 feet (measured from the K.B.) under the auspices of the Eastern Gas Shales Project. The core face was examined wet and dry and described in detail by M.E. Dowse in June, 1979. Colors were determined by comparison with the Geological Society of America Color Chart (Goddard et al, 1948).

Stratigraphic Summary

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Gamma Ray Log Tops

2702-2706	Berea Sandstone
2706-3906	Upper Devonian undivided
3906-5178	Lower Huron Member of Ohio Shale
5178-5380	Java Formation
5380-5614	Angola Shale Member of West Falls Formation
5614-6265	Rhinestreet Shale Member of West Falls Formation
6265-6437	Sonyea Formation
6437-6511	Genesee Formation
6511-6520	Tully Limestone
6520-6570	Mahantango Formation
6570-6626	Marcellus Shale
6626-	Onondaga Limestone

Core Tops

Core begins in Rhinestreet Shale Member of West Falls Formation

6312.5-6441.5	Sonyea Formation
6441.5-6511.9	Genesee Formation
6511.9-6516.9	Tully Limestone
6516.9-6571.4	Mahantango Formation
6571.4-6624.9	Marcellus Shale
6624.9	Onondaga

Top	Thickness	
		Rhinestreet Shale Member of West Falls Formation
6102.1	10.8	Shale: greenish-gray (5GY 5/1 to 5GY 3/1) (75%) interbedded with dark gray to gray black (N-2 to N-3) (25%). Darker shale increases downward; shale is silty and banded.
		6102.1 Shale: dark-greenish-gray (5GY 3/1), silty, bedded with thin beds (0.5 mm) of light-gray shale (N-6) making up about 10% of the interval. Pyrite nodule (3 mm) interrupts bedding.
		6102.5 Shale: dark greenish-gray (5GY 3/1), silty, banded with several laminae of light-greenish-gray shale (5GY 8/1), large pyrite nodule (2 cm) and smaller scattered nodules, unidentified dark fossil fragment. Shale darkens in color toward the base of the interval.
		6103.9 Shale: greenish-gray (5GY 5/1), color lighter at base of interval, finely laminated. Abundant pyrite at the top of the interval in blebs that are elongate parallel bedding. The basal contact is irregular and undulose but very sharp. Fragments of the underlying shale are included in the overlying shale. Pyrite nodules (½ cm) are present on both sides of the contact but are more abundant below the contact.

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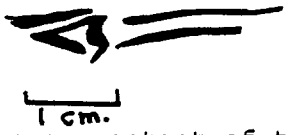
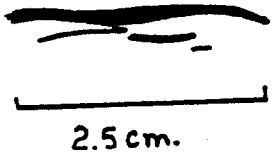
1 cm.

		6104.08 Shale: dark-gray (N-3), 10% pyrite.
		6104.12 Shale: dark-greenish-gray (5GY 4/1), abundant pyrite, disseminated and in small nodules.
		6104.2 Shale: dark-gray (N-3), silty, laminated, pyrite is abundant in the basal .05 feet both disseminated and in lenses. The basal boundary is gradational over a narrow interval (1 mm).
		6104.9 Shale: greenish-gray (5GY 4/1) some pyrite nodules at the top of the interval. 6105.2 to 6105.3 core is broken, some dark shale on lower end, suggests dark shale on lower end, suggests dark shale lamina in interval was not recovered.
		6105.4 Shale: dark-gray (N-3), pyrite lens in

Top	Thickness	
		interval may be a burrow.



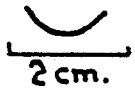
The upper contact of the interval is not present. The lower contact has a sharp change in color, it is undulose and irregular with some intertonguing.



6105.45 Shale: dark-greenish-gray (5GY 4/1) silty, laminated with some dark-gray shale beds, pyrite nodules and concretions. Dark-gray (N3) laminae (0.5 to 2 mm thick) at 6106.0, 6106.15, 6106.2, 6106.25. The core generally breaks cleanly at upper contact. The lower contact is irregular and undulose. The greenish-gray shale underlying the contact contains about 30% very-fine, dark-colored, shale fragments; the dark-colored shale fragments are generally less than 1 mm long and paper thin, they show subparallel alignment near the contact. The zone of dark shale fragments is about 1 cm wide with the number of dark shale fragments decreasing downward.

6105.9 Top of core has four nodes, raised 2-3 cm above the surface, the bumps are 2-3 mm in diameter, the shale laminae lap over the bumps, which may be small pyrite nodules.

6106.2 Pyrite: curved lamina, also disseminated in shale.



6106.55 Concretion, composed of noncalcareous shale. The concretion is zoned, the

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Top	Thickness	
		outer 1 cm is composed of shale similar to the adjacent shale but lighter in color. The core of the concretion is coarser-grained and lighter in color. Several fractures filled with dark-colored shale are present, the fractures generally curve at the boundary between the inner and outer zone of the concretion and thin toward the outer margin of the concretion. The contact with the adjacent shale is generally rounded and irregular.

6107.1 Shale: dark-gray (N-1 to 3), silty with disseminated pyrite.

6107.15 Shale: greenish-gray (5GY 5/1), laminated. Pyrite is present disseminated in the beds and as small nodules. The nodules are birds-eye shape and are concordant with bedding.

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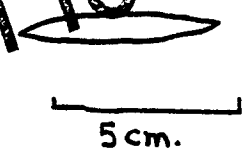

6107.2 Shale: grayish-black (N-2), silty. The shale is very crumbly it streaks and weathers gray.

6107.65 Shale: dark-gray (N-3), silty.

6107.7 Shale gray-black (N-2), silty, crumbly.

6107.8 Contact: The contact zone between the overlying gray-black shale and underlying greenish-gray shale is gradational with laminations of the dark-gray shale in the greenish-gray shale. Lamina are wavy. Small scale cut and fill features are present.

6107.9 Shale: dark-greenish-gray (5GY 3/1), silty, laminated with lenses and laminae (1 mm) of light-greenish-gray (5GY 6/1) shale, these light laminae are discontinuous and increase in number down section. Dark-gray laminae up to 1 mm

Top	Thickness	
		thick are present at 6108.18, 6108.48, and 6108.29.
		6109.45 Shale: gray-black (N-2) silty, the basal contact is sharp with intertonguing of dark-colored shale with underlying grayish-green shale.
		6109.5 Shale: dark-greenish-gray (5GY 4/1), silty, laminated, slightly lighter at base.
		6109.75 Shale: gray-black (N-2).
		6109.8 Shale: dark-greenish-gray (5GY 4/1), top centimeter contains many small, dark-colored shale flecks.
		6109.92 Shale: gray-black (N-2) 1 cm thick, underlain by zone of dark-colored fragments in greenish-gray shale. Dark-colored shale fragments are generally less than 1 mm in length, very elongate and aligned subparallel with bedding.
		6110 Shale: light-olive-gray (5Y 6/1).
		6110.2 Shale: greenish-gray (5GY 5/1). Color changes are gradational, two very-thin, black shale beds in interval from 6110 to 6110.37 with underlying zone of fragments.
		6110.37 Shale: gray-black (N-2) with zone of fragments underlying dark shale bed.
		6110.4 Shale: greenish-gray (5GY 5/1).
		6110.55 Shale: light-olive-gray (5Y 6/1), silty, laminae of lighter-colored material are slightly coarser-grained.
		6110.7-6110.9 - missing
		6110.9 Shale: dark-gray (N-3).
		6111.0 Shale: olive-gray
		6111.1 Shale: dark-gray. Thin, black-shale bed at 6111.14
		6111.7 Shale: olive-gray
		6111.8 Shale: dark-gray
		6112.0 Shale: olive-gray
		6112.15 Shale: dark-gray, thin, black shale beds at 6112.23 and 6112.28.
		6112.4 Shale: dark-olive-gray
		6112.5 Shale: dark-gray
		6112.8 Shale: gray-black (N-3 to N-2) crumbly. Note: This interval is crumbly and bagged. It is labeled as .1 foot, but looks longer.

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Top	Thickness	

SUMMARY
6102.1 to 6110.

The shale varies in color from greenish gray to dark greenish gray with dark-gray to gray-black beds. The color changes are gradational in the greenish-gray shales, but are sharp between these shales and the gray-black shales. The contacts are often undulose and tongues of black shale are seen in the underlying greenish-gray shales. The dark-colored shale beds are underlain by a zone up to 1 cm wide which includes small pieces of dark-colored shale, generally fragments are elongate and aligned subparallel to bedding. The upper contacts are frequently places where the core breaks and are sharp.

6112.9	14.4	Shale: varies in color from gray black (N-2) to olive gray (5Y 6/1), laminated. Color changes are gradational except for the dark-colored shales which have sharp basal contacts. Variation in color appear cyclic in places.

6112.9 Shale: dark-greenish-gray, laminated.
6113.05 Shale: gray-black
6113.06 Shale: dark-greenish-gray.
6113.20 Shale: gray-black
6113.30 Shale: greenish-gray to dark-gray, laminated.
6113.75 Shale: gray-black
6113.76 Shale: dark-greenish-gray
6113.9 Shale: dark-gray to gray-black
6114.4 Shale: dark-greenish-gray
6114.4-6114.87 - missing
6114.87 Shale: gray-black
6114.9 Shale: dark-greenish-gray, color gradually darkens toward base of interval.
6115.2 Shale: greenish-gray (5GY 5/1), dark lamina at 6115.3.
6115.3 Shale: greenish-gray (5GY 6/1)
6115.45 Shale: greenish-gray (5GY 5/1)
6115.48 Shale: medium-gray (N-4), silty, some lighter laminae with small-scale, cross beds. The basal contact is sharp and undulose.
6115.53 Shale: dark-gray (N-3) grading down section to olive-gray shale (5Y 5/1) then grading down section to medium-gray (N-4) shale. The basal contact is sharp but undulose.
6115.71 Shale: dark-gray (N-3) with few laminae of gray-black (N-2) and olive-gray (5Y 5/1) shale, laminated, .5 cm bed of light-olive-gray (5Y 6/1) at base.

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Top	Thickness	
		6116.5 Shale: gray-black (N-2) at top, lighter-colored shale underneath. Contact is a zone of mixed material with fragments of dark-colored shale in underlying unit, gradual color change to olive-gray shale.
		6116.74 Shale: olive-gray, disseminated pyrite.
		6116.85 Shale: gray-black (N-2) with a sharp upper contact and an irregular lower contact.
		6116.86 Shale: dark-greenish-gray, color lightens and changes gradationally to olive-gray shale with disseminated pyrite.
		6116.89 Shale: greenish-gray, pyritic layer in middle of interval.
		6117.1 Shale: brown-black
		6117.11 Shale: greenish-gray
		6117.26 Shale: brown-black
		6117.3 Shale: dark-greenish-gray
		6117.4 Shale: greenish-gray, lighter than the overlying unit. The upper contact is sharp.
		6117.[illegible] Shale: gray-black
		6117.[illegible] Shale: dark-greenish-gray
		6117.92 Shale: black, thin bed
		6117.9[illegible] Shale: dark-greenish-gray
		6118.3[illegible] Shale: gray-black
		6118.31 Shale: olive-gray grading into light-greenish-gray (5GY 5/1); with coarser lamination than the overlying dark-greenish-gray shale.
		6118.5 Shale: gray-black, 1 mm thick
		6118.5 Shale: dark-greenish-gray
		6118.8 Shale: interbedded dark-gray (N-3) and gray-black (N-2), crumbly.
		6118.9 Shale: dark-greenish-gray to olive-gray, laminated.
		6119.25 Shale: gray-black, 1 mm bed, underlain by dark-greenish-gray to olive-gray laminated shale.
		6119.4 Shale: gray-black
		6119.4-6119.64 - missing
		6119.7 Shale: dark-greenish-gray
		6119.9 Shale: interbedded gray-black, light-olive-green, and greenish-gray shale. The sequence is gray-black shale, dark-greenish-gray shale, 2.5 cm thick, light-olive-gray shale, dark-greenish-gray shale, 1 mm bed of gray-black shale, greenish-gray shale, olive-gray shale,

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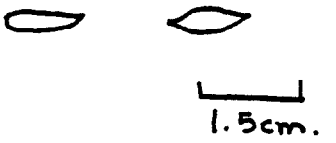
Top	Thickness	

gray-black shale. Cyclicity is apparent. The general pattern is a sharp upper boundary, underlain by gray-black shale underlain by greenish-gray shale which gradually becomes lighter down section. The boundary at the base of the gray-black shale is a sharp break in color, but there are tongues of black shale in the underlying greenish-gray shale; and small dark-colored shale fragments are included in the top centimeter of the greenish-gray shales. The lightest-colored shales at the base of each cycle are generally coarser-grained. The shale is laminated. The laminae are generally flat lying and parallel. No evidence of burrowing and few bedding structures.

6127.3	2.02	Shale: gray-black (N-2), with minor greenish-gray shale.
		6127.3 Shale: gray-black (N-2), laminated, breaks into plates. Occasional burrows filled with dark-olive-gray shale.



		6128.0 Shale: dark-greenish-gray, laminated.
		6128.2 Shale: gray-black, crumbly breaks into plates less than 1 cm thick.
		6129.32 to 6129.57 Missing
6129.32	3.14	Shale: gray-black (N-2) to dark-gray (N-3) interbedded with greenish-gray shale (5GY 3/1). The dark-colored shale is dominant.
		6129.[illegible] Shale: dark-greenish-gray alternating with dark-gray to gray-black. Laminated, the greenish-gray shales are thicker. The lamination is inclined to the core and are generally subparallel. The boundaries are sharp with no truncation of lamina. Some of the dark-colored shales are rich in pyrite. Concretions at 6130.2. Dark-colored shale laminae wrap over the top of the concretion and are depressed under the concretion. The larger concretions interrupts the laminae.

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Top	Thickness		
			and greenish-gray shale.
		6120.5	Shale: dark-greenish-gray
		6120.6	Shale: olive-gray, with more conspicuous lamination; underlain by dark-greenish-gray shale, with three thin zones of interbedded light-olive-gray to medium-gray shale.
		6121.08	Shale: dark-greenish-gray with a 1 mm gray-black shale lamina at top, 5mm gray-black shale lamina at 6121.28.
		6121.31	Shale: light-olive-gray to medium-gray
		6121.40	Shale: greenish-gray
		6121.41	Shale: light-colored bed 1 cm thick
		6121.42	Shale: gray-black, 1 mm lamina overlies dark-greenish-gray shale.
		6121.8	Shale: light-olive-gray, banded
		6121.85	Shale: dark greenish-gray
		6122.09	Shale: medium-gray, (N-4) with two thin, black shale beds (1 mm thick) and interbedded dark-greenish-gray shale.
		6122.18	Shale: light-olive-gray
		6122.25	Shale: medium-gray (N-4) to dark-greenish-gray.
		6122.47	Shale: light-olive-gray.
		6122.53	Shale: dark-gray (N-3) to dark-greenish-gray. Sharp break in color at upper contact.
		6122.57	to 6122.79 Missing
		6122.79	Shale: dark-greenish-gray, lighter-colored at base
		6122.9	Shale: gray-black (N-2) interbedded with dark-greenish-gray shale beds 1-2 cm thick. The upper boundaries of the dark-colored shale beds are sharp. The basal boundaries are irregular with a sharp color contrast.
		6124.55	to 6124.82 Missing
		6124.82	Shale: dark-greenish-gray
		6125.15	Shale: dark-greenish-gray, laminated with a few, very-thin, dark-gray shale laminae.
		6126.5	Shale: alternating thin laminæ, of dark-greenish-gray and gray-black.

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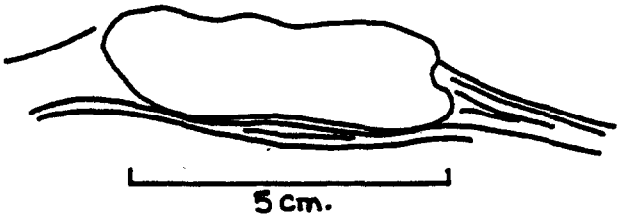
SUMMARY

6112.9 to 6127.3

This interval is composed of dark-greenish-gray shale with scattered beds of lighter-colored shale and many thin beds of dark-gray to

Top	Thickness	



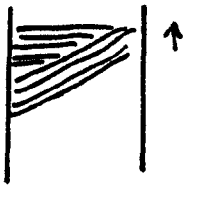
The underlying gray-black shale is laminated with slightly undulose laminae. Some of the laminae are composed almost entirely pyrite.

6130.45 Shale: greenish-gray.

6130.50 Shale: gray-black, laminated, wavy, undulose. The base of the dark-colored shale beds truncates the laminae of the underlying units, pyritic.

6130.55 Shale: dark-gray (N-3) and dark greenish-gray (5GY 5/1) interbedded, laminated. The laminae are generally flat-lying and parallel, laminae are occasionally truncated. Several filled fractures are present.

6130.93 Shale: greenish-gray (5GY 5/1) and dark-gray to gray-black (N-2 to N-3) interbedded, lamination most conspicuous in darker-colored shale. Laminae are inclined to core, and change orientation from preceding interval.



Pyrite is abundant (up to 10%) as nodules ranging in size from 1 mm to 1 cm.

6130.93 Shale: gray-black grades to greenish-gray.

6131.2 Shale: dark-gray

6131.4 Shale: dark-gray

6131.69 Shale: greenish-gray

6131.75 Shale: dark-gray

6132.21 Shale: greenish-gray

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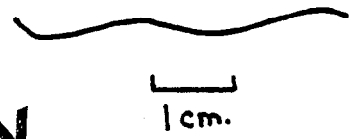
Top	Thickness	
		6132.31 Shale: dark-gray, pyrite layer at base.
6132.46	4.99	Shale: gray-black (60%) and dark-greenish-gray (40%), banded. Lamination, flat lying, parallel. Occasional pyrite knots and lenses, shale lamination wrap around pyrite blebs. Dark-greenish-gray shale bed from 6134. 9 to 6135.0.
		6137.1 to 6137.34 Missing
6137.45	3.27	Shale: banded, gray-black and greenish-gray, interbedded with light-colored shales.
		6137.45 Shale: medium-gray (N-4) grades down into darker-colored banded shale. Upper boundary is sharp.
		6138.20 Shale: medium-gray to light-olive-gray, sharp basal boundary, with small cut and fill structures.



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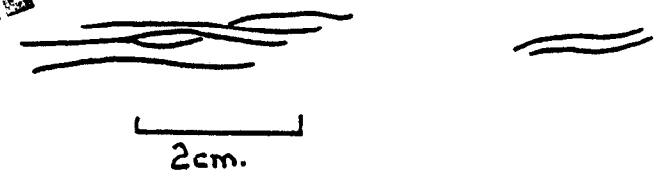
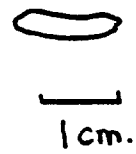
		6138.35 Shale: banded, 60% gray-black and 40% gray green. Gray-black and medium-gray shale interbedded at 6138.45 to 6138.7 with wavy laminae, also some lenses of lighter-colored material.



		6139.25 Shale: light olive-gray, sharp upper boundary.
		6139.35 Shale: dark-gray, laminated.
		6139.40 Shale: light-olive-gray, grades into banded shale; sharp upper boundary
		6139.5 Shale: banded, gray-black and greenish-gray, a few lenses of lighter-colored material.
6140.72	4.98	Shale: gray-black (N-2) banded with dark-greenish-gray (5GY 3/1). The dark-colored shale breaks in flat plates.
		6142.42 to 6142.73 Missing
		6144.41 to 6144.81 Missing
		6144.9 Pyrite nodule, laminae not visible but on top of core, there is a bump over the nodule.

Top	Thickness	



6145.7	9.9	Shale: greenish-gray and dark-gray, interbedded
		6145.7 Shale: greenish-gray
		6145.91 Shale: dark-gray, abundant disseminated pyrite in some layers.
		6146.0 Shale: greenish-gray
		6146.3 Shale: dark-gray
		6146.35 Shale: greenish-gray
		6146.7 Shale: dark-gray, laminated, irregular lower contact.
		6146.75 Shale: greenish-gray
		6146.82 Shale: dark-gray, irregular basal boundary.

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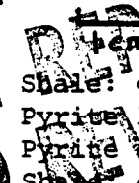

6146.85	Shale: greenish-gray
6147.4	Pyrite lenses
6147.5	Pyrite clots
6147.57	Shale: dark-gray
6147.6	Shale: greenish-gray, slight color variation, occasional laminae of medium-gray shale 1 mm thick
6147.8	Pyrite nodule
6148.38	Fossils, pyritized, ostracods (?)

6148.5	Shale: dark-gray
6148.58	Shale: dark-greenish-gray, color varies slightly in interval. Relatively sharp color break at upper boundary. 1 mm dark-colored shale lamina at 6148.84.
6149.19	Shale: dark-gray
6149.2	Shale: greenish-gray to medium-gray, color changes are gradational
6149.50	to 6149.73 Missing

Top	Thickness	
		6149.73 Shale: gray (N-3) with slight greenish tint, laminated with a few lighter-colored beds.
		6150.8 Shale: gray (N-4)
		6150.91 Shale: dark-gray (N-3)
		6151.16 Shale: gray-black
		6151.9 Shale: dark-gray to dark-greenish-gray, several beds (1 cm thick) of lighter-colored shale; gradational color changes.
		6153.62 Shale: dark-gray
		6153.63 Shale: dark-greenish-gray with some lighter-colored beds.
		6154.16 to 6154.54 Missing
		6155.06 Shale: dark-gray
		6155.07 Shale: greenish-gray
		6155.26 Shale: dark-gray
		6155.27 Shale: greenish-gray to medium-gray
6155.6	.7	Shale: gray-black (N-2) with streaks of dark-gray, silty. The shale breaks into plates. There is a 1 cm layer of pyrite, underlain by 2 mm of pyritic, gray-black shale. The basal boundary is not sharp.
6156.3	3.15	Shale: alternating dark-greenish-gray (5GY 4/1) and gray-black (N-2)
		6156.3 Shale: greenish-gray
		6156.67 Pyrite lens
		6156.74 Shale: gray-black, laminated, laminae are irregular and wavy, boundaries are sharp and inclined to the core. Pyrite is present in lenses and elongate nodules, shale laminae bend around the pyrite nodules and thicken at the edges of the nodules.

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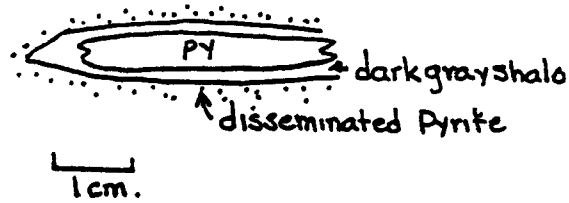
1 cm.

		6156.85 Shale: greenish-gray, 5% pyrite nodules, ½ to 1 cm in size. One large pyrite nodule is present. The nodule is zoned, the core is composed of fine disseminated pyrite, surrounded by a 1 mm thick zone of dark-gray shale. The shale is surrounded by a halo of fine-grained, disseminated pyrite which grades into the country rock. The left end tapers into the adjacent shale beds, the right end of the nodules ends abruptly.

Top	Thickness	



6157.17 Shale: dark, pyrite nodules, laminae of shale bent around the nodule.

6157.2 Shale: greenish-gray, pyritic. Pyrite layer at 6157.45; 40% pyrite at 6157.75; pyrite nodule at 6157.7.
6157.85 Shale: dark-gray, pyritic.
6157.86 Shale: greenish-gray, pyrite layer at 6157.81; dark-colored shale lamina at 6158.1.
6158.1 Shale: dark-gray
6158.26 Shale: greenish-gray
6158.46 Shale: dark-gray
6158.5 Shale: greenish-gray
6158.85 Shale: dark-gray with thin greenish-gray laminae in middle.
6158.87 Shale: greenish-gray
6159.17 to 6159.47 Missing.

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SUMMARY
6127.3 to 6159.4

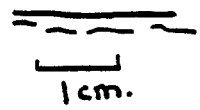
This interval is composed of interbedded greenish-gray and dark-gray to gray-black shales. The color of the lighter shales does not vary greatly. Contacts between the dark-colored shales and the lighter-colored shales are not as sharp as in the overlying unit and appear slightly gradational. Dark-colored shale fragments are not included in greenish-gray shale underlying dark-colored shale beds. Pyrite is common in the interval.

6159.47	21.63	Shale: alternating gray-black (N-2) shale and greenish-gray shale. The greenish-gray shale varies from light-greenish-gray (5GY 6/1) to dark greenish-gray (5GY 3/1) with some olive-gray shale and other tints. 6159.47 Shale: greenish-gray, dark-colored shale stringer at 6159.8.

Top	Thick-ness	
		6160.1 Shale: medium-gray (N-5), very small cut and fill structure is present.

The core is broken along a bedding surface, the surface is very smooth but undulose.

6160.32 Shale: gray-black, the upper boundary is sharp and undulose. The lower boundary is gradational with interbedded greenish-gray shale and dark-colored shale lamina; with a few thin discontinous stringers of dark-colored shale in the underlying greenish-gray shale.



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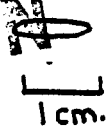
6160.33 Shale: greenish-gray. At 6160.41 there is a bed of small concretions.



Light-gray shale bed at 6160.88. Thin dark-colored shale stringers are present at 6160.92 and 6161.34. The lowermost 0.1 foot of the interval is lighter in color.

6161.6 Shale: dark-gray to gray-black, bagged because it is disintegrating.

6161.7 Shale: greenish-gray, with a gradationa; color change to (5GY 6/1) at the base. At the top of the interval on the core top numerous organic fragments are included in the greenish-gray shale.

6161.98 Shale: gray-black (N-2)

Top	Thickness		
		6162.0	Shale: dark-gray (N-3). The uppermost part of the interval includes fragments from the overlying gray-black shale.
		6162.63	Shale: gray-black (N-2), contacts are inclined to core. The basal boundary is sharp.
		6162.65	Shale: dark-gray (N-3)
		6163.0	Shale: gray-black (N-2), sharp basal boundary, few gray-black stringers below contact.
		6163.53	Shale: greenish-gray, color gradually becomes lighter down section, numerous thin, short (to 1.5 cm) stringers of dark-colored shale are present, aligned parallel bedding; through the interval.
		6164.17	to 6164.55 Missing
		6164.55	Shale: dark greenish-gray
		6164.7	Shale: gray-black
		6164.15	Shale: greenish-gray
		6165.27	Shale: gray-black
		6165.3	Shale: greenish-gray
		6165.45	Shale: gray-black
		6165.5	Shale: greenish-gray, dark-colored shale stringers are present at 6165.71 and 6165.94. Pyrite nodules 0.5 to 1 mm in size, are present at 6165.6 and 6166.0
		6166.6	Shale: gray-black, pyritic
		6166.66	Shale: dark-greenish-gray, pyrite layer at 6166.78 dark-colored stringer at 6166.91.
		6167.3	Shale: medium-gray, banded.
		6167.4	Shale: dark-gray stringer overlies gray shale (N-4 to N-3) 2 mm dark-gray shale bed at 6167.44.
		6167.65	Shale: olive-gray, pyritic
		6167.7	Shale: gray (N-3)
		6167.82	Shale: light-gray (N-4 to N-5) laminated. Sharp upper boundary.
		6167.85	Shale: dark-gray (N-3); pyrite at 6168.14
		6168.28	Shale: light-gray (N-4 to N-5)
		6168.3	Shale: dark-gray (N-3)
		6168.45	Shale: interbedded light-gray (N-4 to N-5) and dark-gray (N-3), finely laminated, laminae are flat lying.
		6168.71	Shale: dark-gray (N-3)
		6168.75	Shale: dark-greenish-gray.
		6168.92	Shale: greenish-gray, slightly lighter colored than adjacent shales.

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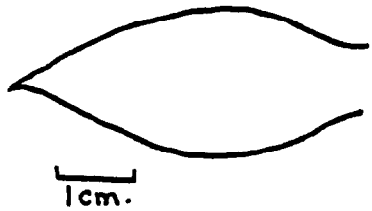
Top	Thickness	
		6169.09 Shale: dark-greenish-gray
		6169.25 Shale: greenish-gray, lighter colored than overlying unit.
		6169.33 to 6169.66 Missing
		6169.66 Shale: gray-black, sharp basal boundary.
		6169.7 Shale: dark-greenish-gray. 6169.8 A large pod of olive gray shale at 6169.8.



		6170.1 Shale: dark-gray
		6170.4 Shale: dark-gray interbedded with lighter-colored shale.
		6171.05 Shale: gray-black
		6172.23 to 6172.56 Missing
		6172.56 Shale: dark-greenish-gray
		6173.0 Shale: gray-black
		6173.1 Shale: dark-greenish-gray, several concretions are present, one large concretion composed of olive-green shale. Small pyritized concretions with pyrite nodules at 6173.25 and 6173.51.
		6173.75 Shale: gray-black, sharp basal boundary.
		6173.85 Shale: greenish-gray, light-olive-gray shale from 6174.05 to 6174.14; dark-colored shale stringer at 6172.7
		6174.42 to 6174.89 Missing
		6174.89 Shale: gray-black, sharp basal boundary
		6174.95 Shale: greenish-gray, lighter-colored zone at 6175.2 with small pyrite nodules. Dark-colored shale stringers and beds at 6175.5, 6175.88, and 6176.03. Zone of small concretions at 6176.1

		6176.44 Shale: gray-black
		6176.48 Shale: dark-greenish-gray
		6176.86 Shale: gray-black
		6176.91 Shale: dark-gray (N-3). The upper contact is undulose and irregular, the basal boundary is sharp.

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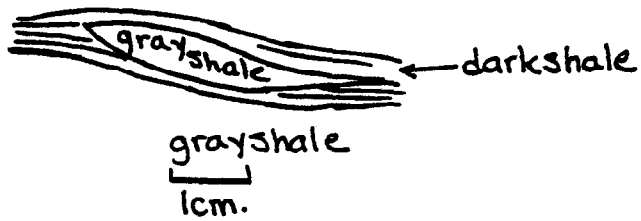
Top	Thick-ness	



6177.08 Shale: gray-black
6177.1 Shale: dark-gray (N-3)
6177.35 Shale: gray-black. At the base irregular nodules of gray shale are surrounded by dark-colored shale.
6177.4 Shale: dark-gray (N-3) at 6177.5 gray-black (N-2) lamina.

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6177.61 At 6177.61 gray-black shale bed, inclined to core, boundaries are wavy and undulose.

6177.78 Shale: gray-black
6178.0 Shale: dark-greenish-gray pyrite nodules at 6178.1
6178.2 Shale: gray-black
6178.3 Shale: greenish-gray
6178.36 Shale: gray-black
6178.85 Shale: greenish-gray, abundant pyrite in small nodules and concretions.
6178.09 to 6178.35 Missing
6180.0 Shale: gray-black
6180.05 Shale: dark greenish-gray, at 6180.1 several large fragments of gray-black

Top	Thick-ness	
		shale. Slickensides are present in the gray shale on the top of the core.

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Gray-black shale fragment, 8 cm long, present at 6180.4

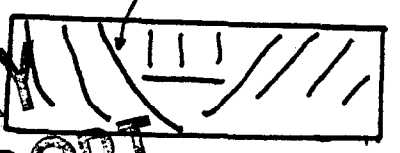
Gray-black shale fragment at 6180.75, fragment is pyritic.

SUMMARY
6159.47 to 6181.1

The interval is composed of alternating beds of greenish-gray and gray-black shale. Toward the base of the interval the proportion of the dark-colored shale increases. The base of the interval was placed at 6181.1 because it marks the top of a thick gray-black shale section. Perhaps the real change in lithology is higher, but cannot be easily recognized.

6181.1	25.99	Shale: gray-black (N-2) with occasional greenish-gray beds, the shale powders dark-gray, silty, core breaks into plates. 6181.1 Shale: gray-black 6182.5 Shale: dark-greenish-gray, pyritic

Top	Thickness		
		6182.9	Shale: gray-black
		6183.15	Shale: dark-greenish-gray
		6183.45	Shale: gray-black; white, silt stringers at 6185.8; three thin (less than 1 cm) laminated gray shale beds from 6187.1 to 6187.3
		6188.65	Shale: olive-gray (5Y 4/1) with fuzzy bands of dark-greenish-gray shale. Boundaries are sharp and inclined to core; disseminated pyrite.
		6188.66	Shale: gray-black, fractured. Fracture zone from 6190.45 to 6190.9, slickensides.



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		6190.9	Shale: gray-black, platy
		6194.6	Concretion: composed of dark-greenish-gray shale, fractured, fractures filled with calcite, base at 6194.85.
		6194.85	Shale: gray-black. Curved, slickensided fractures, at 6205.0

6207.01	4.22	Shale: interbedded gray black (60%) and dark greenish gray (40%)	
		6207.01	Shale: dark-greenish-gray (5GY 4/1); concretion at 6207.2
		6207.32	Shale: gray-black, pyrite layer at base
		6207.65	Shale: greenish-gray
		6207.81	Shale: gray-black
		6207.84	Shale: greenish-gray
		6207.95	Shale: gray-black
		6208.1	Shale: greenish-gray
		6208.26	Shale: gray-black
		6209.09	Shale: greenish-gray, gray-black shale bed (1 mm) at 6209.28
		6209.33	Shale: gray-black
		6209.88	Shale: greenish-gray
		6210.01	Shale: gray-black
		6210.16	Concretion; composed of greenish-gray shale, fractures filled with calcite. Base of concretion is rounded.

Top	Thickness	
6211.22	26.58	Shale: gray-black (N-2) with some gray shale beds, silty, breaks into plates.
		6211.22 Shale: gray-black
		6211.97 Shale: gray (N-3)
		6212.0 Shale: gray-black (N-2)
		6212.35 Shale: gray (N-3), sharp upper boundary.
		6212.44 Shale: gray (N-4), upper contact is fuzzy.
		6212.91 Shale: gray-black to gray (N-2 to N-3) laminated, occasionally lighter in color, color changes are gradational. Thin (1 cm) bed of medium-gray shale at 6213.41.
		6214.12 Shale: gray (N-3 to N-4); pyrite lens at 6214.8, darker-colored shale band at 6214.87.
		6215.11 Shale: dark-gray (N-3).
		6215.3 Shale: gray (N-3 to N-4), bed of medium-gray shale 1 cm thick at base. Color changes are sharp.
		6215.5 Shale: dark-gray (N-3)
		6216.6 Shale: gray-black (N-2), breaks into thin plates.
		6217.2 Shale: dark-gray to gray-black, gradational change to slightly lighter-colored shale from overlying unit; lighter beds increase down section. Breaks into thicker plates than adjacent units.
		6222.2 Shale: gray-black, punky and disintegrating
		6222.5 Shale: dark-gray
		6226.23 Shale: medium to dark-gray (N-3 to N-4), gradational upper contact.
		6226.58 Shale: dark-gray with some lighter-colored beds. There is a cycle of gradually lighter-colored beds downward. Sharp basal boundary.
		6226.9 Shale: gray-black (N-2), disintegrating.
		6228.0 Shale: dark-gray, color gradually lightens downward.
		6231.74 Shale: medium-gray (N-4) sharp-color boundary at top.

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Top	Thickness		
		6231.95	Shale: dark-gray (N-3 to N-2)
		6232.71	Shale: medium-gray (N-4) to greenish-gray
		6232.91	Shale: dark-gray (N-3)
		6233.71	Shale: medium-gray (N-4) to greenish-gray, dark-colored stringer at 6233.37
		6233.49	Shale: dark-gray (N-3 to N-2)
		6235.0	Shale: gray (N-4) to greenish-gray
		6235.12	Shale: dark-gray, lighter colored toward base.
		6235.95	Shale: medium-gray (N-4) to greenish-gray, dark-colored zone (1.5 cm thick) at base, sharp upper and lower boundaries.
		6236.18	Shale: dark-gray

SUMMARY
6181.1 to 6237.8

The interval consists of dark-gray to gray-black shale. The distinction of the two colors is not sharp and differentiation was made on the basis on general appearance. The darker-colored shale is generally punky in appearance and break into thinner plates. The dark-gray shales are more coarsely laminated and vary slightly in shade, occasional medium-gray beds are present. The upper boundaries of the lighter-colored units are gradational, whereas basal boundaries are sharp.

6237.8	4.45	Shale: dark-greenish-gray (5GY 3/1) with occasional gray-black shale beds.	
		6238.0	Shale: dark-greenish-gray (5GY 3/1)
		6238.8	Shale: gray-black and dark-greenish-gray interbedded, sharp irregular boundaries.

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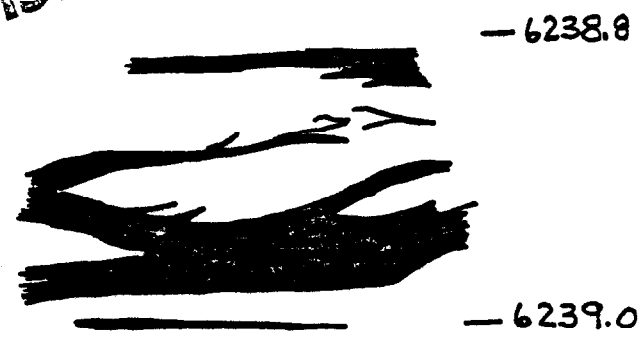
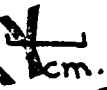


6239.0	Shale: dark-greenish-gray
6240.2	Shale: gray-black
6240.3	Shale: greenish-gray, pyrite lens

Top	Thickness	

6240.5 Shale: gray-black
6240.58 Shale: greenish-gray; small pyrite concretion at 6240.9



Thin dark-colored shale lamina at 6241.12; pyrite nodules at 6241.48
6241.5 Shale: gray-black
6241.52 Shale: greenish-gray; pyrite nodules at 6242.02 and 6242.15

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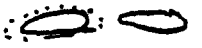

6242.25	4.05	Shale: gray-black with a few dark-greenish-gray beds. Gray-black shale is punky and disintegrating. 6242.25 Shale: gray-black 6243.15 Shale: dark-gray, coarser laminae. 6243.42 Shale: gray-black 6242.74 Shale: dark-gray (N-3), coarser laminae, slickensides on core top at base of interval. 6244.25 to 6244.64 Missing 6244.64 Shale: gray-black 6244.65 Shale: dark-gray (N-3) 6244.82 Shale: gray-black
6246.3	9.1	Shale: dark-greenish-gray (5GY 4/1) with darker-colored shale beds. 6246.3 Shale: greenish-gray (5GY 4/1) abundant pyrite nodules and some layers rich in disseminated pyrite. The pyrite is most abundant near the base and decreases upward. 6246.63 Shale: dark-gray (N-3), coarser laminae. 6246.8 Shale: greenish-gray 6247.0 Shale: dark-gray

Top	Thickness		
		6247.03	Shale: greenish-gray, concretion from 6247 to 6247.5, center of concretion similar to country rock. The rim of the concretions is slightly lighter in color.
		6247.3	Shale: dark-gray (N-3), color darkens downward
		6247.5	Shale: dark-greenish-gray, sharp upper boundary Pyrite nodule at 6247.6; dark-colored shale bed at 6247.8.
		6248.05	Shale: gray-black, boundaries inclined.
		6248.48	Shale: greenish-gray
		6248.68	Shale: gray-black, boundaries are irregular with some dark-colored shale stringers in the overlying shale.
		6248.73	Shale: dark-greenish-gray
		6248.81	Shale: gray-black
		6249.0	Shale: dark-gray, coarser laminae, abundant pyrite
		6249.18	- 6249.42 Missing
		6249.42	Shale: dark-gray, color gradually lightens down section.
		6249.56	Shale: gray (N-4)
		6250.06	Shale: dark-gray (N-3)
		6250.1	Shale: medium-gray (N-4) color gradually lightens downward to greenish gray (5GY 6/1). Color changes are not sharp, core is banded, darkens again toward base. The basal boundary is sharp.
		6250.63	Shale: dark-gray (N-3) slight color variation, finely banded
		6250.95	Shale: medium to dark-gray (N-4 to N-3)
		6251.81	Shale: dark-gray (N-3) grades into greenish-gray shale at 6251.87
		6252.42	Shale: dark-gray (N-3), sharp boundaries.
		6252.5	Shale: greenish-gray to dark-gray
		6253.3	Shale: gray-black. The boundary between the gray-black shale and underlying greenish-gray shale is very irregular (6253.6-6253.7)

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Top	Thickness	

1 cm.

		6253.7 Shale: greenish-gray, occasional dark-colored stringers in the middle of the interval
		6254.26 Shale: dark-gray
		6254.37 to 6254.85 Missing
		6255.15 Shale: dark-greenish-gray, boundary is irregular but sharp.
6255.41	7.99	Shale: dark-gray to gray-black with a few greenish-gray shale beds.
		6255.41 Shale: dark-gray to gray-black, platy, punky. Pyrite lens at 6256.69.

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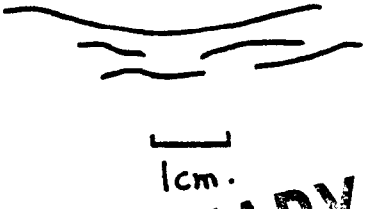
1 cm.

		6256.69 Shale: dark-greenish-gray (5GY 3/1), abundant pyrite, boundaries are not sharp and shale color grades to dark gray at base of interval.
		6257.3 Shale: greenish-gray (5GY 4/1) upper boundary is sharp.
		6257.41 Shale: dark-gray to gray-black
		6258.22 Shale: greenish-gray (5GY 4/1), sharp boundaries
		6258.42 Shale: dark-gray (N-3)
		6258.6 Shale: dark-greenish-gray
		6259.05 Shale: gray-black grades to dark-gray
		6260.6 to 6261.1 Concretion, fractures filled with calcite in the concretion.
		6261.1 Shale: dark-gray, laminae bend around base of concretion, abundant pyrite lenses and laminae.
6263.4	4.6	Shale: interbedded dark-gray and greenish-gray shale
		6263.4 Shale: greenish-gray (5GY 4/1) color

Top	Thickness		
			is slightly variable, dark-colored shale stringer at 6263.82
		6264.44	to 6264.83 Missing
		6265.35	Shale: dark-gray
		6265.40	Shale: greenish-gray
		6265.7	Shale: gray-black, color lightens towards base, lower boundary is gradational
		6266.1	Shale: greenish-gray
		6266.31	Shale: dark-gray to gray-black.
		6266.48	Shale: greenish-gray
		6266.87	Shale: gray-black to dark-gray
		6267.14	Shale greenish-gray, dark-colored stringer at 6267.52.
6268.0	4.2	Shale: gray-black (N-2) interbedded with greenish-gray shale.	
		6268.0	Shale: gray-black
		6269.4	Shale: dark-greenish-gray
		6269.8	Shale: gray-black
		6270.24	Shale: greenish-gray
		6270.6	Shale: gray-black
		6271.06	Shale: greenish-gray
		6271.2	Shale: gray-black
6272.2	13.3	Shale: greenish-gray interbedded with gray-black shale.	
		6272.2	Shale greenish-gray, light-colored stringer at 6273.5. Sharp boundary with underlying shale.
		6273.5	Shale: greenish-gray, dark-colored flecks near top.



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			color gradually becomes lighter toward base.
		6273.79	Shale: greenish-gray, lighter-colored toward base, sharp upper boundary.
		6274.21	Shale: greenish-gray, lighter-colored toward base
		6274.95	Shale: gray-black
		6275.10	Shale: greenish-gray
		6275.2	Shale: gray-black
		6275.5	Shale greenish-gray, lighter-colored toward base
		6276.26	Shale: greenish-gray, lighter-colored toward base
		6277.0	Shale: dark-gray

Top	Thickness		
		6277.2	Shale: greenish-gray, lighter colored in middle of interval.
		6277.6	Shale: dark greenish-gray grades to gray (N-4) at base.
		6278.62	Shale: dark-gray
		6279.15	Shale: greenish-gray (5GY 5/1), sharp upper boundary but laminae of dark-colored shale are present in the upper part of interval.
		6279.36	to 6279.63 Missing
		6279.63	Shale: dark-gray, lighter-colored laminae are present and increase to 10% at base.
		6280.6	Shale: medium to dark-gray (N-3 to N-4)
		6280.82	Shale: medium-gray (N-4) coarse-grained layer in middle
		6280.95	Shale: gray-black, bagged
		6281.9	Shale: dark-greenish-gray
		6281.73	Shale: gray-black
		6282.15	Shale: dark-greenish-gray

SUMMARY

6273.2 to 6282.5

This interval includes some of the lightest-colored shale in the core. There is a cyclicity of dark-colored shale grading downward to lighter-colored shale with a sharp break in color at the top of the next dark-colored shale. The dark gray shales are laminated with a few lighter-colored laminae, contacts between the dark and light-colored shales are gradational in some places and sharp in others.

6282.5	30		Shale: dark-gray to gray-black, silty, core breaks into plates. The interval is generally monontonous in appearance.
		6282.5	Shale: gray-black
		6284.0	Shale: dark-gray to dark-greenish-gray, occasional light-colored lamina.
		6285.22	Shale: gray-black, disintegrating, pyritic at base, 1 mm greenish-gray lamina at 6286.22.
		6287.6	Shale: gray-black to dark-gray grades to dark greenish-gray shale at 6288.4. Concretion at 6290.6, shale laminae curve around the concretion. From 6291.6 the color varies from dark gray to dark gray green with occasional light-colored laminae. Color changes are gradational.
		6296.4	Shale: dark-greenish-gray, laminated, pyrite nodules up to 5 mm in size at 6296.46 the top of the core has nodes where shale laminae warp over nodules. Pyrite at 6297.0.

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Top	Thickness	
		6298.9 Shale: gray-black
		6299.15 Shale: medium-gray (N-4) grades into dark-gray shale (N-3), upper boundary is gradational.
		6304.3 Shale: dark-gray to dark-greenish-gray, occasional lighter-colored bands. Concretion at 6304.3. Conspicuous lighter-colored band at 6311.0-6311.5.
6312.5	8.4	Shale: gray-black grading to dark-gray, some thin (1 cm) light-colored bands. Breaks into plates.
	Cashaqua	Shale Member of Sonyea Formation
6320.9	30.7	Shale: greenish-gray (5GY 4/1) occasional lighter and darker-colored beds, finely bedded to laminated. Near the top are several stringers of light-gray (N-6) shale.
		6346.1 Pyrite nodules
		6348 Pyrite nodules, small
6351.6	42.5	Shale: light-medium-gray (N-5) with a slight bluish tint.
		6352.6 Nodules; composed of light-gray shale (N-7)
		6353.[illegible] Nodules; composed of light-gray shale (N-7) in a layer, some dark-colored stringers.
		6356.8 Light-gray (N-7) shale stringers.
		6357.5 Fossil: cephalopod, two brachiopod valves.
		6357.74 Light-colored shale bed, additional light-colored shale laminae at 6358.1, 6358.86, 6359.1. They may be concretions. Boundaries are irregular and undulose, but sharp. Burrowing present.
		6360.6 Fossil: gastropod (?), 3 mm.
		6361.9 Fossil: cephalopod, small linguloid brachiopod, burrows, most visible on core top as dots 2-3 mm in size.
		6362.3 Concretion: light
		6362.45 Concretion: light
		6363.2 Fossil: <u>Styliolina</u> (?), on core top

2 cm. long

		6362.5 Fossil: Cephlaopod, 2 cm in diameter
		6362.6 Light-colored shale bed
		6362.85 Light-colored shale bed

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Top	Thickness	
		6363.75 Fossils: 1 cm in length
		6365.15 Fossils: abundant fossils, small brachiopods and cephalopods.
		6365.9 Concretion
		6367.96 Fossil: 4 cephalopods on core top
		6368.45 Fossil: Cephalopods
		6369.04 Light-colored shale bed
		6369.15 Light-colored shale bed
		6373.24 Pyrite layer
		6377.05 to 6377.2 Concretions: small, composed of coarser-grained material
		6379.05 Fossil: cephalopod
		6379.19 Fossil: Styliolina (?)
		6379.8 Fossil: cephalopod
		6380.2 - 6379.6 and 6380.2 small clots composed of mottled gray and white shale, laminae of shale wrap around clots.

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		6381.65 Fossil: cephalopod and Styliolina (?)
		6382.6 Fossil: cephalopods
		6383.85 Fossil: small brachiopods
		6383.3 Fossil: cephalopod, coiled, 4 cm in diameter.
		6384.98 Fossils: small beasts
		6389.2 Concretion: light-gray, shale mottled, shale laminae bend around the concretion.
		6390.28 Pyrite lamina
6394.1	40.48	Shale: dark greenish-gray (5GY 4/1 to 5GY 3/1) occasionally dark gray (N-3) scattered gray-black shale beds.
		6394.1 Shale: dark-gray (N-3), concretion at 6394.4.
		6394.46 Shale: dark-greenish-gray, pyritic, gradational upper boundary.
		6396.6 Concretion: 7 cm long, 3.5 cm thick.
		6396.76 Fossils: brachiopod on core top with many small fossils.
		6396.85 Fossil: brachiopod
		6397.7 Concretions
		6398.0 Shale: dark-greenish-gray (5GY 4/1 to 5GY 3/1), occasionally shading to dark-gray (N-3) shale, scattered gray-black beds.

Top	Thickness		
		6400.56	Burrows: pyritized
		6402.2	to 6402.8 Pyrite: fairly common through interval as small nodules.
		6407.0	Shale: gray-black, bagged
		6406.35	Shale: dark-greenish-gray
		6407.48	Fossil: brachiopod
		6408.5	Fossils: brachiopods, 5 about 1 cm across.
		6408.73	Fossils: brachiopod
		6409.10	Shale: dark-gray (N-3)
		6409.5	Shale: dark greenish-gray
		6410.8	Shale: gray-black
		6411.0	Pyrite: lens, shale laminae bent around pyrite lens.

1 cm.

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		6411.2	Shale: greenish-gray, a few lighter-colored beds towards base.
		6411.5	Fossils: brachiopods
		6411.6	Fossils: 3 small cephalopods, Styliolina (?)
		6411.2	Shale: becomes slightly darker
		6434.1	Fossils: on core top many small dark spots (less than 1 mm in diameter) spores or ostracods.

Middlesex Shale Member of Sonyea Formation

6434.58	6.92	Shale: interbedded dark-greenish-gray and dark-gray to gray-black.	
		6434.58	Shale: dark-greenish-gray, gradually darkens in color downward
		6435.2	Pyrite: small nodules
		6435.9	Shale: dark greenish-gray, colors darkens downward, short pyrite laminae.
		6437.1	Shale: dark greenish-gray, darkens downward, several cycles like this are present. Light-gray silt beds (1 mm thick) at 6438.1 and 6439.5 with wavy lamination
		6440.5	Shale: greenish-gray, pyritic

SUMMARY

6320.9 to 6441.5

This interval is composed of a monotonous series of dark-colored

Top	Thickness	

shale. There are few conspicuous changes in lithologic character and the interval was subdivided on the basis of subtle color changes. From 6230.9 to 6351.6 and 6394.1 to 6441.5, the shales are darker in color and the core breaks into plates. From 6351.6 to 6394.1, the core is slightly lighter-colored and does not break into plates. Where the core breaks into plates, the top and bottom of a plate were examined every 3 to 4 inches. Because most of the fossils are noted on the core tops, many more fossils may be present than noted, because every piece was not examined.

From 6434.58 to 6441.5 the shale is cyclic in color, with dark-colored shale grading into dark-colored shale. The boundaries of each cycle are generally sharp.

West River Shale Member of Genesee Formation

6441.5	14.40	Shale: greenish-gray with some olive gray, lighter-colored than overlying units; banded with a small proportion of dark-colored shale, cyclic.
		6441.5 Shale: greenish-gray to gray, pyritic darker-colored zone, 1 cm thick at 6442.03.
		6442.4[illegible] Shale: gray-black, sharp break in color, includes a few lighter-colored, coarse-grained beds.
		6443.5[illegible] to 6443.76 Missing
		6443.76 Shale: greenish-gray to gray; concretion from 6443.9 to 6444.5, fractures filled with calcite, but there is an open pore in the center.
		6445.[illegible] Shale: dark-gray, pyrite lamina at top, light-gray shale (N-7) lenses at 6445.2, dark-colored shale laminae curve around light-colored laminae.
		6445.35 Shale: gray, gradational boundary, burrowed
		6445.75 Shale: darker in color, gradational change
		6445.9 Fossil: linguloid brachiopod (?), small.
		6446.4 Shale: medium-gray (N-4), pyritic; thin dark-colored bed at 6447.3; irregular dark-gray shale (N-3) bed at 6447.5
		6448.11 - 6448.37 Missing
		6448.37 Shale: dark-gray (N-3)
		6448.40 Shale: gray (N-4) grades to darker-colored shale at 6448.5 with a sharp basal boundary. 2-3 mm pyrite lens at 6448.5
		6448.65 Shale: gray (N-4) grades to dark-colored

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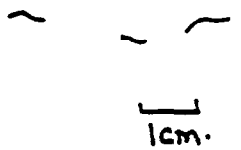
Top	Thickness		
			shale (N-3) sharp basal boundary.
		6448.9	Shale: gray, pyrite, unidentified fossil at 6449.1
		6449.7	Shale: darker in color, gradational upper boundary.
		6449.95	Shale: lighter, in color, numerous little curved pyrite lenses, may be replaced fossils



Interval gradually darkens in color toward base. At 6453.2 a thin light-gray silt lamina; surrounded by dark-colored shale.

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			Small, dark-colored fossils at 6451.4
		6451.45	Shale: lighter in color, sharp upper boundary
		6452.56	Shale: dark-gray, gradational upper boundary
		6452.80	Shale: lighter in color, sharp upper boundary, pyrite as nodules and disseminated in lower part of interval.
		6453.74	Shale: dark-gray, gradational color change from overlying unit, disseminated pyrite.
		6453.97	Shale: lighter in color, sharp color break at top
		6455.6	Shale: gray-black, crumbly
		6455.76	Shale: lighter in color.
6455.9	8.3	Shale: interbedded greenish-gray and gray-black shale.	
		6455.9	Shale: greenish-gray, darkens to dark gray (N-3) unidentified fossils at 6456.4, 6457.7 and 6459.2.
		6459.7	Shale: lighter-colored than base of previous interval, but darker in color than the top of previous interval.

Top	Thickness	
		Gradually darkens downward.
		6460.6 Shale: gray-black, disintegrating
		6460.95 Shale: greenish-gray, pyrite nodules 2 cm diameter at 6461.0
		6463.6 Shale: gray-black
		6463.8 Shale: greenish-gray.
		6464.19 - 6464.42 Missing
6464.42	38.18	Shale: dark-greenish-gray, breaks into plates, beginning to disintegrate
		6464.42 Shale: dark-greenish-gray to greenish-black, platy
		6464.6 Fossils: brachiopods
		6464.7 Pyrite: contorted laminae
		6464.7 to 6464.8 elongate dark fragments, plant fragments (?)
		6468.2 Fossils: brachiopods, cephalopod
		6469.0 Fossil: small brachiopod
		6470.5 Fossil: cephalopod
		6472.43 - 6472.71 Missing
		6472.71 Thin zone of bituminous material
		6472.43 Shale: dark-greenish-gray to gray-black, generally not as punky as overlying interval.
		6501.7 Slickensides on surface.

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Geneseo Shale Member of Genesee Formation

6502.60	9.3	Shale: black (N-1), very silty, pwoders brown gray, bedding inclined to core, rare fossils.

SUMMARY

6464.2 to 6511.9

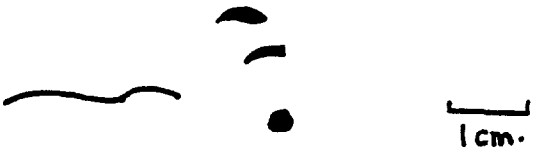
There is a very gradational change downward from very-dark-greenish-gray and greenish-black to black shale. The change is gradational and most noticeable when doing a side by side comparison of samples from top and bottom of the interval. Fossils are present, but the number decrease down section.

Tully Limestone

6511.9	5.06	Limestone: olive-gray (5Y 4/1),shaly, pyritic. The upper contact is irregular with irregular stringers of dark-colored shale in the limestone. Many pyrite nodules pyritized fossils.

1cm.

Top	Thickness	
		6511.9 to 6512.2 Fracture: coated with calcite
		6512.47 to 6512.53 darker-colored layer, irregular, burrowed
		6512.55 to 6512.7 Pyrite, circular nodules, which may be burrows. Fossils at 6512.8 and 6513.5



		6514.44 to 6514.85 Missing
		6514.85 Limestone becomes more shaly, color darkens toward base. Basal boundary not present because core is crumbly and disintegrating.

Mahantango Formation

6516.96	.74	Shale: black, crumbly
6517.70	2.75	Shale: dark-greenish-gray to gray-black with some bluish-gray, burrowed, limestone.
		6517.7 Shale: greenish-gray to gray (N-4), calcareous banded, burrowed, some burrows pyritized.

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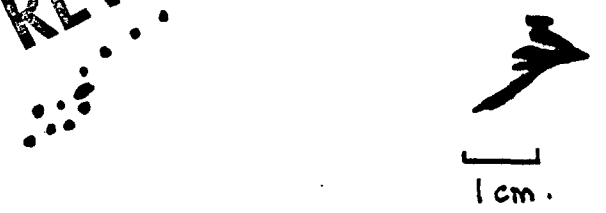
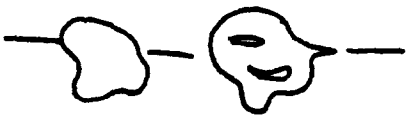


		6512.3 Shale: dark-gray (N-3), gradational upper boundary.
		6518.9 Limestone: blue-gray, gradational boundary
		6519.52 - 6519.78 Missing
		6519.78 Shale: gray (N-4) to greenish-gray, calcareous, pyritic, at 6520.6 to 6520.2 light-gray (N-5) beds, fossils at 6520.3.
6520.45	1.93	Shale: black to gray-black, calcareous, powders brown, large pyrite nodules 1-2 cm in diameter.
		6522.0 Brachiopods
6522.38	6540.0	Shale: gray-black,powders dark gray, banded with greenish-gray shale, slightly calcareous, gradational boundaries.
		6522.38 Shale: gray-black, slightly calcareous, powders gray. Pyrite nodules (2.0 to

Top	Thickness		
			3.5 cm) at 6523.4 and 6524.1. Pyritized brachiopod at 6523.4.
		6524.4	Shale: color lightens slightly
		6526.0	Pyrite; laminae and large nodules 4 cm in diameter.



4 cm.

		6526.0	Shale: gray (N-5) interbedded with light-gray (N-7) shale, slightly calcareous, vertical filled fractures.
		6526.7	Shale: gray (N-5) gradually darkens to (N-4); light-colored nodules at 6527.0, 6527.4, 6527.8 and 6528.0.
		6529.0	Shale: becomes lighter in color
		6530.[illegible]	Shale: darker in color, gradational boundary.
		6532.2	Fossils: cephalopod, crenulated brachiopods
		6532.3	Shale: lighter in color (N-4) gradational color change
		6532.[illegible]	Shale: light-gray (N-6), sharp upper boundary gradually darkens to medium-gray (N-3) at 6533.45.
		6534.4	Shale: light-gray (N-6), sharp boundaries may be a concretion.
		6535.2	Shale: dark-gray (N-3)
		6536.25	Shale: gradually becomes lighter in color
		6536.75	Shale: medium-gray (N-4 to N-5) sharp boundaries.
		6537.23	Shale: gradually becomes darker in color (N-4), some lighter-colored zones.
		6538.95	Shale: lighter in color
		6539.1	Shale: medium-gray (N-4) darkens to (N-2); the powdered shale changes from gray to brown gray in color, the change is gradational.
		6539.8	Pyrite
6540.0	31.4		Shale: gray-black (N-2). The powdered shale changes from brown to gray in color. The shale breaks into plates, occasional pyrite layers. The shale was powdered and examined every half foot through the interval
		6540.0	Shale: gray-black, powders brown, light-gray concretion at 6545.6 to 6545.7.

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Top	Thickness	
		6547.9 Shale: gray-black, powders brownish gray
		6548.3 Shale: gray-black, powders brown
		6548.8 Shale: gray-black, powders brownish gray
		6549.4 Shale: gray-black, powders brown
		6549.7 Shale: gray-black, powders brownish gray
		6550.05 Shale: gray-black, powders gray
		6552.4 Shale: gray-black, powders brownish gray
		6552.6 Shale: gray-black, powders gray
		6552.9 Shale: gray-black, powders brownish gray
		6553.7 Shale: gray-black, powders gray
		6555.5 Shale: gray-black, powders brownish gray
		6557.0 Shale: gray-black, powders gray
		6557.5 Shale: gray-black, powders brown
		6558.0 Shale: gray-black, powders brownish gray
		6558.5 Shale: gray-black, powders brown
		6559.0 Shale: gray-black, powders gray
		6559.5 Shale: gray-black, powders brown
		6560.0 Shale: gray-black, powders brownish gray
		6561.0 Shale: gray-black, powders gray
		6562.0 Shale: gray-black, powders brownish gray
		6563.0 Shale: gray-black, powders gray
		6565.0 Shale: gray-black, powders brownish gray
		6566.5 Shale: gray-black, powders brown
		6567.0 Shale: gray-black, powders brownish gray
		6568.0 Shale: gray-black, powders brown
		6568.5 Shale: gray-black, powders brownish gray
		6569.0 Shale: gray-black, powders brown
		6569.5 Shale: gray-black, powders gray
		6570.0 Shale: gray-black, powders brownish gray
		6571.4 Shale: gray-black, powders brown

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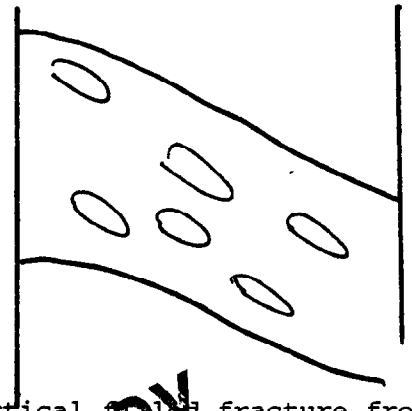
SUMMARY
6540.0 to 6571.41

This interval is monontonous in appearance, composed of gray-black shale which breaks into plates. Although the general character of the interval doesn't change, the powder color of samples ranges from gray (much lighter than the shale) to brownish gray (lighter than the shale with a brown tint) to brown (almost as dark as shale). The streak was examined every half foot through the interval

Marcellus Shale

6571.41	31.47	Shale: Black (N-1), silty, powders brown, most of the interval has crumbled and disintegrated into little chips, silt is present both as laminae and as grains through the shale. Coarse silt laminae are present at 6588.6 to 6588.9, occasional small fossils are present.
6602.6	1.8	Limestone: dark-gray (N-3), Upper and lower boundaries are inclined and sharp. Abundant fossils,

Top	Thickness	
		coral, brachiopods. From 6603.0 to 6603.3, mottled dark shale zone, fossiliferous.



		Vertical filled fracture from 6603.7 to 6604.4. Coquinite bed, 1 cm at base.
6604.4	20.55	Shale: black (N-1) silty, powders brown
		6614.4 to 6615.6 Very silty layer, silty laminae continue to 6616.6
		6618.75 Pyrite: large, zoned, nodule

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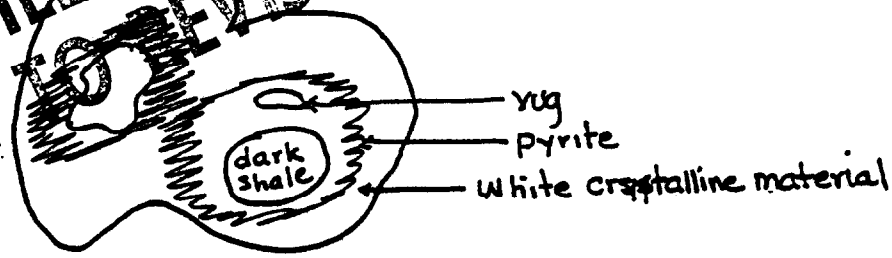

		6624.7 to 6624.60 Missing
		6624.60 Silt bed

Onondaga Limestone

6624.95	1.75	Limestone: dark gray (N-3) grading to (N-4), shaly, boundary is gradational, the overlying shale beds are very calcareous. Limestone is fractured and fractures are filled with fine crystalline material.
6626.70	8.9	Limestone: dark-gray, medium-gray and brownish-gray, fossiliferous
		6626.7 Limestone: dark-gray grades into brownish gray
		6627.15 Limestone: dark-gray (N-4), very-fossiliferous, light-colored zones at 6677.45 and 6627.8, sharp upper boundary
		6628.13 Limestone: brownish-gray
		6628.17 Limestone: medium-gray grades into lighter-colored fossiliferous, burrows, dark-colored laminated beds at 6633.2 and 6633.3, 6634.6 fossils. 6633.42 and 6633.5; large coral at 6634.5
6633.6		Base of core.

APPENDIX 2
Description of Samples from Wood 72

W.H. Orem No. 1 (1200) well
Wood 72
Located 2.75 mi W of 81°40' and 0.02 mi S of 39°05', SW-Belleville Quadrangle, Harris District, Wood County, West Virginia, Elevation 684'.
Drilled by New Penn Development Corporation, Port Allegany, PA to a depth of 5896 feet.
Shows of gas at 3550, and 3625, well plugged and abandoned.

Samples from 1998 ft. to 4193 were examine dry using a binocular microscope.

Stratigraphic Summary

2012-2015	Berea Sandstone
2015-3145	Upper Devonian undivided
3145-3670	Lower part of the Huron Member of the Ohio Shale
3670-3779	Big White Slate
3779-4175	Rhinestreet Shale Member of West Falls Formation and Sonyea Formation
4175-	Top of Onondaga Limestone

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Top	Thickness	
		Mississippian
1998	8	90% Shale: medium to dark gray (N-5 to N-4), silty noncalcareous. 10% siltstone: white, rounded, quartz, hematite specks; porous
		Berea Sandstone
2006	9	80%: shale, gray (50% -N-5) (50% -N-4), silty. 20% siltstone: white, rounded grains, quartz, hematitic
		Upper Devonian Undivided
2015	9	70% shale: (60% -N-4)(40%-N-5) silty 30% siltstone (N-6), shaly, calcareous
2024	60	shale: medium-gray N-5, silty
2084	26	shale: medium-gray (N-4) with slight brownish tint, silty
2110	42	shale: gray (N-4), silty, scattered brownish-colored fragments
2152	20	shale: gray (N-5), silty
2172	30	shale: gray (N-4), silty
2202	38	shale: gray (N-4), silty, occasional fragments of lighter-gray, coarser-grained, shaly, siltstone
2240	10	shale: gray (N-4), silty
2250	74	shale: gray (N-5), silty
2324	1[illegible]	shale: as above, with occasional pieces of siltstone, white to light gray in color
2334	39	shale: gray (N-5 to N-4), silty
2373	[illegible]	shale: as above with 20 to 30% brownish-gray, silty, shale fragments
2382	74	shale: gray (N-5), silty
2456	26	shale: gray (N-4), silty
2482	21	shale: gray (N-5), silty
2503	31	shale: gray (N-4), silty
2534	41	shale: dark-gray (N-3), silty, peices of calcite fracture filling 2544-2554 - a few pieces of red, silty, shale
2575	59	shale: gray (N-4), silty
2634	54	shale: dark-gray (N-3), silty, occasional red-brown, silty, shale fragments.
2690	162	shale: gray (N-4), silty 2710-2720 a few red-brown fragments
2852	38	shale: gray (N-4), slightly darker in color than above, some red-brown, silty, fragments. 2880-2890 pyritized spores
2890	60	shale: gray (N-4), silty
2950	10	shale: as above, pyrite, spore?, 1% red-brown, silty shale.

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Top	Thick-ness	
2960	10	shale: gray (N-4), a few red-brown fragments, a few fragments have small dark spots.
2970	10	shale: gray (N-4), silty, small pyritized spores, possible fragment of Foerstia.
2980	165	shale: gray (N-4), silty, a few red-brown fragments.
		Lower Part of the Huron Member of Ohio Shale
3145	55	shale: mixed N-3 and N-4, silty, darker fragments are finer-grained.
3200	62	shale: gray, N-4, silty
3262	20	70% shale: gray, N-4, silty 30% shale: light-gray (N-5), silty, coarser-grained than dark-colored shale.
3282	20	shale: as above with a few fragments of dark-colored shale (N-3)
3302	15	shale: as above with 10% dark-gray (N-3) shale. Some small pyritized spores in the lighter-colored shale.
3317	28	shale: gray; 40% (N-4); 40% (N-5); 20% (N-3), silty.
3345	55	shale: gray (N-3 to N-4), silty
3400	60	shale: gray (N-4), silty, occasional fragments of dark-gray (N-3) shale.
3460	56	shale: dark-gray (N-3), silty, some brownish-colored fragments
3516	76	shale: gray (N-4), silty, mixed with some darker-colored (N-3) shale 3545-3564 darker-colored fragments contain a few small spores
3592	24	shale: as above but slightly darker in color
3616	54	shale: dark-gray (N_3 to N-2) with slight brownish tint, silty but finer-grained than above, occasionally pyritic. From 3643 to 3652-shale powders brown.
		Big White Slate
3670	26	shale: light-gray (N-6), silty
3696	83	shale: mixed N-4 and N-5; N-5 predominates.
		Rhinestreet Shale Member of West Falls Formation and Sonyea Formation
3779	36	shale: dark-gray (N-3) about 20% of the sample is tinted brown and powders brown.
3815	30	shale: lighter in color, fewer brown fragments
3845	40	shale: as above with scattering of dark-colored fragments

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Top	Thick-ness	
3885	55	shale: darker-colored than above, silty, contains 10% darker-colored fragments that powder brown
3940	19	shale: darker in color, 20 to 30% powder brown.
3959	9	shale: lighter in color, 10 to 20% darker-colored fragments
3968	47	shale: darker, 40% darker-colored fragments
4015	29	shale: slightly lighter in color, less than 10% dark-colored fragments
4054	70	shale: black to gray-black (N-1 to N-2) slight brown tint, powders brown, silty but very-fine-grained silt.
4124	31	shale: as above with 20% gray fragments (N-3), some of the darker-colored fragments powder gray brown.
4158	8	shale: as above, very slightly calcareous. 10% limestone, finely-crystalline, brown, some fossils.
4166	9	shale: dark-gray, 50% powders gray; 50% powders brown, 5-10% limestone: brown, finely-crystalline
4175	18	shale: gray black, powders brown, a few pieces of limestone
		Onondaga Limestone
4193	5	limestone: brown gray cherty

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APPENDIX 3
Depth to Formation tops in wells with Gamma-Ray logs

Key

Braxton 1074	-	County and well permit Number
El	-	Elevation from which log was measured
D	-	Devonian Clastic Sequence
H	-	Huron Member of Ohio Shale
J	-	Java Foramtion
WF	-	West Falls Formation
S	-	Sonyea Formation
G	-	Genesee Formation
T	-	Tully Limestone
MH	-	Mahantango Formation
MR	-	Marcellus Shale
O	-	Onondaga Limestone
NP	-	Not Present
4895?	-	Top is uncertain
?	-	unit may be present
TD	-	Total Depth, given for shallow wells only

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Permit Number	El	D	H	J	WF	S	G	T	MH	MR	O	TD
Braxton 1074	942	1870	2908	4282 (1)								4360
Braxton 1068	1049	2120	3177	4550 (1)								4618
Braxton 1121	1113	2150	3220	4630? (1)								4655
Braxton 1126	1473	2438	3505	4758	5014	6115	6367	NP	NP	6500	6560	
Calhoun 2503	1230	2625	3760	4882	5100	5953	6136	NP	NP	6242	6250	
Calhoun 2524	1219	2610	3890	4840	5062	6000	6150 (2)					
Calhoun 2548	935	2420	3550	4602	4820	5714	5870 (2)					5900
Doddridge 71 (3)	1141	2308	3540?	4961	5170						6712	
Doddridge 1674	1127	2612	3705	5235 (1)								5330
Doddridge 1781	786	2345	3512	4895?								
Doddridge 1849	996	2385	3470	4970?								
Doddridge 1867	1094	2624	3710	5044 (1)								5044
Gilmer 1978	959	2275	3390	4660	4888	5950	6233	NP	6384	6390	6434	
Gilmer 2333	812	2145	3225	4540	4763 (1)							4820
Gilmer 2486	1126	2360	3580	4640	4860	5830	6040 (2)					6203
Gilmer 2943	860	1863	2927	4260	4504	5696	6004	6184	6201	6226	6286	
Gilmer 3012	1045	2061	3128	4555	4785	5918	6228	6410	6427	6454	6510	
Jackson 1017	742	2456	3661	4165	4308	4758	NP	NP	NP	NP	4790	
Jackson 1063	882	2565	3788	4317	4461	4936	NP	NP	NP	NP	4971	
Jackson 1118	936	2604	3815	4347	4490	4956	NP	NP	NP	NP	4990	
Jackson 1123	717	2381	3577	4070	4214	4650	NP	NP	NP	NP	4680	
Jackson 1128	751	2408	3605	4100	4242	4673	NP	NP	NP	NP	4705	
Jackson 1131	600	2294	3484	3975	4147	4545	NP	NP	NP	NP	4578	
Jackson 1134	957	2299	3495	3996	4140	4576	NP	NP	NP	NP	4607	
Jackson 1136	936	2555	3751	4257	4400	4840	NP	NP	NP	NP	4872	
Jackson 1140	820	2488	3693	4210	4356	4814	NP	NP	NP	NP	4847	
Jackson 1154	675	2353	3570	4080	4224	4680	NP	NP	NP	NP	4710	
Jackson 1156	948	2620	3810	4292	4432	?	NP	NP	NP	NP	4891	
Jackson 1163	728	2287	3454	3964	4104	4524	NP	NP	NP	NP	4566	
Jackson 1183	705	2367	3566	4068	4226	4662	NP	NP	NP	NP	4694	
Jackson 1190	769	2404	3590	4115	4260	4700	NP	NP	NP	NP	4732	
Jackson 1191	755	2398	3584	4090	4248	4672	NP	NP	NP	NP	4703	
Jackson 1193	867	2513	3704	4220	4376	4804	NP	NP	NP	NP	4835	

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Permit Number	El	D	H	J	WF	S	G	T	MH	MR	O	TD
Jackson 1197	1028	2652	3822	4328	4470	4893	NP	NP	NP	NP	4930?	
Jackson 1200	661	2305	3500	4011	4170	4601	NP	NP	NP	NP	4630	
Jackson 1201	864	2495	3674	4195	4336	4768	NP	NP	NP	NP	4804	
Jackson 1203	1059	2720	3934	4561	4720	5238	NP	NP	NP	NP	5294	
Jackson 1212	635	2145	3305	3878	4030	4486	NP	NP	NP	NP	4540	
Jackson 1215	696	2354	3560	4060	4170	4646	NP	NP	NP	NP	4675	
Jackson 1216	804	2429	3608	4107	4252	4668	NP	NP	NP	NP	4705	
Jackson 1217	889	2513	3690	4190	4334	4751	NP	NP	NP	NP	4788	
Jackson 1218	884	2531	3724	4245	4390	4832	NP	NP	NP	NP	4865	
Jackson 1219	865	2494	3664	4171	4326	4737	NP	NP	NP	NP	4772	
Jackson 1220	908	2534	3714	4217	4360	4795	NP	NP	NP	NP	4820	
Jackson 1223	854	2470	3643	4145	4290	4714	NP	NP	NP	NP	4742	
Jackson 1224	679	2318	3496	4009	[illegible]	4576	NP	NP	NP	NP	4612	
Jackson 1235	753	2392	3570	4080	[illegible]	4650	NP	NP	NP	NP	4690	
Jackson 1241	657	2270	3460	3955	[illegible]	?	NP	NP	NP	NP	4553	
Jackson 1246	747	2125	3283?	3771	[illegible]	4302	NP	NP	NP	NP	4348	
Jackson 1247	771	2362	3525	4040	[illegible]	4601	NP	NP	NP	NP	4645	
Jackson 1267	869	2428	3585	[illegible]	[illegible]	4604	NP	NP	NP	NP	4635	
Jackson 1268	789	2329	3470	3945	[illegible]	4463	NP	NP	NP	NP	4493	
Jackson 1269	837	2375	3532	4004	4135	4535	NP	NP	NP	NP	4570	
Jackson 1275	789	2232	3360	3790	[illegible]	[illegible]	NP	NP	NP	NP	4310	
Jackson 1282	832	2298	3440	[illegible]	4035	[illegible]	NP	NP	NP	NP	4442	
Jackson 1293	875	2440	3587	[illegible]	[illegible]	[illegible]	NP	NP	NP	NP	4632	
Jackson 1366	940	2520	3745	4390	4504?	5112?	5180?	NP	NP	NP	5210	
Jackson 1369	846	2315	3426	3830(1)								3934
Jackson 1371	673	2110	3227	3642(1)								3742
Jackson 1421	758	2120	3195	3741	3876	4242	NP	NP	NP	NP	4290	
Mason 69	609	1825	2711	2993	3111	NP	NP	NP	NP	NP	3310	
Mason 71	874	2475	3473	3818	3930	4223	NP	NP	NP	NP	4230	
Mason 134	930	2426	3542	3950	4079(4)							4119
Mason 146	665	1754	2734	3052	3160	NP	NP	NP	NP	NP	3390	
Pleasants 667	1085	1270	2530	3426	3610	4295	4378	NP	NP	NP	4440	
Pleasants 694	929	2220	3376	4554	4770	5522	5629	NP	5706	5716	5740	

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Permit Number	El	D	H	J	WF	S	G	T	MH	MR	O	TD
Putnam 722	942	2426	3604	4060	4197	4614	NP	NP	NP	NP	4650	
Putnam 735	623	2120	3330	3848	3997	4480	NP	NP	NP	NP	4511	
Putnam 741	792	2283	3487	4010	4161	4641	4671?	NP	NP	NP	4682	
Putnam 762	717	2372	3582	4096	4242	4702	NP	NP	NP	NP	4750	
Putnam 803	984	2578	3793	4305	4450	4910	NP	NP	NP	NP	4950	
Putnam 805	935	2517	3720	4248	4395	4880	NP	NP	NP	NP	4910	
Putnam 806	1075	2618	3818	4335	4430	4958	NP	NP	NP	NP	4989	
Ritchie 1256 (5)	1011	2058	[illegible]	4374	4574	5260	5380	NP	NP	NP	5473	
Ritchie 3242	832	[illegible]	[illegible]	[illegible]	4648	5304	5420	NP	NP	5504?	5518	
Ritchie 3611	1108	2540	[illegible]	[illegible]	5165 (4)							5999
Roane 714	675	1890	[illegible]	[illegible]	[illegible]	5010	5105	NP	NP	NP	5176	
Roane 716	840	2120	[illegible]	[illegible]								4300
Roane 1483	801	2365	[illegible]	4315	[illegible]	5160	5226	NP	NP	NP	5308	
Roane 1676	853	2221	[illegible]	[illegible]	[illegible]	5405	5531	NP	NP	NP	5599	
Roane 2002	1072	2580	[illegible]	[illegible]	[illegible]	5628	5758	NP	NP	NP	5856	
Roane 2077	956	2235	3372	[illegible]	[illegible]	5510	5632 (2)					5700
Tyler 427	967	2370	3520	[illegible]	[illegible]	[illegible]	6209	6344	6347	6367	6428	
Wetzel 410	1056	2594	4025?	[illegible]	[illegible]	[illegible]	7010	7168	7190	7300	7350	
Wetzel 645	1355	2706	3906	[illegible]	[illegible]	[illegible]	6437	6511	6520?	6570	6626	
Wirt 531	1051	2385	3597	[illegible]	[illegible]	[illegible]	5635	NP	NP	NP	5735	
Wirt 537	1132	2333	3564	[illegible]	4754	5472	5600	NP	NP	NP	5698	
Wirt 548	671	1491	2734	3664	3880	4594	4668	NP	NP	NP	4777	
Wirt 566	688	2052	3320	4230	4446	5150	5240	NP	NP	NP	5329	
Wirt 746	1113	2626	3845	4768	4840	5503	5632	NP	NP	NP	5726	
Wood 351	1065	765	1918	2965	3171	3765?	3860?	NP	NP	?	4022	
Wood 518 (6)	970	1702	3321	4320	4514	5200	?	NP	NP	?	5520	
Wood 586	859	2335	3517	4150	4305	4818	NP	NP	NP	NP	4871	
Wood 593	635	1815	2970	3425	?	3965	NP	NP	NP	NP	4018	
Wood 594	792	2160	3290	3818	3953	4350	NP	NP	NP	NP	4394	
Wood 598	749	2085	3220	3780	3920	4333	NP	NP	NP	NP	4382	
Wood 709		1822	2980	3488	3727 (4)							4034
Wood 752	649	?	2993	3500	3630	3992	NP	NP	NP	NP	4040	
Wood 755	723	1931	3095	3602	3735	4104	NP	NP	NP	NP	4158	

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Permit Number	El	D	H	J	WF	S	G	T	MH	MR	O	TD
Wood 756	726	?	3530	4230	4390	4948	NP	NP	NP	NP	5011	
Wood 758	783	1997	3150	3676	3802	4170	NP	NP	NP	NP	4220	
Wood 759	672	1886	3040	3558	3690	4060	NP	NP	NP	NP	4110	
Wood 769	624	1820	2960	3460	3590	3948	NP	NP	NP	NP	3992	
Wood 803	730	2247	3460	4140	4305	4844	NP	NP	NP	NP	4915	
Additional wells outside area												
Lewis 1864	1160	1722	2825	4434	4665	5915	6256	6448	6485	6595	6653	
Marshall 539	1435	2922	4240	5645	5913	7055	7293	7395	7420	7528	7575	

Notes:

1 TD in Java Formation
2 TD in Genesee Formation
3 Logged from 3300-5500, D and O top from Sample Studies
4 TD in West Falls Formation
5 Well on Burning Springs Anticline Flank dip = 14°
6 Well on Burning Springs Anticline Flank dip = 22°, thrust fault at 5430, repeats lower portion of well.

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