DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Petroleum source rock potential of the Upper Ordovician black shale sequence, northern Appalachian basin

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[1]Reston, Virginia

1989

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ABSTRACT

In the Appalachian basin, the widespread black shales of Mississippian through Devonian age and of Late Ordovician age are sufficiently rich in organic matter to be hydrocarbon source rocks. The younger Devonian and Mississippian sequence is less deeply buried and better exposed within the basin than the Upper Ordovician sequence. As a result, the Upper Ordovician shales have not been evaluated as extensively for their hydrocarbon potential. An appraisal of the Upper Ordovician black shale sequence has been made for the northern part of the basin west of the Allegheny front in New York, Pennsylvania, Ohio, and West Virginia. The region contains a relatively continuous sequence of dark-gray to grayish-black shale of Late Ordovician age. Within the Upper Ordovician black shales, a sequence was delineated based on its physical properties that were indicative of a potential source rock. This unit, informally defined here as the Utica sequence comprises all or part of the Utica Shale and its correlatives, the Antes Shale, the lower part of the Reedsville Shale, the lower part of the Martinsburg Shale, the Point Pleasant Formation, and the basal part of the undivided Cincinnatian Series.

The thickness of the Utica sequence ranges from less than 200 feet in western Ohio to more than 600 feet along the Allegheny front in southwestern Pennsylvania. Structure contours indicate that the base of the Utica sequence is about 2,000 feet below sea level in central Ohio and plunges eastward to about 12,000 feet below sea level in central and northeastern Pennsylvania.

Geochemical analyses of 175 samples from the Utica sequence from 104 localities in New York, Ohio, Pennsylvania, and West Virginia indicate that the sequence has an average total organic carbon content of 1.34 weight percent. Conodont alteration indices and the production index for these rocks indicate the maturation, with respect to hydrocarbon generation, ranges from diagenetic in the shallow western part of the basin to catagenetic in the deep eastern part of the basin. This data is supported by the temperatures of maximum pyrolytic hydrocarbon generation. The 400 to 600 ft. sequence of shale in eastern New York and central and eastern Pennsylvania is in the middle to upper catagenetic stage and is now in the gas window, but probably also produced oil; the 200 to 300 ft. sequence of shale in the western part of New York, Pennsylvania, and West Virginia and the eastern part of Ohio is in the lower catagenetic stage and is now in the oil window.

The genetic potential of the shales in New York, Pennsylvania, and West Virginia where they are deepest, indicates that the potential for further generation of oil from these shales is poor and the potential for further gas generation is fair. However, in Ohio, the potential for further generation oil in the shale is fair to good.

PETROLEUM SOURCE ROCK POTENTIAL OF THE UPPER ORDOVICIAN BLACK SHALE SEQUENCE, NORTHERN APPALACHIAN BASIN

BY

Laure G. Wallace and John B. Roen

INTRODUCTION

Middle and Upper Ordovician dark-gray to black shales crop out in an east-trending belt across the northern part of New York and in a northeast-southwest trending fold and thrust belt from eastern New York to Alabama. (fig. 1). Elsewhere in the Appalachian basin the dark-gray to black shales of Middle and Late Ordovician age are in the subsurface of Ohio, New York, Pennsylvania, West Virginia, western Virginia and in the subsurface of the overthrust belts in eastern Tennessee and southern Virginia.

Relative to the younger Devonian-Mississippian black shale sequence, which is shallower and somewhat better exposed within the basin, the more deeply buried and more thermally mature Upper and Middle Ordovician shales have not been extensively evaluated for their hydrocarbon potential. The purpose of this report is to determine the distribution, organic richness and hydrocarbon potential of the Upper Ordovician dark-gray to black shales in the northern part of the Appalachian basin. The investigation included establishing a stratigraphic framework of the Upper Ordovician sequence and geochemical analyses of surface and subsurface shale samples from the sequence to evaluate the hydrocarbon potential. The study area included part of the states of Ohio, New York, Pennsylvania, and West Virginia.

ACKNOWLEDGEMENTS

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We greatly appreciate the geochemical analyses performed by George Claypool of the U.S. Geological Survey. His expert assistance as well as that of Jerry Clayton, also of the U.S. Geological Survey, have been invaluable in the preparation of this paper.

We acknowledge the assistance of Lawrence V. Rickard and Henry Bailey of the New York Geological Survey, John Harper of the Pennsylvania Topographic and Geological Survey, Lawrence H. Wickstrom and Garry Yates of the Ohio Geological Survey, and Douglas G. Patchen and Katherine Lee Avary of the West Virginia Geological Survey.

METHOD OF STUDY

Stratigraphic cross sections, isopach maps, a structure contour map, and a drilling depth map were prepared from lithologic logs supplied by state geological surveys and the Geological Sample Log Company of Pittsburgh, Pa. A total of 147 lithologic logs were used for control points in this study (fig. 2 and appendix 1).

Shale color is an important factor in the study because, as a rule, the

Figure 1. Generalized outcrop of Middle and Upper Ordovician dark-gray to black shale in the Appalachian basin

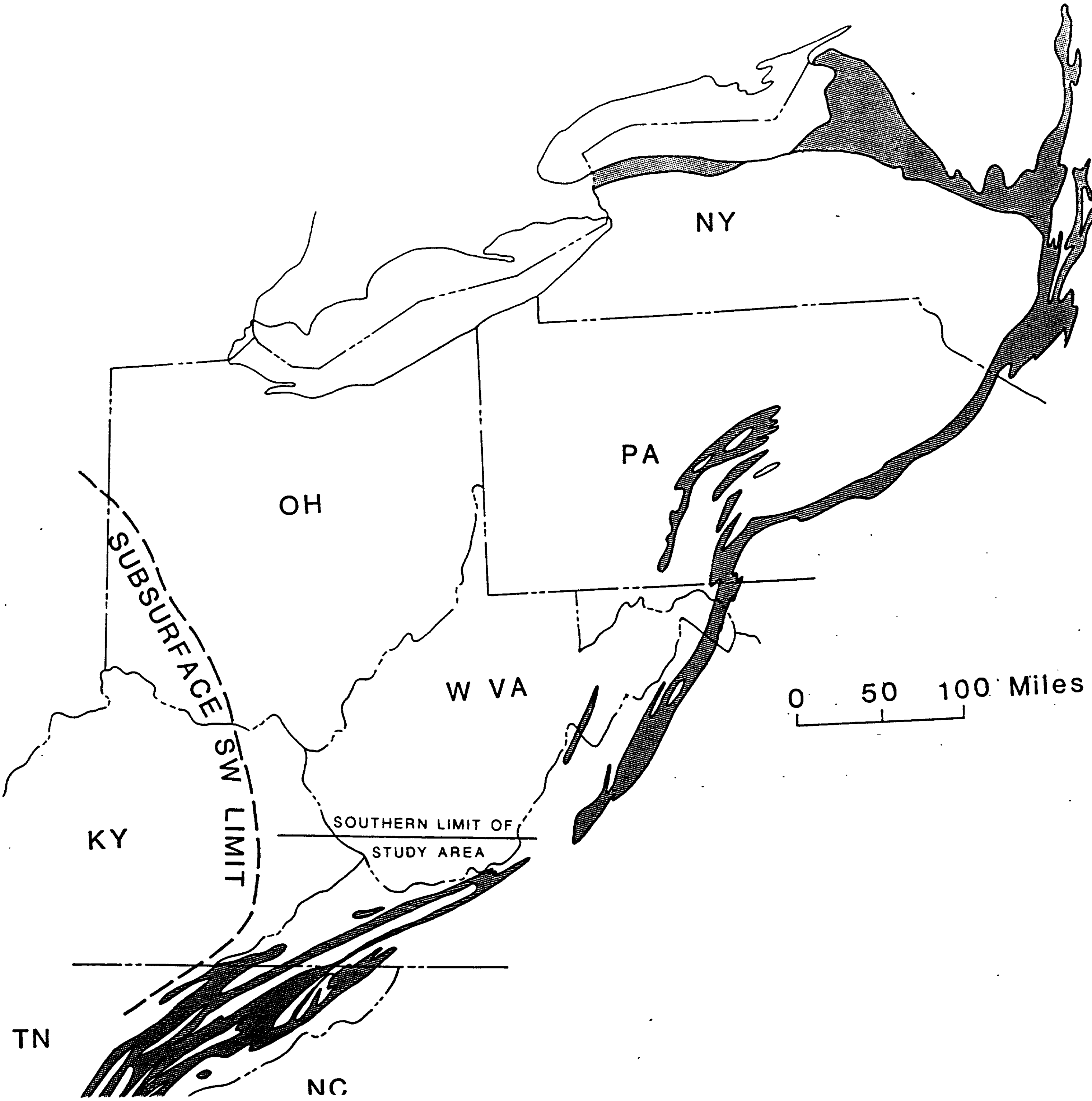
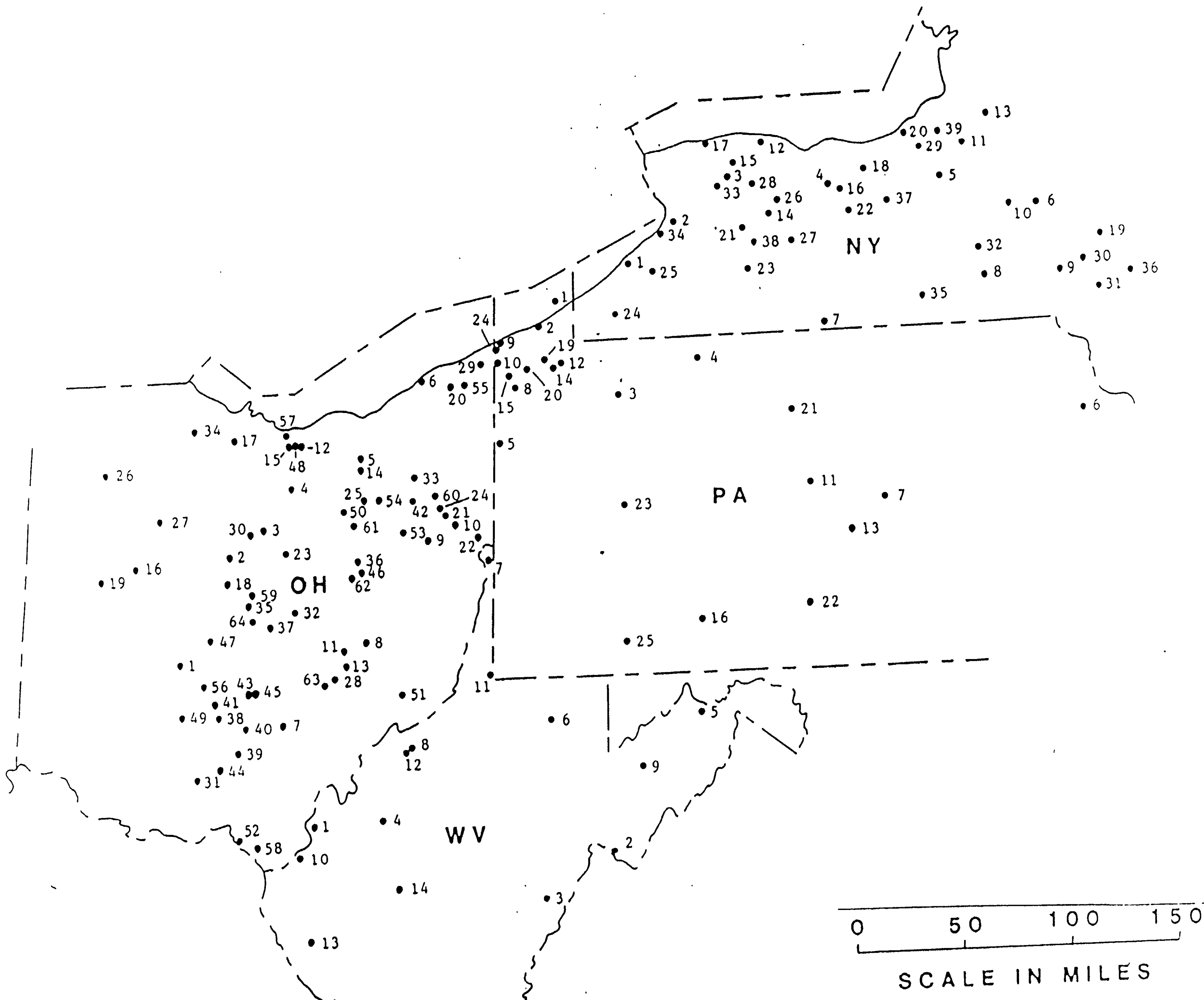

NY
PA
OH
W VA
KY
TN
NC
SUBSURFACE SW LIMIT
SOUTHERN LIMIT OF STUDY AREA
0 50 100 Miles

Figure 2. Location of wells used in the construction of stratigraphic cross sections, isopach map, structure map, and drilling depth map for this study. Number shown for wells in each state refers to well identification list by state in Appendix 1.


NY
PA
OH
WV
0 50 100 150
SCALE IN MILES

darker the shale, the greater the total organic carbon (TOC) values. By using the color chart of Goddard and others (1948), we defined the shale to be studied in this report by the following colors: black (N1), grayish-black (N2), dark-gray (N3), medium-dark-gray (N4), brownish-black (5YR2/1), dusky-brown (5YR 2/2), greenish-black (5GY2/1), and olive-black (5Y2/1).

Seven stratigraphic cross sections (pls. 1-7 and fig. 3) were constructed to show the stratigraphic position and distribution of the Utica sequence across the basin. The Upper Ordovician black shale and related rock sequence was subdivided into three units based on lithology and shale color as defined above. The lithologic units are listed below in ascending order:

1. Limestones and shale units which contain less than of 85% medium-dark-gray to black shale. This unit is in part the Trenton Group or Limestone.
2. Shale units which contain 85% or more medium-dark-gray to black shale. This is the Utica sequence of our paper.
3. Siltstone, sandstone, and shale which contain less than of 85% medium-dark-gray to black shale.

We have informally applied the name Utica sequence to the rock that consists of 85% or more medium-dark-gray to black shale. Although not formally recognized throughout the basin, the name Utica is informally accepted, in part, in all of the states in the study area. Datum for the stratigraphic cross sections is the uppermost limestone of the Ordovician Trenton Group. Locally, such as in eastern New York and elsewhere in West Virginia, the Trenton Limestone grades vertically and laterally with the dark shale sequence and extends 150 feet higher in the section. (fig. 4). In these areas the datum was shifted to where the medium-dark-gray to black shale makes up less than 85% of the interclated sequence (pl. 3 nos. 3, 4, 7, and 35).

175 shale samples from 124 localities (appendix 2) throughout the entire study area were analyzed using a standard pyrolysis method (Rock-Eval). Each sample was also analized for TOC. Samples collected from Ohio and West Virginia were from the subsurface. Samples collected from New York and Pennsylvania were from the surface and subsurface.

STRUCTURAL SETTING

The Appalachian region is divided into four broad regions approximately parallel to the NE - SW axis of the basin. They are the Blue Ridge, Peidmont, Valley and Ridge and Appalachian Plateaus provinces.

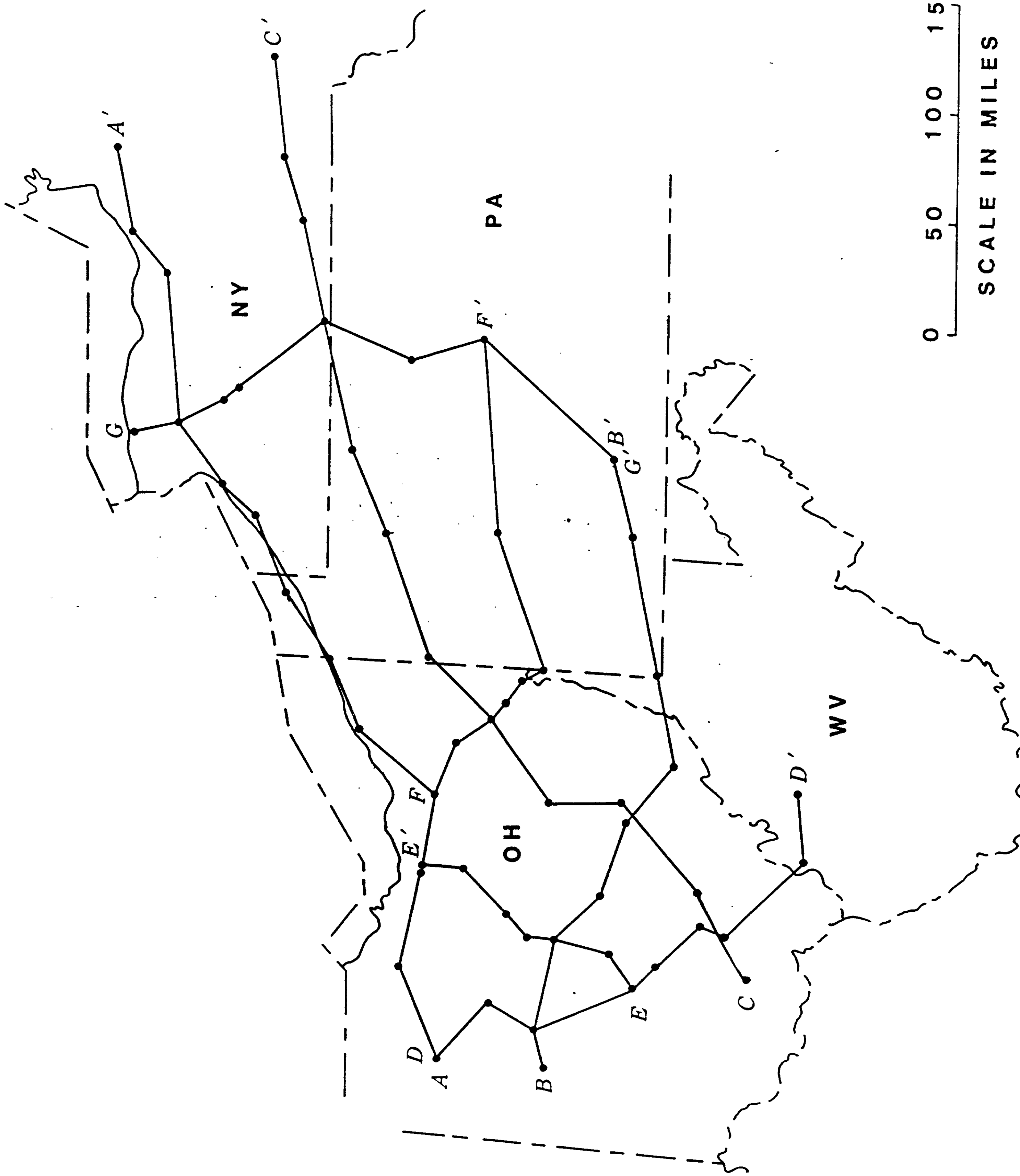
The Blue Ridge and Piedmont provinces are composed primarily of metamorphic and igneous rocks. The Valley and Ridge and Appalachian Plateaus provinces are composed almost entirely of Paleozoic sediments.

The Appalachian basin lies in the latter of these two provinces. In the eastern part of the basin, the Valley and Ridge is extensively folded and faulted with crystalline rocks of the Blue Ridge thrust over Paleozoic rocks. The western part of the basin, the Appalachian Plateaus, is an asymetrical foreland fold province dipping gently southward from New York and southeastward from Ohio. It is characterized by low amplitude folding and few faults.

The basin is approximately 1,000 mi. long and ranges from 75 to 350 mi.

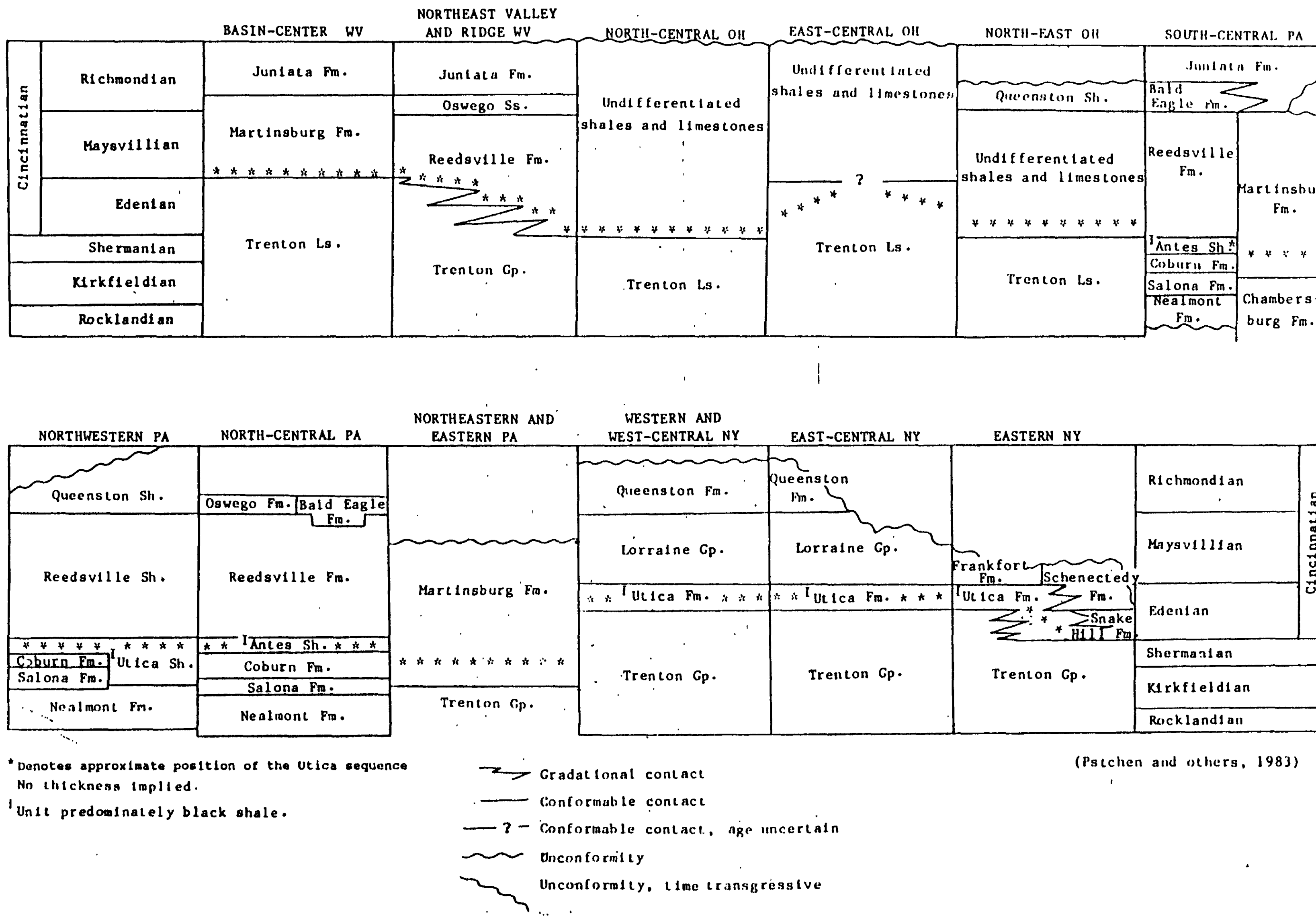
Figure 3. Location of cross sections showing stratigraphic framework of the Utica sequence.

Fig 3



13 a.

Figure 4. Regional correlation chart by Patchen and others (1983) showing Upper Ordovician shale units including the Utica sequence of this paper in the northern and central part of the Appalachian basin. The asterisks denote the approximate portion of the black shales of the Utica sequence as used in this paper.


BASIN-CENTER WV
NORTHEAST VALLEY AND RIDGE WV
NORTH-CENTRAL OH
EAST-CENTRAL OH
NORTH-EAST OH
SOUTH-CENTRAL PA
Cincinnatian
Richmondian
Maysvillian
Edenian
Shermanian
Kirkfieldian
Rocklandian
Juniata Fm.
Martinsburg Fm.
Trenton Ls.
Oswego Ss.
Reedsville Fm.
Trenton Gp.
Undifferentiated shales and limestones
?
Queenston Sh.
Bald Eagle Fm.
Antes Sh.
Coburn Fm.
Salona Fm.
Nealmont Fm.
Chambersburg Fm.
NORTHWESTERN PA
NORTH-CENTRAL PA
NORTHEASTERN AND EASTERN PA
WESTERN AND WEST-CENTRAL NY
EAST-CENTRAL NY
EASTERN NY
Reedsville Sh.
Utica Sh.
Oswego Fm.
Queenston Fm.
Lorraine Gp.
Utica Fm.
Frankfort Fm.
Schenectedy Fm.
Snake Hill Fm.
* Denotes approximate position of the Utica sequence
No thickness implied.
I Unit predominately black shale.
Gradational contact
Conformable contact
? Conformable contact, age uncertain
Unconformity
Unconformity, time transgressive
(Patchen and others, 1983)

19 a.

in width. The volume of Paleozoic rocks present today is approximately 510,000 to 525,000 cubic miles (Colton, 1961; de Witt, personal comm., 1988).

The structure map drawn on the base of the organic-rich Utica sequence (fig. 5) shows a dip in the basin from 2,000 ft. below sea level in central Ohio to 12,000 ft below sea level in central and northeastern Pennsylvania.

The structure contour map on the base of the Upper Ordovician dark-gray to black shale sequence was combined with generalized surface elevation (Diment and Urban, 1981) to produce a drilling depth map to the base of the shale.

The drilling depth to reach the base of the Utica sequence ranges from 2,000 ft. in western Ohio and northern New York to more than 14,000 ft. in central Pennsylvania and northeastern West Virginia (fig. 6).

STRATIGRAPHY

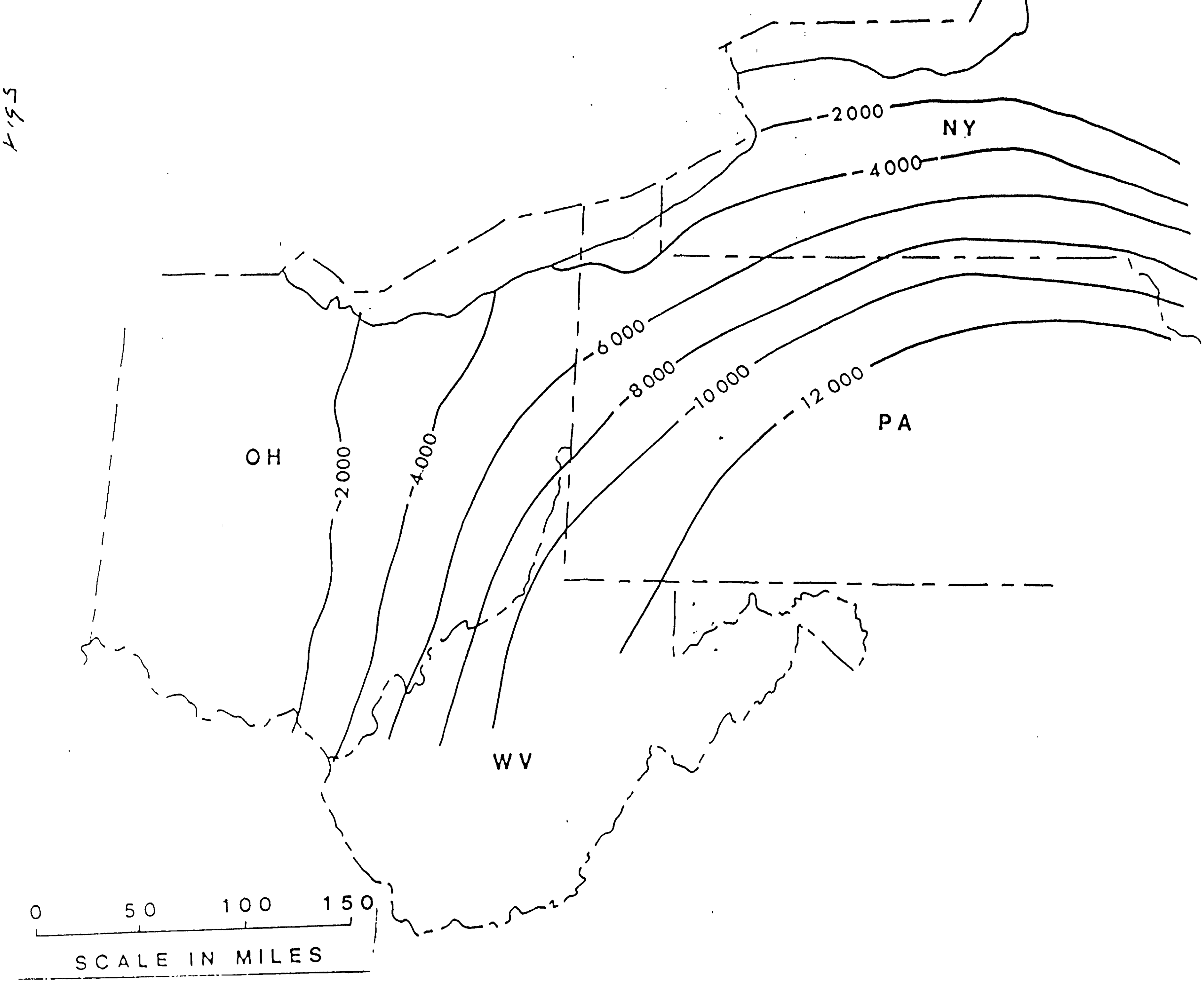
In the northern part of the central Appalachian basin, the extensive Upper Ordovician black marine shale, rich in organic matter is designated here as the Utica sequence. This sequence in various parts of the basin consists of the Upper Ordovician Utica Shale (Emmons, 1842; Kay, 1937), the Antes Shale (Kay, 1944a, 1944b) the lower part of the Reedsville Shale (Ulrich, 1911; Kay 1944a, 1944b), the lower part of the Martinsburg Shale (Keith, 1894), the Point Pleasant Formation (Newberry, 1873: Weiss and Norman, 1960), and the basal part of the undivided Cincinnatian Series (Meek and Worthen, 1865). Because of interfingering with older rock sequences, the sequence may locally include some black shale from older stratigraphic units. The blanket-like Utica sequence is about one foot thick in western Ohio and thickens eastward to more than 700 feet in parts of Pennsylvania and adjacent West Virginia (fig. 7). The black marine shales of the Utica lie stratigraphically above the northern and central part of the extensive Middle Ordovician carbonate sequence from Tennessee to New York. The Trenton Limestone or Trenton Group is the most commonly identified carbonate unit beneath the Utica sequence in this part of the basin. (fig 4).

Correlation of stratigraphic units within the Utica sequence, presently accepted by state geological surveys for specific areas in the states of the central Appalachians, is from the American Association of Petroleum Geologists' COSUNA - Northern Applachian Region Chart (Patchen and others, 1983). The chart emphasizes the age relationship between the various stratigraphic units of the organic-rich Utica sequence and contiguous strata (fig. 4).

The Ordovician Utica Shale as described by G.M. Kay (1937), for exposures at Utica, Oneida Co., New York is dark-gray to black shale rich in organic matter which has been correlated westward across the Appalachian basin to western Ohio and southward to central West Virginia.

In New York, the Utica Shale overlies limestones of the Trenton Group and underlies the Lorraine Shale (pl. 7; pl. 1). From a black, slightly silty shale about 200 ft thick in the western part of the state, the Utica Shale thickens eastward with an increasing amount of clastic materials to grade laterally into the silty gray shales of the Snake Hill Formation (Ulrich, 1911: Kay, 1937) in the Hudson River Valley of eastern New York. Although most of the Upper Ordovician black shale lies in the Utica Shale

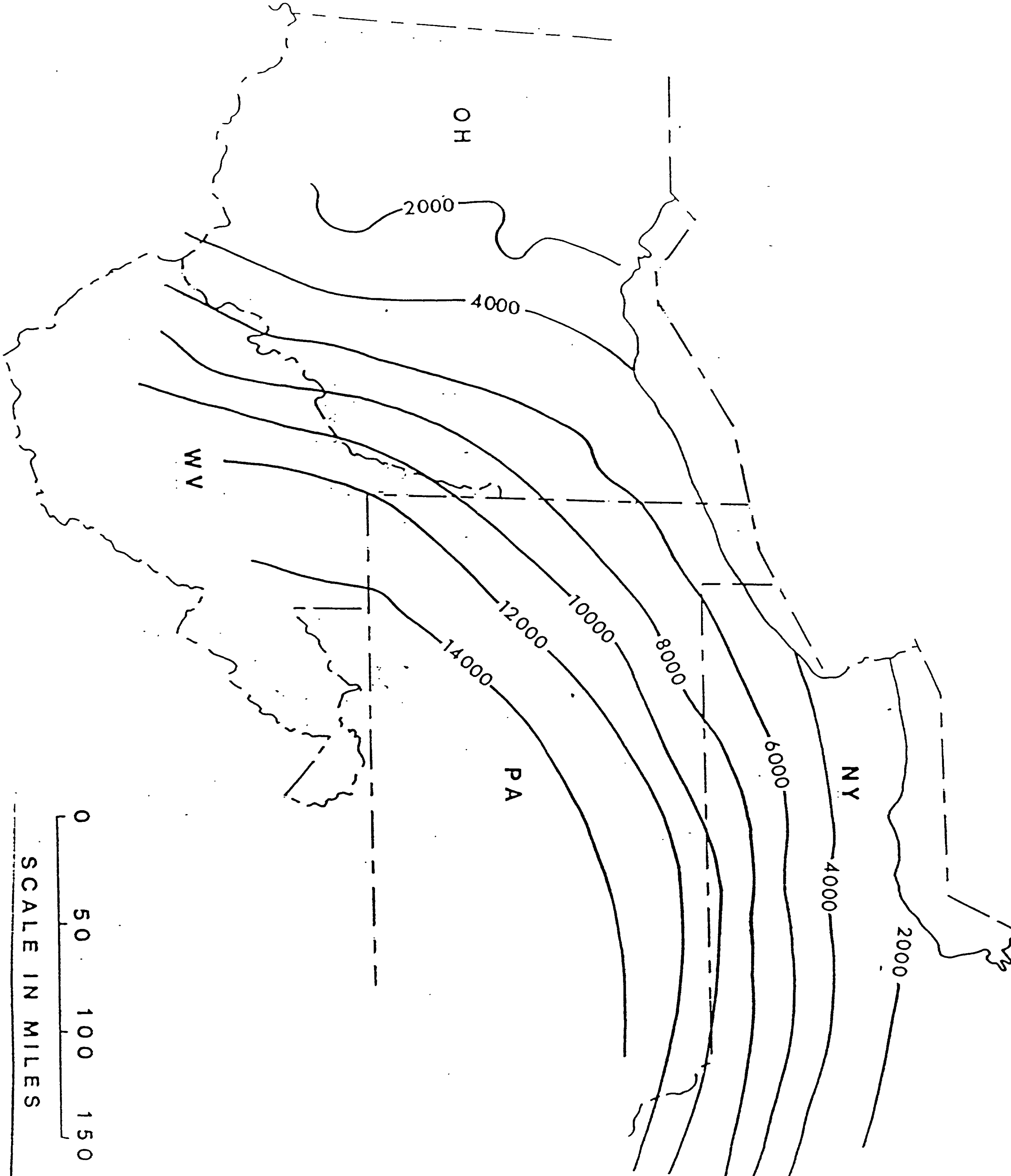
Figure 5. Structure contour map drawn on the base of the Upper Ordovician Utica sequence. Elevation is in feet, datum is mean sea level. Contours are in feet, contour interval 2,000 feet.



NY
2000
4000
6000
8000
10000
12000
PA
OH
2000
4000
WV
0
50
100
150
SCALE IN MILES

Figure 6. Generalized map showing drilling depth to base of the Upper Ordovician Utica sequence. Contour interval is 2,000 feet.

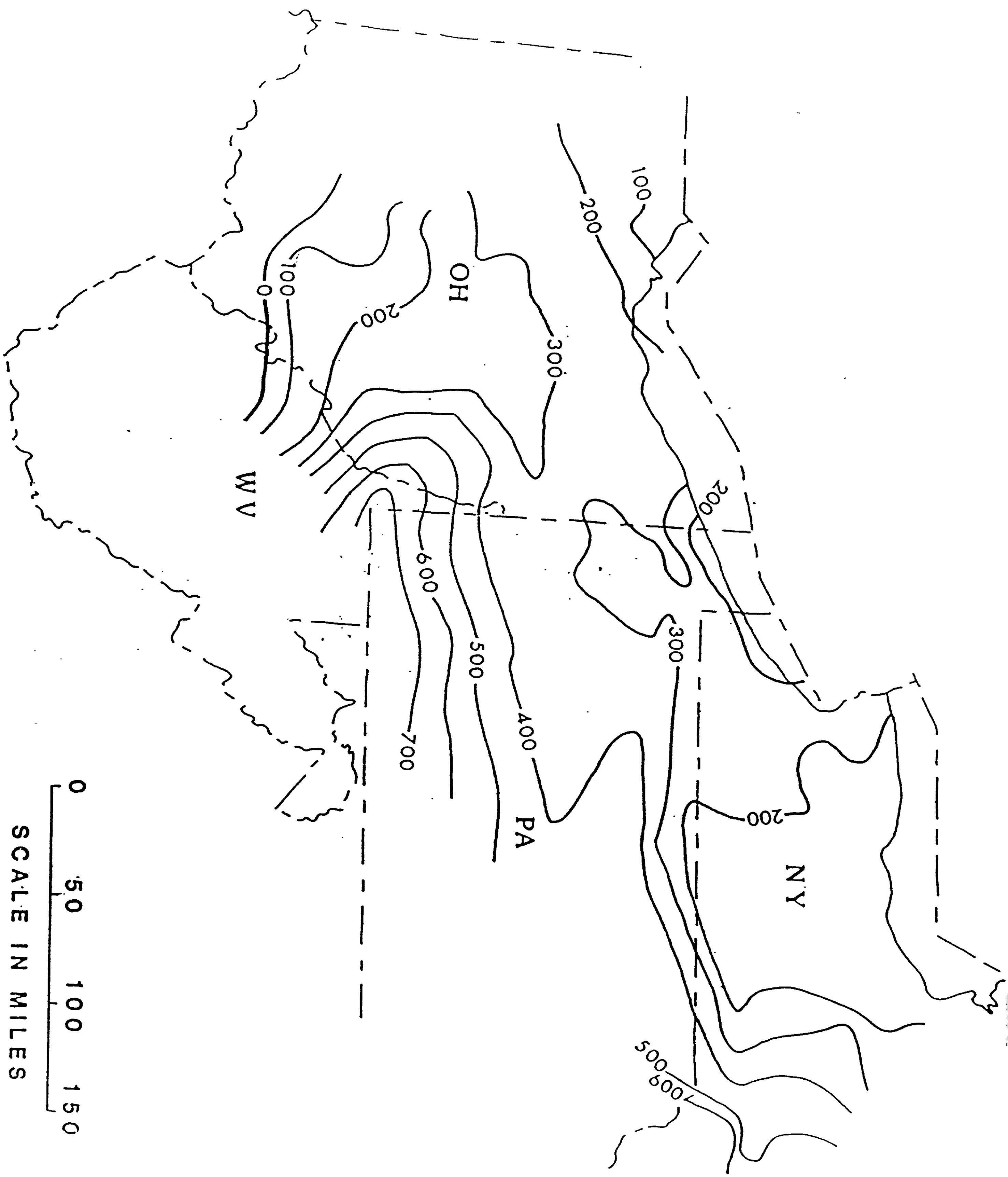
f196


OH
WV
PA
NY
2000
4000
6000
8000
10000
12000
14000
0
50
100
150
SCALE IN MILES

17 a.

Figure 7. Isopach map of the Upper Ordovician Utica sequence. Contour interval is 100 feet.

Fig 7



OH
WV
PA
NY
0
100
200
300
400
500
600
700
SCALE IN MILES
0 50 100 150

18 a.

above limestones of the Trenton Group or its equivalents, in parts of south-central New York, it locally intertongues with limestones in the upper part of the Trenton Group (Vanuxem, 1838) (pl. 3).

In Pennsylvania, the Utica Shale is formally recognized in the subsurface of the northeastern and north-central part of the state. The Utica Shale becomes more calcareous toward central Pennsylvania, where it grades into the calcareous black shale of the Antes Shale or into the limestone and intercalated black shales of the Coburn and Salona Formations (Kay, 1944b; Field, 1919) and may rest upon the Nealmont Limestone in the lower part of the Trenton Group (Weed, 1982). West of the Allegheny front in western and southwestern Pennsylvania, the Utica Shale or its equivalents are overlain by the lighter gray shales of the Reedsville Shale (pl. 1).

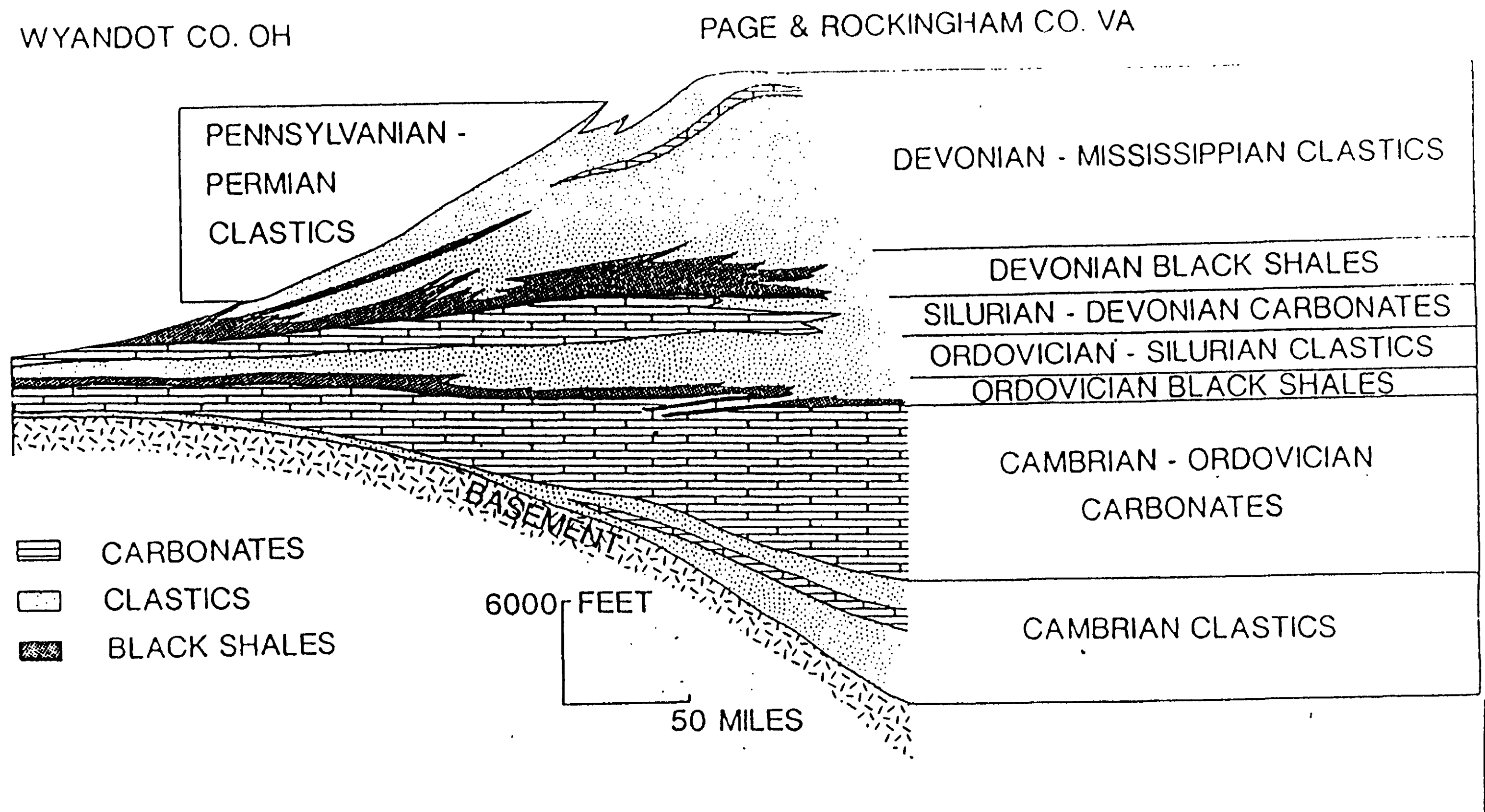
Eastward across the Valley and Ridge Province of Pennsylvania, the Antes Shale and Reedsville Shale grade into the siltier shales of the Martinsburg Formation. There, the Antes is locally recognized as the basal unit of the Martinsburg.

The West Virginia Geological Survey does not feel that there is adequate subsurface control in West Virginia to permit subdivision of the Martinsburg Formation or the equivalent Reedsville Shale. However, the name Utica Shale is informally recognized as the basal part of the Reedsville Shale in the western part of the state and the basal part of the Martinsburg in the eastern part of the state. It overlies limestones of the Trenton Group.

The Utica Shale is a recognized unit by the Ohio Geological Survey in the northwestern and northeastern parts of Ohio. Throughout the rest of Ohio, the Utica is incorporated in the basal part of the undifferentiated Cincinnatian Series (pl. 1). The black shale facies of the Utica sequence grades southwestward and feathers out in the lighter gray shales of the lower part of the undifferentiated Cincinnatian Series of south-central Ohio (pl. 3). In much of Ohio the Utica Shale and its equivalents overlie the Trenton Limestone or its local equivalent, the Point Pleasant Formation. The Point Pleasant Formation grades from limestone in the basal part to dark shale rich in organic matter in the upper part. Consequently, rocks in the upper part of the Point Pleasant Formation have been included in our assessment of Ordovician shales rich in organic matter. Rocks of the Point Pleasant Formation in Ohio were originally referred to as the Cynthiana Member of the Lexington Limestone of Kentucky (Campbell, 1898). However, Wickstrom and others (in press) recommend abandoning the name Cynthiana Member in Ohio. We have not subdivided the Point Pleasant on the cross sections; it is included locally as part of the Utica sequence of this report or Cincinnatian undivided.

In summary, the northern part of the Appalachian basin's extensive Upper Ordovician Utica sequence is composed of the Utica Shale and correlatives units, the Antes Shale, the basal Reedsville Shale, the lower part of the Martinsburg Formation, the Point Pleasant Formation and the basal part of the undifferentiated Cincinnatian Series. In the study area, this sequence of black shale lies stratigraphically above a Middle Ordovician carbonate unit identified as the Trenton Limestone and correlative units. The stratigraphic position of the Ordovician black shale sequence relative to the enclosing rocks is shown in a generalized section that illustrates the cyclic nature of the basin fill (Fig. 8).

Figure 8. Diagramatic section from Wyandot County in north western Ohio to Page and Rockingham Counties in western central Virginia illustrating the cyclic facies in the Appalachian basin.


WYANDOT CO. OH
PAGE & ROCKINGHAM CO. VA
PENNSYLVANIAN - PERMIAN CLASTICS
DEVONIAN - MISSISSIPPIAN CLASTICS
DEVONIAN BLACK SHALES
SILURIAN - DEVONIAN CARBONATES
ORDOVICIAN - SILURIAN CLASTICS
ORDOVICIAN BLACK SHALES
CAMBRIAN - ORDOVICIAN CARBONATES
CAMBRIAN CLASTICS
BASEMENT
CARBONATES
CLASTICS
BLACK SHALES
6000 FEET
50 MILES

SOURCE ROCK GEOCHEMISTRY

In order to assess the petroleum potential of the Ordovician Utica sequence, we needed to evaluate the petroleum-generative potential and the thermal maturity of the Upper Ordovician dark-gray to black shale sequence.

Samples were collected from 104 subsurface and surface localities throughout the study area (appendix 2). The samples collected for source rock geochemistry are distributed as follows: 40 samples in New York (Fig. 9), 37 samples in Ohio (Fig. 10), 19 samples in Pennsylvania (Fig. 11) and 8 samples in West Virginia (Fig. 12). The smaller number of samples collected in Pennsylvania and West Virginia indicate the sparsity of drilling to the appropriate depth in these areas. Where possible samples were collected from the basal and upper part of the Utica sequence.

Rock-Eval analysis was completed on all of the samples and resulted in a regional analysis of the thermal maturation and the genetic potential of the Ordovician Utica sequence. Figure 13 illustrates the pyrolytic evolution resulting from the Rock-Eval analysis. S_1 is the mg of existing hydrocarbons (HC) present per gm of rock sample, S_2 is the mg of HC generated by kerogen pyrolgsis per gm of rock sample, and S_3 is the oxygen-containing compounds ($C\ O_2$) generated by the Rock-Eval kerogen pyrolysis. T max is the temperature ($^{\circ}C$) of maximum HC generation. These parameters were then used to qualify the source rock potential of the Utica sequence, and to quantitatively appraise its generative capacity. The analytical Rock-Eval data and the evaluating indices are listed in appendix 3.

THERMAL MATURATION

Four parameters derived from the Rock-Eval analysis can give a general indication of whether a source rock is matured to the point of being hydrocarbon productive.

The first of these parameters is the hydrogen index (HI). The HI is the quantity of pyrolyzable organic compounds or hydrocarbons as expressed by the formula $HI = (S_2/TOC) \times 100$, where S_2 is the hydrocarbon released in mg/gm of rock during pyrolysis and TOC is the weight percent of total organic carbon content of the rock.

The second parameter is expressed as the ratio S_2/S_3 where S_3 represents in mg/g of rock the $C\ O_2$ released by pyrolysis.

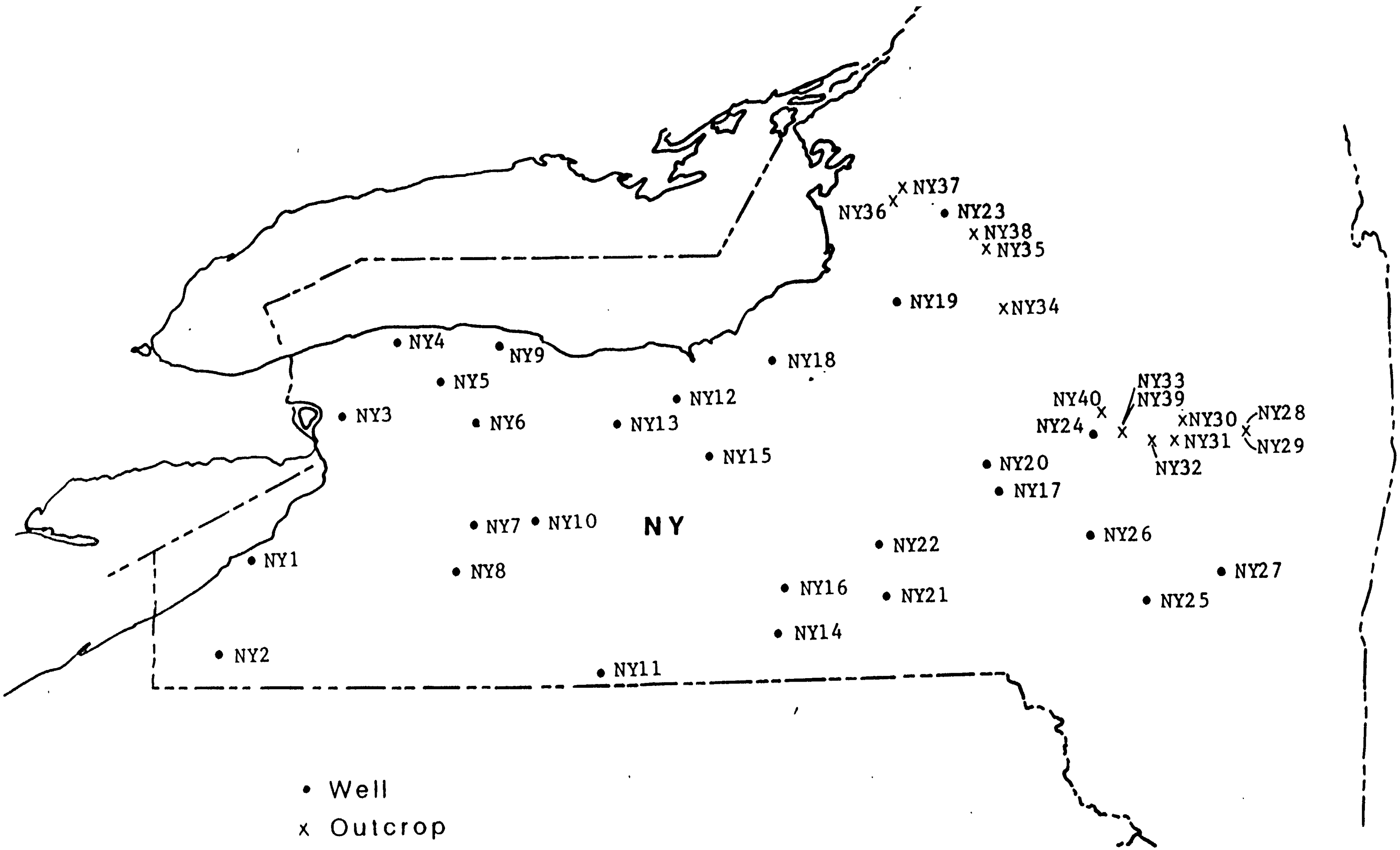
It should be noted that the S_3 value can be appreciably modified by the introduction of oxygen from a source other than organic matter. One of the main sources for additional oxygen is chemical weathering.

Peters (1986) indicates that the HI and the ratio S_2/S_3 are parameters that can give a general indication of whether a source rock has generated oil, oil and gas, or gas. The parameters of Peters (1986) are presented in table 1 of this report.

Using these guidelines, S_2/S_3 ratio and the HI isopleths indicate that the Utica sequence in western and central Ohio shows a tendency toward generating oils whereas in the eastern, more deeply buried section of the basin in Pennsylvania, northern West Virginia, and New York the tendency is toward generating gas (fig. 14 and 15).

The third parameter used as a general indicator of thermal maturity in this study was Tmax, the temperature of maximum hydrocarbon release, or the

Figure 9. Map showing location of samples collected for geochemical analysis in New York. Map location designations are listed by state in the sample locality register in Appendix 2.


NY
NY1
NY2
NY3
NY4
NY5
NY6
NY7
NY8
NY9
NY10
NY11
NY12
NY13
NY14
NY15
NY16
NY17
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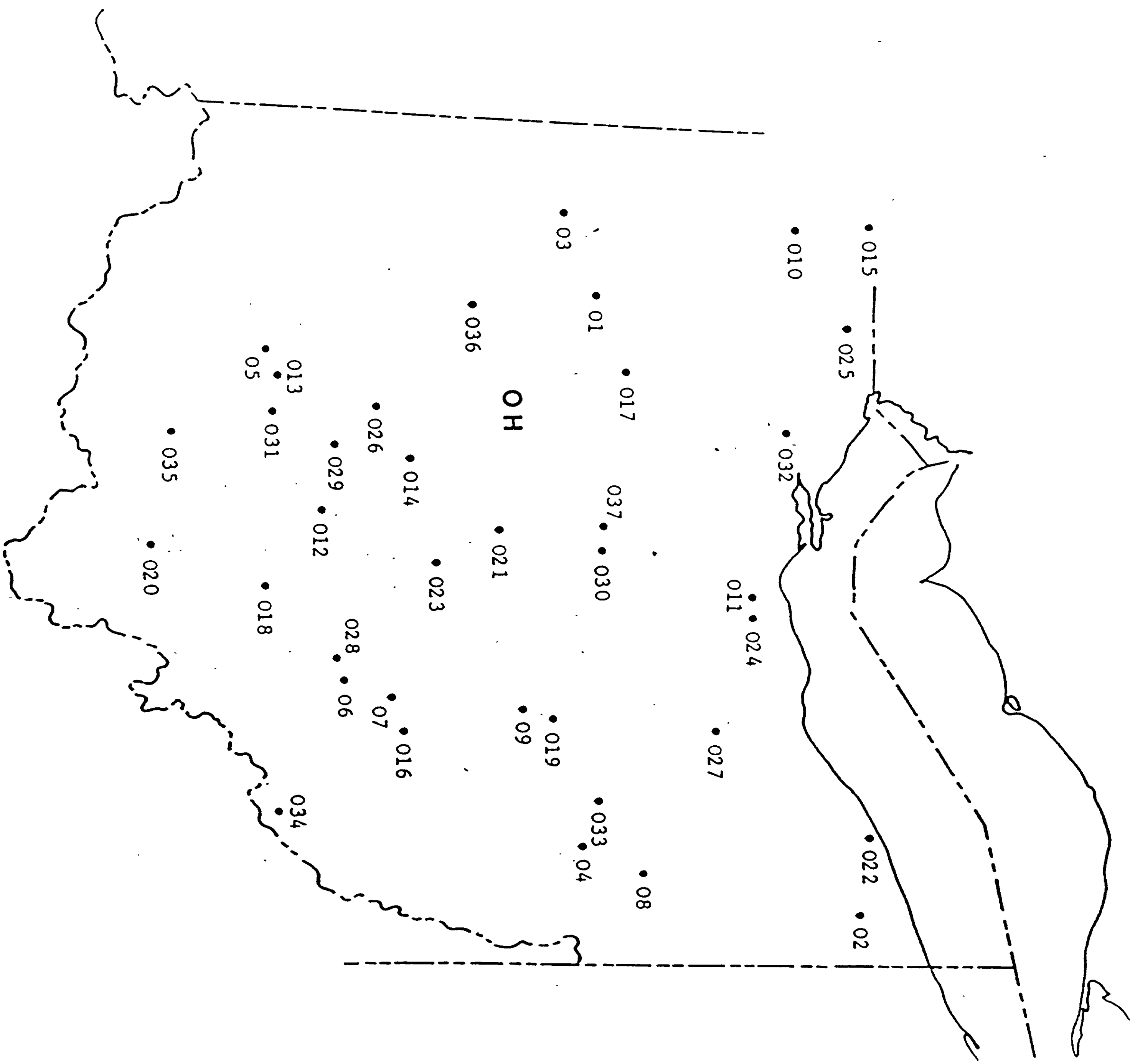
NY19
NY20
NY21
NY22
NY23
NY24
NY25
NY26
NY27
NY28
NY29
NY30
NY31
NY32
NY33
NY34
NY35
NY36
NY37
NY38
NY39
NY40
• Well
x Outcrop

22 a.

Figure 10. Map showing location of samples collected for geochemical analysis in Ohio. Map location designations are listed by state in the sample locality register in Appendix 2.

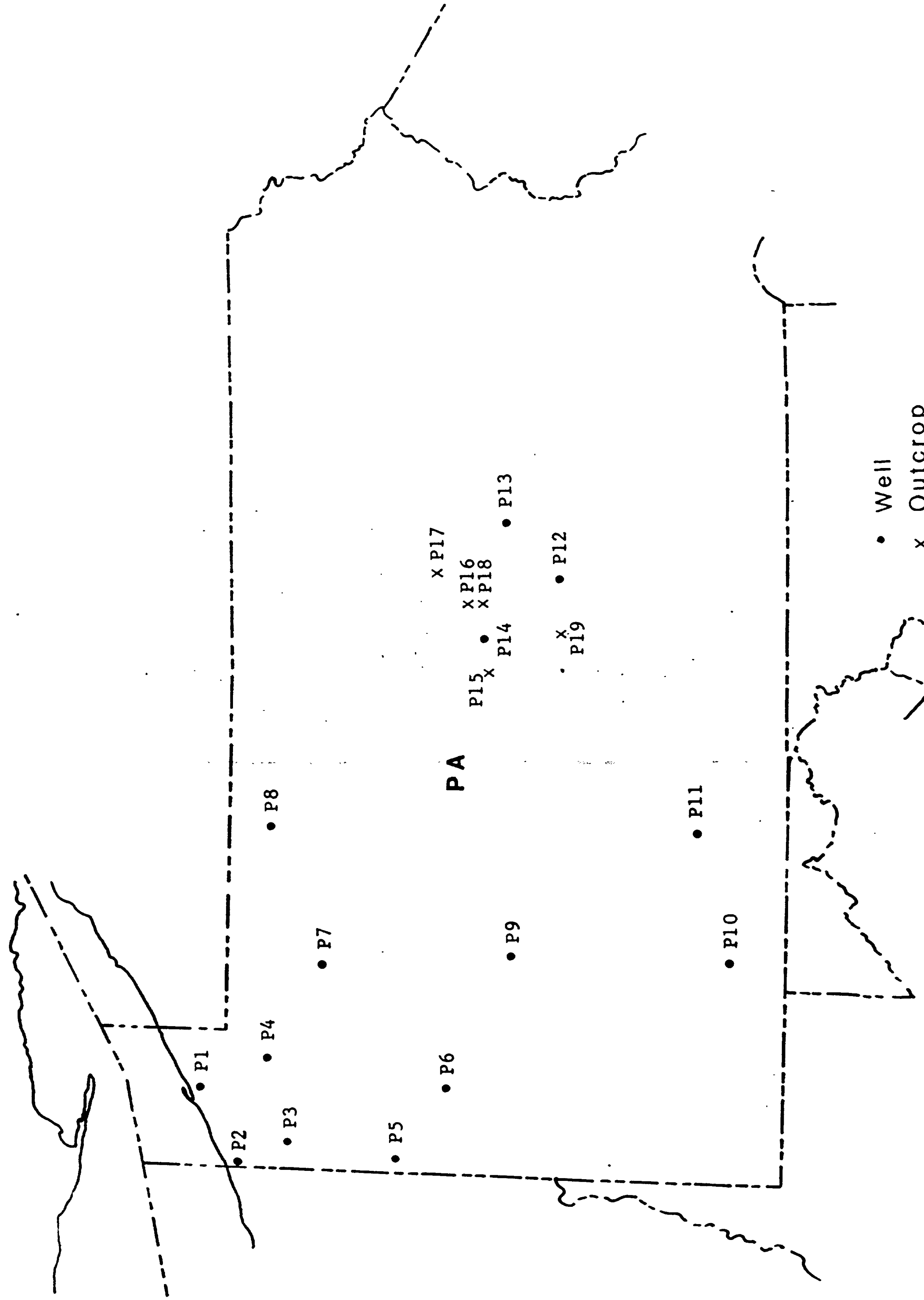
Fig 10


OH
03
010
015
01
025
036
017
05
013
031
026
035
029
014
032
037
012
021
030
020
023
011
024
018
028
06
07
016
09
019
027
034
033
04
08
022
02

23 a.

Figure 11. Map showing location of samples collected for geochemical analysis in Pennsylvania. Map location designations are listed by state in the sample locality register in Appendix 2.

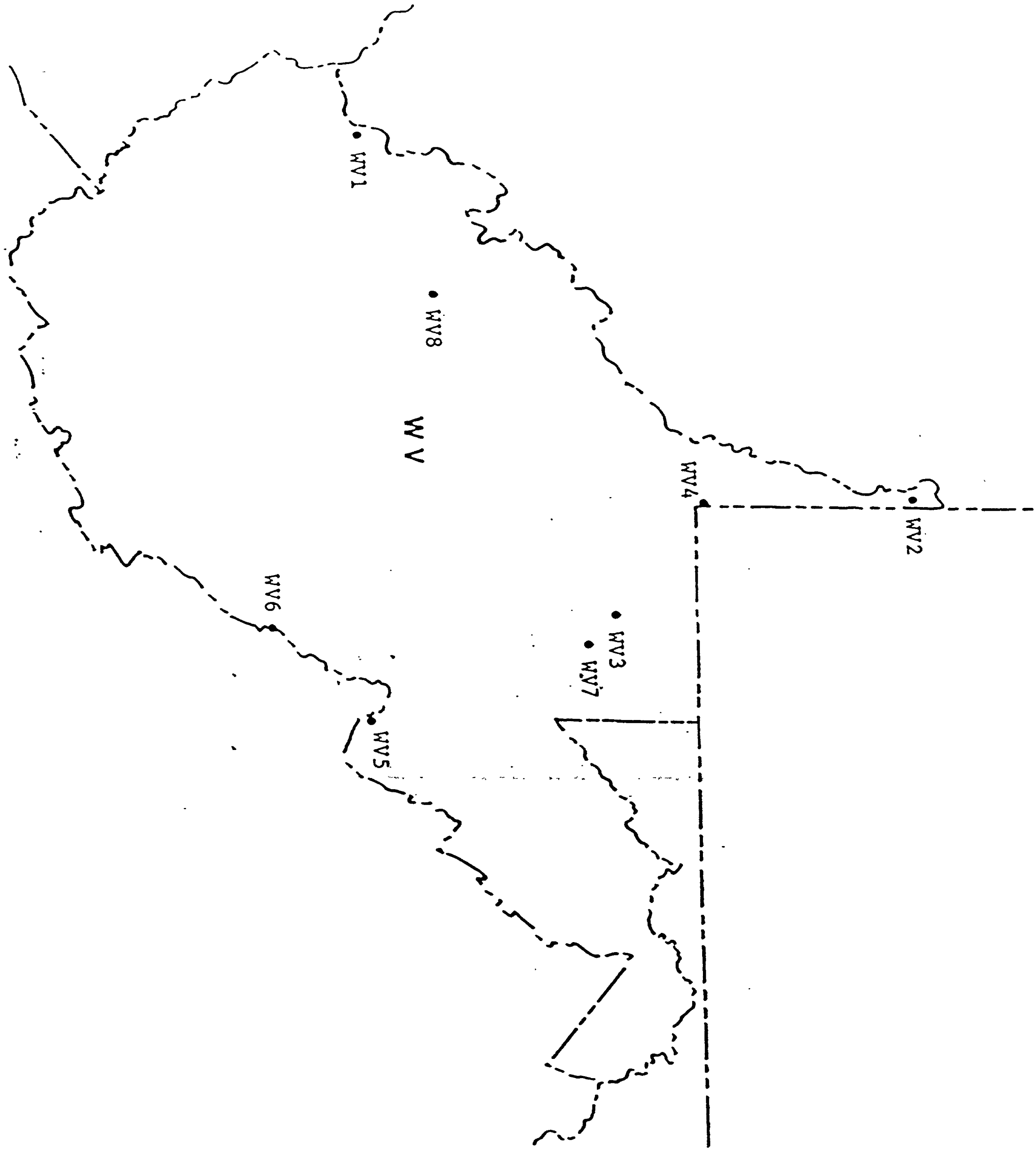
Fig 11



PA
P1
P2
P3
P4
P5
P6
P7
P8
P9
P10
P11
P12
P13
P14
P15
P16
P17
P18
P19
• Well
x Outcrop

Figure 12. Map showing location of samples collected for geochemical analysis in West Virginia. Map location designations are listed by state in the sample locality register in Appendix 2.

Fig 12



25 a.

Figure 13. Schematic pyrogram showing evolution of organic compounds from rock samples during heating. Modified after Peters (1986).

+1913

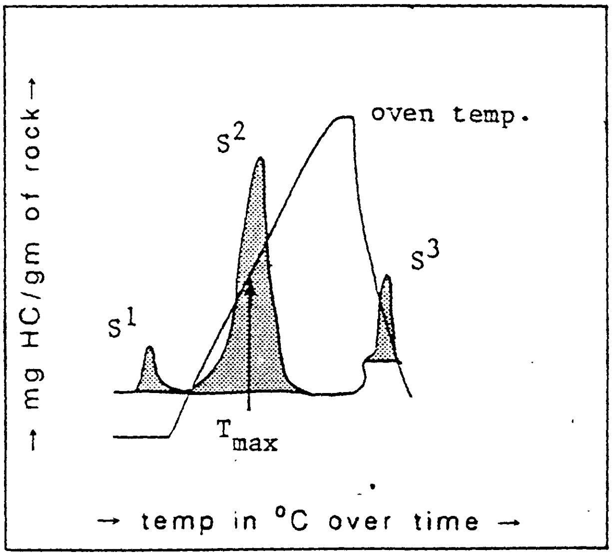


Table 1. Geochemical Parameters Describing Type of Hydrocarbon Generated (Peters, 1986)

Type	HI (mgHC/g C_{org})*	S_2/S_3
Gas	0-150	0-3
Gas and Oil	150-300	3-5
Oil	300+	5+

*Assumes a level of thermal maturation equivalent to R_o = 0.6%

Figure 14. Isopleth map of the hydrogen index (mg HC/g organic C) on the basal part of the Upper Ordovician Utica sequence. Contour interval is 50 mg HC/g organic C.

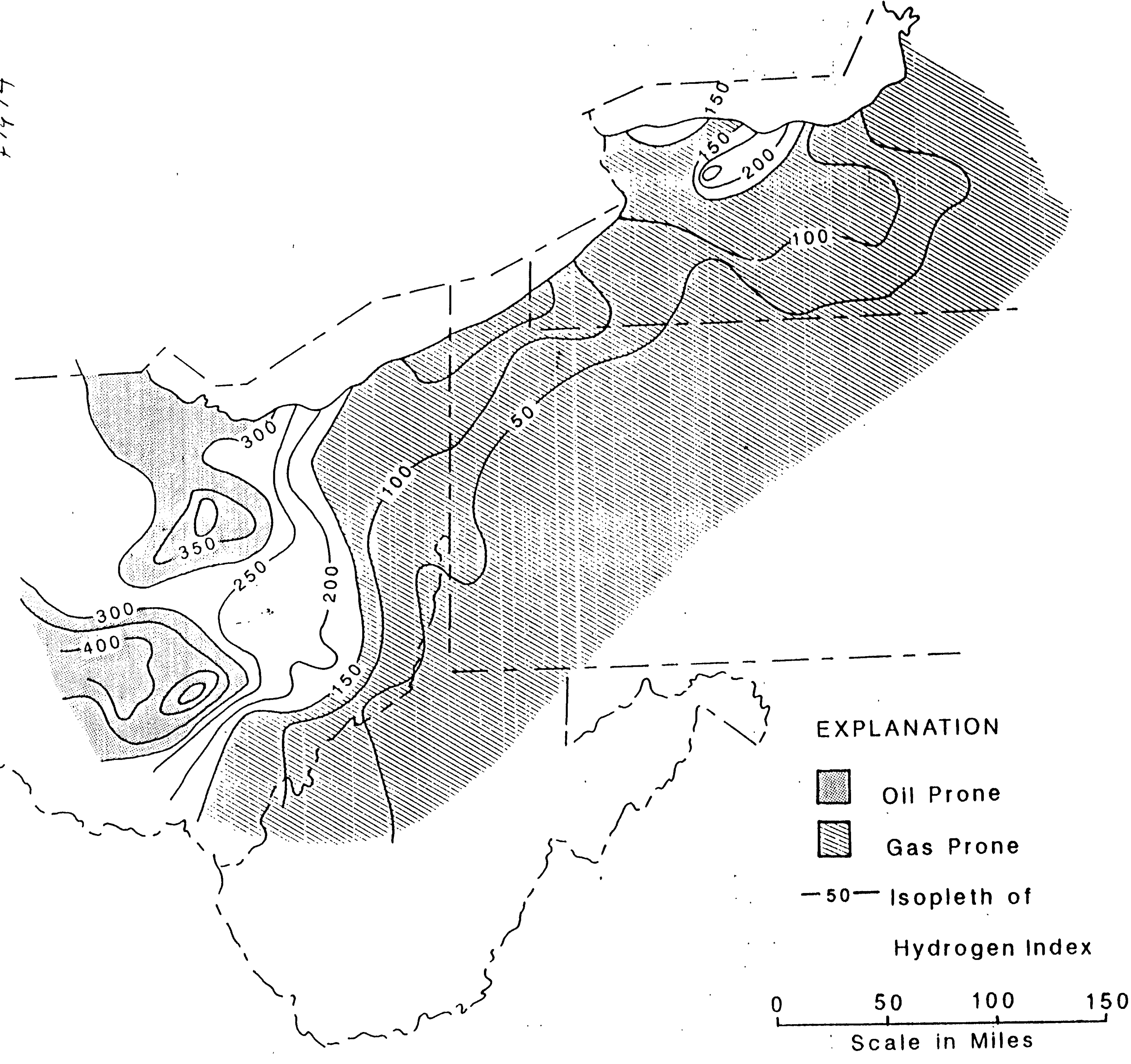

400
300
350
300
250
200
150
100
50
150
150
200
100
150
EXPLANATION
Oil Prone
Gas Prone
—50— Isopleth of Hydrogen Index
0 50 100 150
Scale in Miles

Figure 15. Isopleth map of the ratio S_2/S_3 on the basal part of the Upper Ordovician Utica sequence.

Fig 13

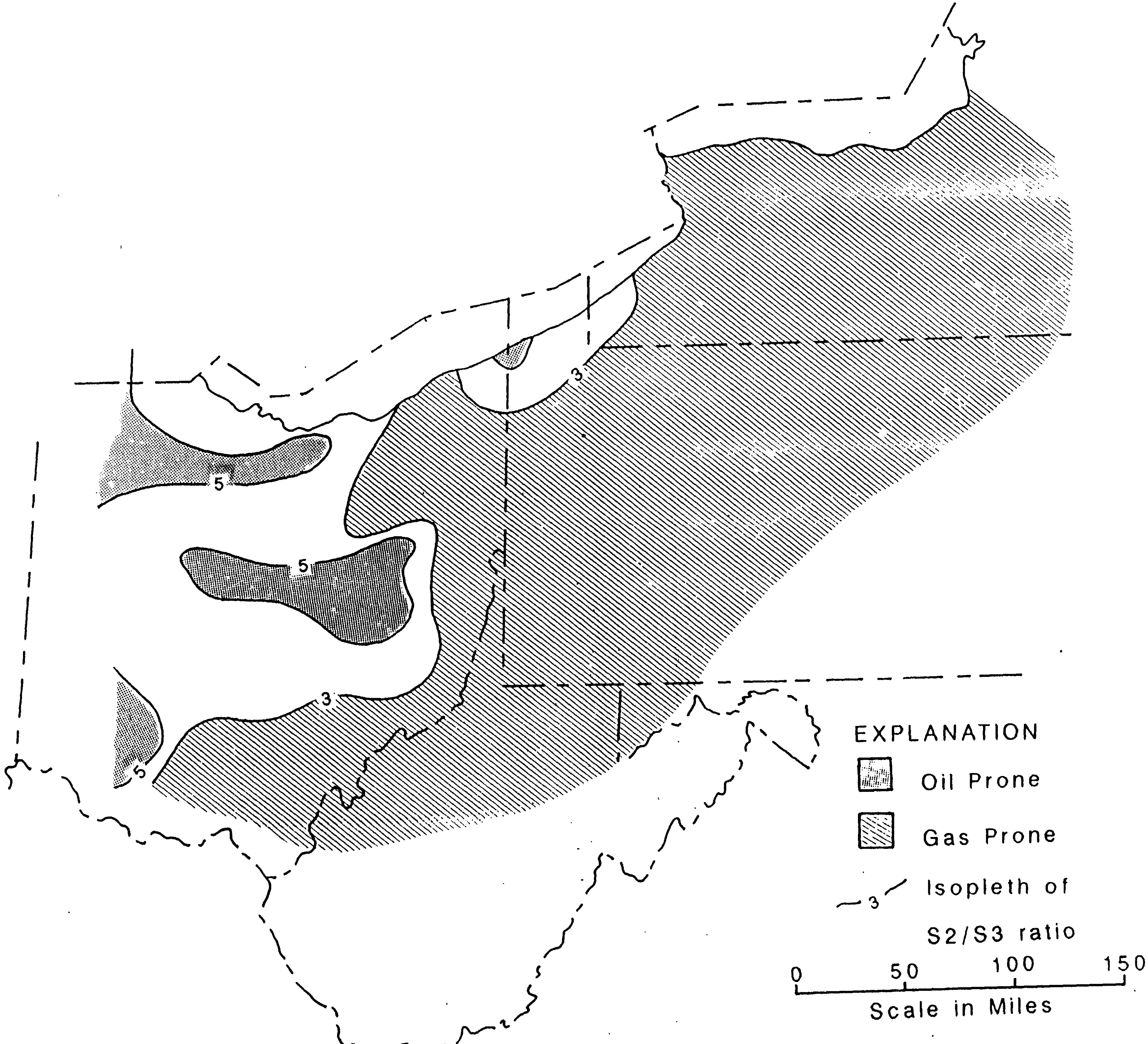

5
5
5
3
3
EXPLANATION
Oil Prone
Gas Prone
Isopleth of S2/S3 ratio
3
0
50
100
150
Scale in Miles

Table 1. Geochemical Parameters Describing Type of Hydrocarbon Generated (Peters, 1986)

Type	HI (mgHC/g C_{org})*	S_2/S_3
Gas	0-150	0-3
Gas and Oil	150-300	3-5
Oil	300+	5+

*Assumes a level of thermal maturation equivalent to R_o = 0.6%

temperature at S_2 (fig. 16 and table 2).

There are many problems associated with the use of Tmax for definitive determinations of maturation level. One limiting factor is that Tmax values are unreliable where S_2 values are less than 0.2 mg HC/g of rock (Peters, 1986). In addition, as suggested in table 2, the type of organic matter also affects the Tmax value. In general, the value of Tmax for gas-prone organic matter is relatively less than the Tmax for oil-prone organic matter (Tissot and Welte, 1978).

An isopleth map of the Tmax, where S_2 (greater than 0.2 mg HC/g of rock) suggests reliable Tmax values, indicates a basic trend toward more mature rocks in the eastern part of the basin. It suggests however, that an oil window (defined by temperatures from approximately 440°C to 470°C) extends farther east into northwest Pennsylvania and western New York than either the HI or S_2/S_3 ratio isopleth maps suggest.

The transformation ratio or production index (PI), the fourth parameter, is the ratio of the amount of petroleum already generated by the kerogen to the total amount of petroleum which the kerogen is capable of generating. The PI or transformation ratio as defined by $PI = S_1/(S_1 + S_2)$, measures the extent to which the genetic potential has been realized (Tissot and Welte, 1978) (appendix 3).

Table 2 reproduced from Peters (1986) indicates a PI of 0.1, in general, represents the transition from immature to mature with respect to oil generation. The isopleth map of the production index (fig. 17) based on samples from the basal part of the Utica sequence supports the increasing level of thermal maturation of Ordovician rocks from west to east across the Appalachian basin. These data also agree with published PI trends in Ohio (Cole and others, 1987).

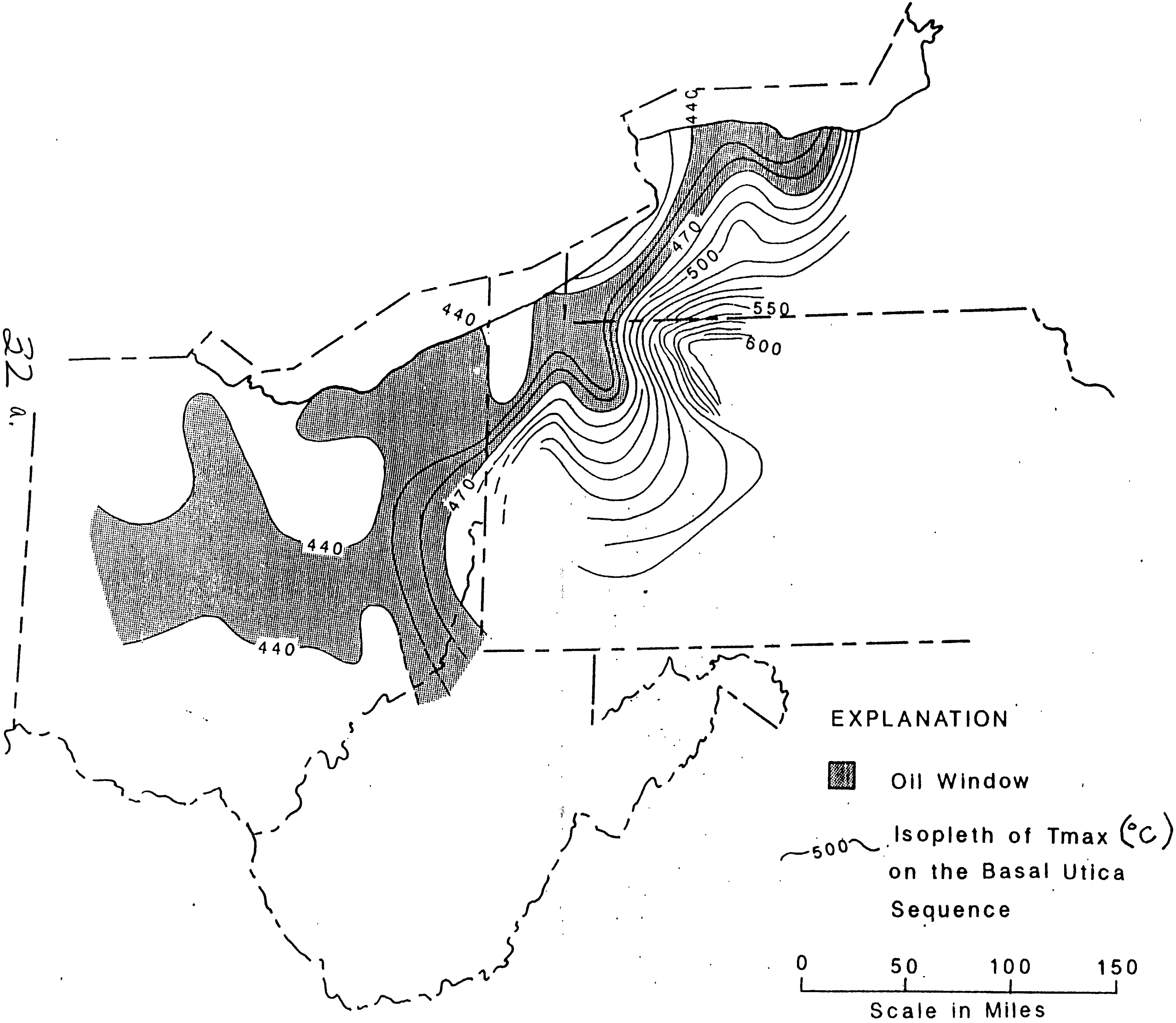
In southcentral Pennsylvania, PI values show a marked decrease. Rather than indicating a thermally less mature area, these values define a region which is thermally too mature for hydrocarbon production. Equipment limitations in determining S_2 values when only small amounts of kerogen are available has the effect of lowering the PI and falsely indicating a less mature area.

In addition to parameters defined by Rock-Eval analysis, conodont color alteration indices (CAI) can be used as a general indicator of thermal maturity.

Harris and others (1978), and Orndorff and others (1987) have shown that conodont color can be a valuable tool for determining maturation because color alteration in conodonts is a result of the depth and duration of burial and the geothermal gradient. Figure 18, showing the conodont color index CAI values across the study area, correlates well with the maturation trend shown by the PI distribution map (Fig. 17).

CAI values from Harris and others (1978) range from 1.5 in central Ohio and westernmost New York, to 4 or 5 in eastern West Virginia, central Pennsylvania and eastern New York (fig. 18). Harris and others (1978) plotted known production of oil and gas against the CAI for Ordovician rocks in the Appalachian basin. They showed that Ordovician oil fields are located in areas having CAI values less than 2, whereas Ordovician gas fields are located in areas having CAI values above 2. CAI values between 4 and 4.5 mark the upper limit for thermally generated dry gas (Harris and others, 1978).

Figure 16. Isopleth map of Tmax (°C) on the basal part of the Upper Ordovician Utica sequence. Oil window indicated by stippled pattern.



440
440
440
440
470
470
500
550
600
EXPLANATION
Oil Window
500 Isopleth of Tmax (°C) on the Basal Utica Sequence
0
50
100
150
Scale in Miles

32 a.

Fig 16

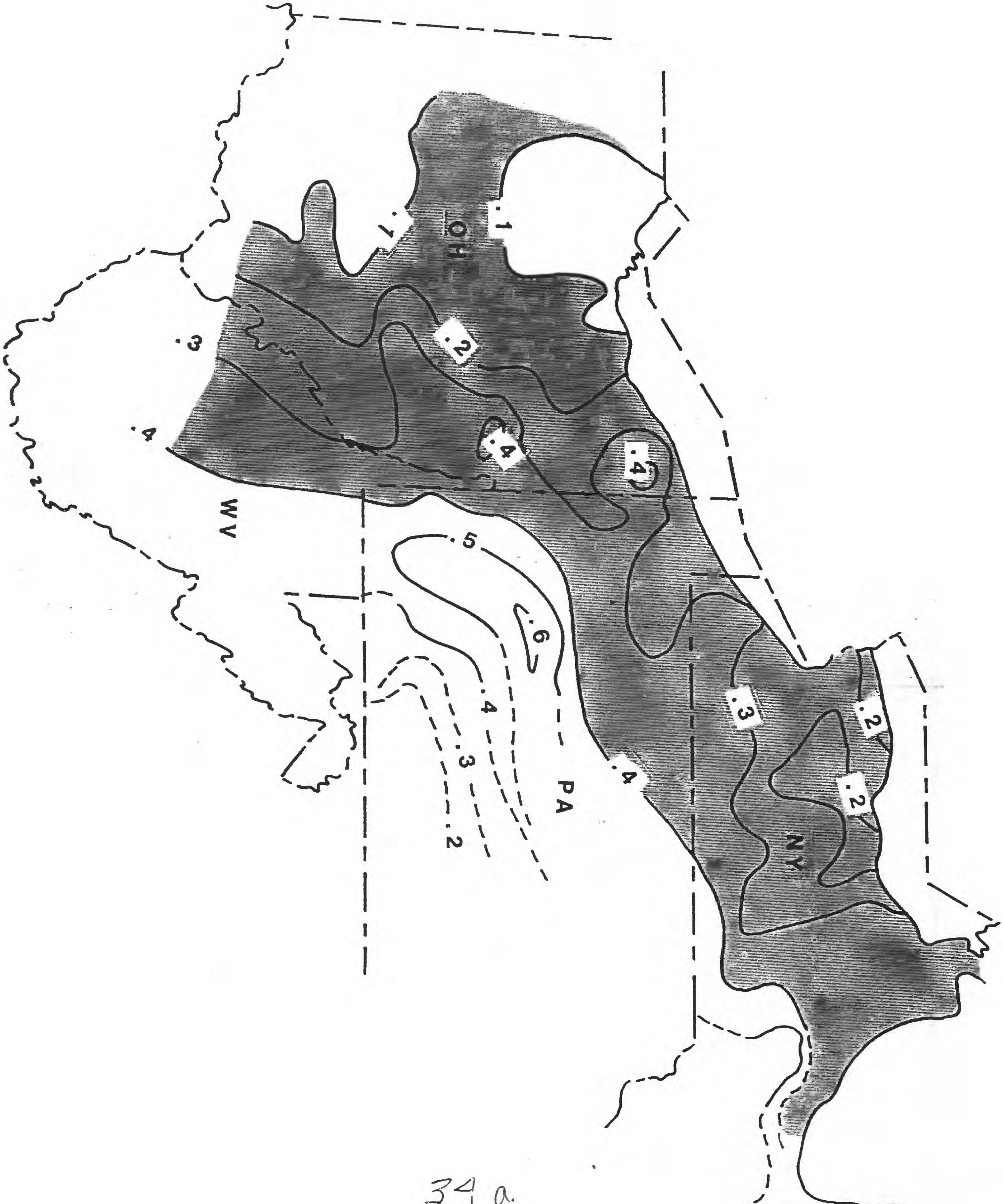
Table 2. Geochemical Parameters Describing Level of Thermal Maturation (Peters, 1986)

Maturation	PI $S_1/(S_1 + S_2)$	Tmax
Top oil window (birthline)	~0.1	~435-445*
Bottom oil window (deadline)	~0.4	~470

*Many maturation parameters (particularly Tmax) depend on the type of organic matter.

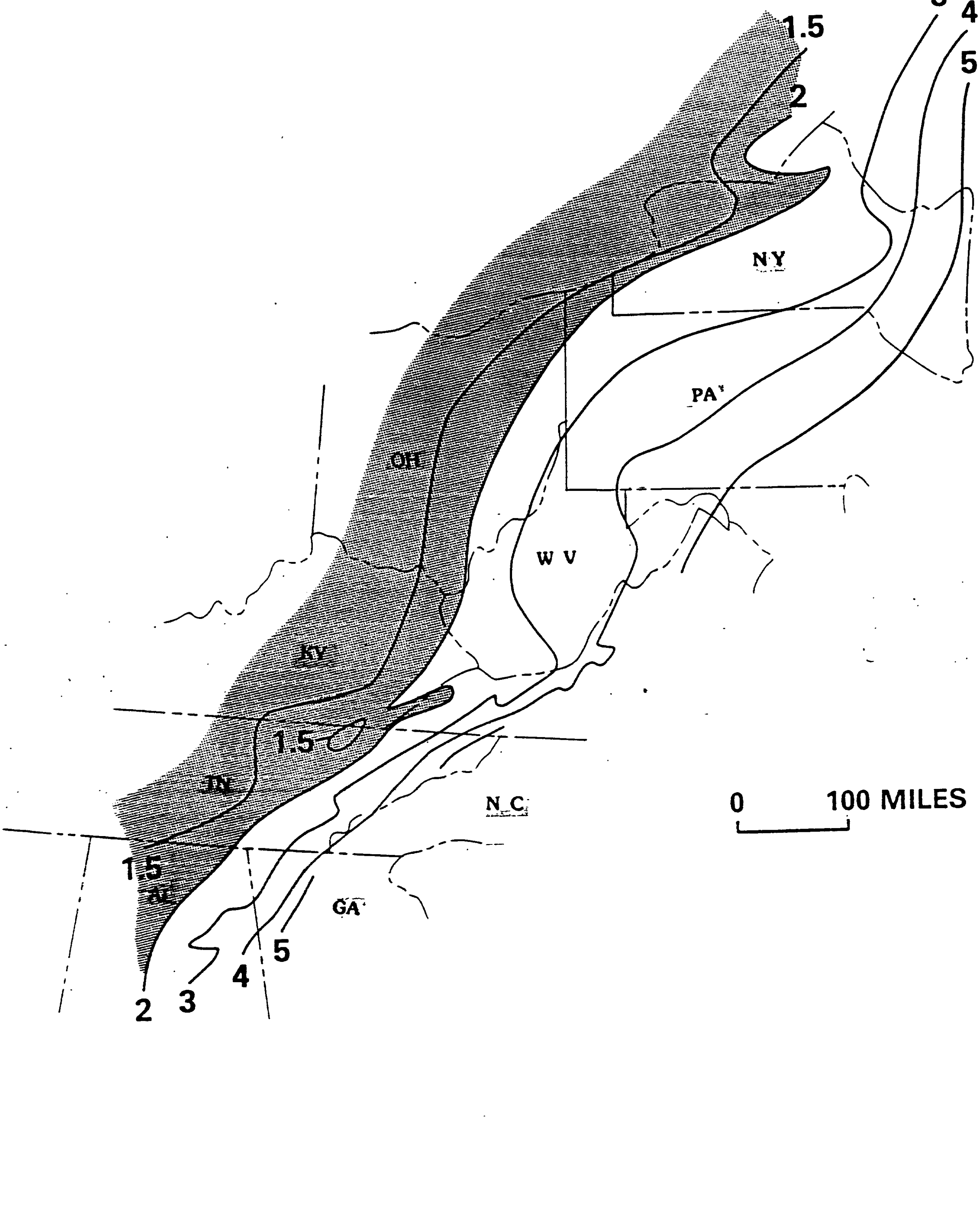
Figure 16. Isopleth map of Tmax ($^{\circ}C$) on the basal part of the Upper Ordovician Utica sequence. Oil window indicated by stippled pattern.

Fig 17



34 a.

Figure 18. Conodont color alteration index (CAI) isograds for Ordovician rocks. Modified from Harris and others, 1978; and Orndorf and others, 1987. Oil window indicated by stippled pattern.


1.5
2
3
4
5
N Y
PA
OH
W V
KY
1.5
TN
N C
1.5
AL
GA
2
3
4
5
0
100 MILES

West of the Allegheny front, the maturation level ranges from the diagenetic stage to the catagenetic stage (fig. 19). The thickest part of the Utica sequence located in eastern New York and central Pennsylvania, is in the middle to upper catagenetic stage of maturation as defined by CAI values between 3 and 5. This sequence, according to CAI values, is now within the gas window. The thinner part of the Utica sequence located in the western part of New York, Pennsylvania, and West Virginia and the eastern part of Ohio is in the lower catagenetic stage of maturation and is within the oil window.

There is an obvious discrepancy in the interpretation of the eastward boundary of the oil window among the four parameters, HI, S_2/S_3 Tmax, and PI. Those analytical factors that affect these results and show a difference, or an overlap of divergent data, are beyond the scope of this paper. There is, however, agreement among geochemists that these parameters generated from pyrolitic data should be used as a generalized predictive model.

GENETIC POTENTIAL

Once the levels of maturation for the Utica sequence were established, the next step was to assess the present potential for production of hydrocarbons. Two parameters were used to assess the genetic potential, TOC and $(S_1 + S_2)$.

The 175 samples collected from the Utica sequence were evaluated for their TOC content (appendix 3). Table 3 summarizes the total organic carbon content values of the 175 samples by state.

Peters (1986) has defined source rock quality in terms of TOC (table 4). Ronov (1958), Tissot and Welte, (1978), and Peters (1986) agree that one percent organic carbon is sufficient to define a shale source rock.

An isopleth map of the TOC values of the shale in the basal part of the Utica sequence is shown in figure 20. The TOC isopleth map shows an increase in TOC on the basal Utica sequence from central Ohio eastward to central Pennsylvania and an increase from northern New York southward to Pennsylvania.

The average TOC value for the entire Utica sequence is 1.34 percent. Based on this average value, Peters (1986) would consider the Utica sequence to have good source rock potential (table 4). Because the high density of low TOC values in Ohio and New York relative to Pennsylvania and West Virginia, the average TOC value may be skewed and not totally representative. The average for the sequence is probably greater than 1.34 percent.

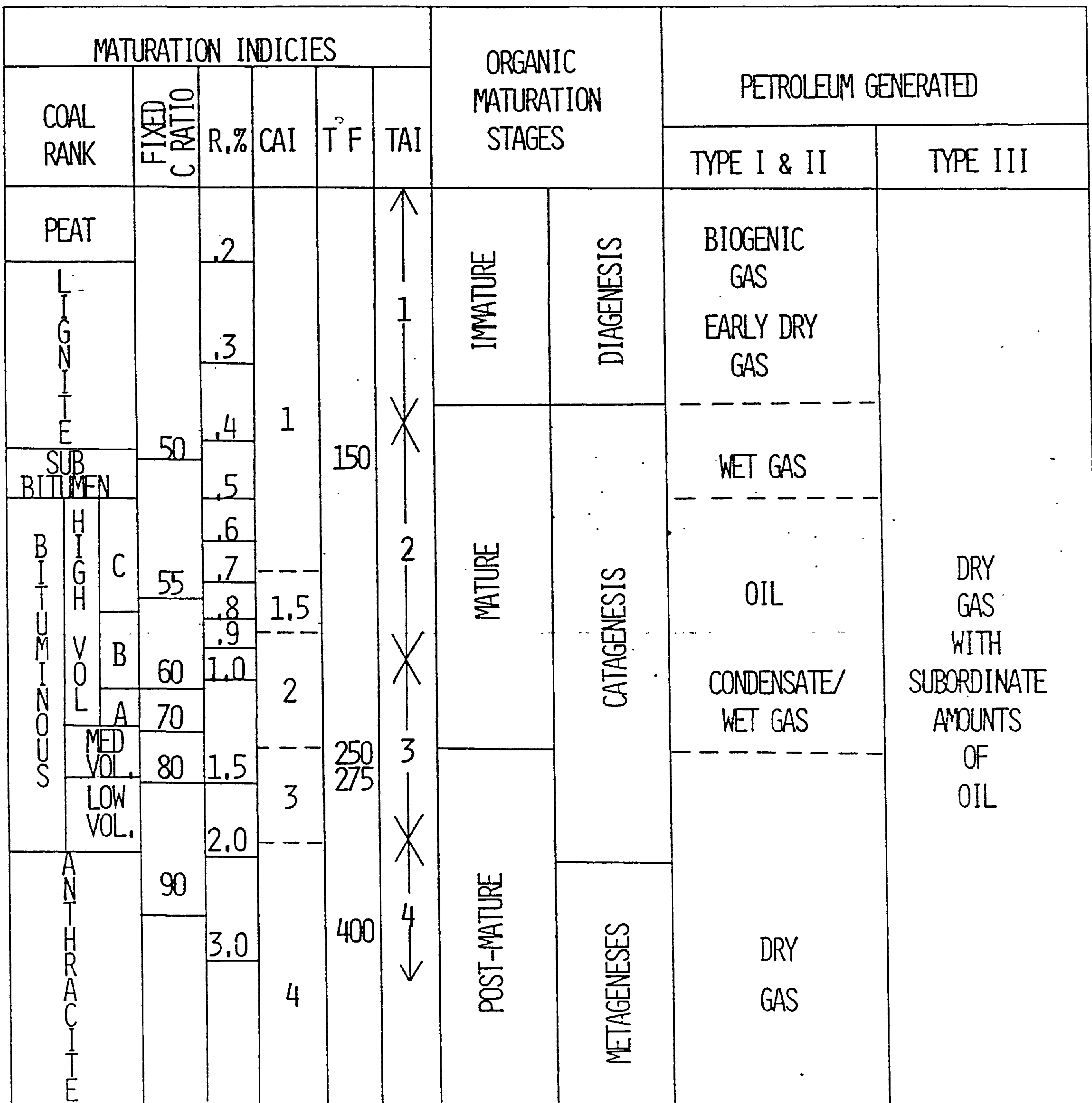
Decreasing values of TOC in the easternmost part of the basin do not represent a lessening of the organic content of the shales, but reflect residual TOC in overly mature parts of the Utica sequence.

TOC values determined from well cuttings can be appreciably decreased if the sample is diluted by rock fragments with a low organic carbon content. When analyzing powdered samples it is not always possible to detect the presence of other rock types. The weathered condition of surface samples can also produce lower TOC values.

S_1 and S_2 values according to Peters' (1986) and Tissot and Welte (1978),

Figure 19. Chart showing the comparison of maturation indices, organic maturation stages, and types of petroleum generation.

Fig 19



MATURATION INDICIES
COAL RANK
FIXED C RATIO
R.%
CAI
T °F
TAI
ORGANIC MATURATION STAGES
PETROLEUM GENERATED
TYPE I & II
TYPE III
PEAT
LIGNITE
SUB BITUMEN
BITUMINOUS
HIGH VOL
C
B
A
MED VOL.
LOW VOL.
ANTHRACITE
50
55
60
70
80
90
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.5
2.0
3.0
1
1.5
2
3
4
150
250
275
400
1
2
3
4
IMMATURE
MATURE
POST-MATURE
DIAGENESIS
CATAGENESIS
METAGENESES
BIOGENIC GAS
EARLY DRY GAS
WET GAS
OIL
CONDENSATE/ WET GAS
DRY GAS
DRY GAS WITH SUBORDINATE AMOUNTS OF OIL

Table 3. Total Organic Carbon in weight percent of 175 samples from the Utica sequence.

NEW YORK		
Subsurface well data		
basal Utica	27 samples	average TOC - 1.18%
upper Utica	19 samples	average TOC - 0.77%
total Utica	46 samples	average TOC - 1.01%
Surface data		
Utica	13 samples	average TOC - 1.37%
Combined surface and subsurface data, Utica	59 samples	average TOC - 1.09%
OHIO		
Subsurface well data		
basal Utica	36 samples	average TOC - 1.49%
upper Utica	5 samples	average TOC - 1.22%
total Utica	41 samples	average TOC - 1.46%
PENNSYLVANIA		
Subsurface well data		
basal Utica	14 samples	average TOC - 2.17%
upper Utica	17 samples	average TOC - 1.38%
total Utica	31 samples	average TOC - 1.74%
Surface samples		
Utica	7 samples	average TOC - 1.45%
Combined surface and subsurface data, Utica	38 samples	average TOC - 1.68%
WEST VIRGINIA		
Subsurface well data		
basal Utica	8 samples	average TOC - 1.52%
upper Utica	6 samples	average TOC - 0.81%
total Utica	14 samples	average TOC - 1.22%

Figure 20. Isopleth map of the total organic carbon (TOC) in weight percent for the basal part of the Upper Ordovician Utica sequence. Contour line dashed where approximate.

Fig 20

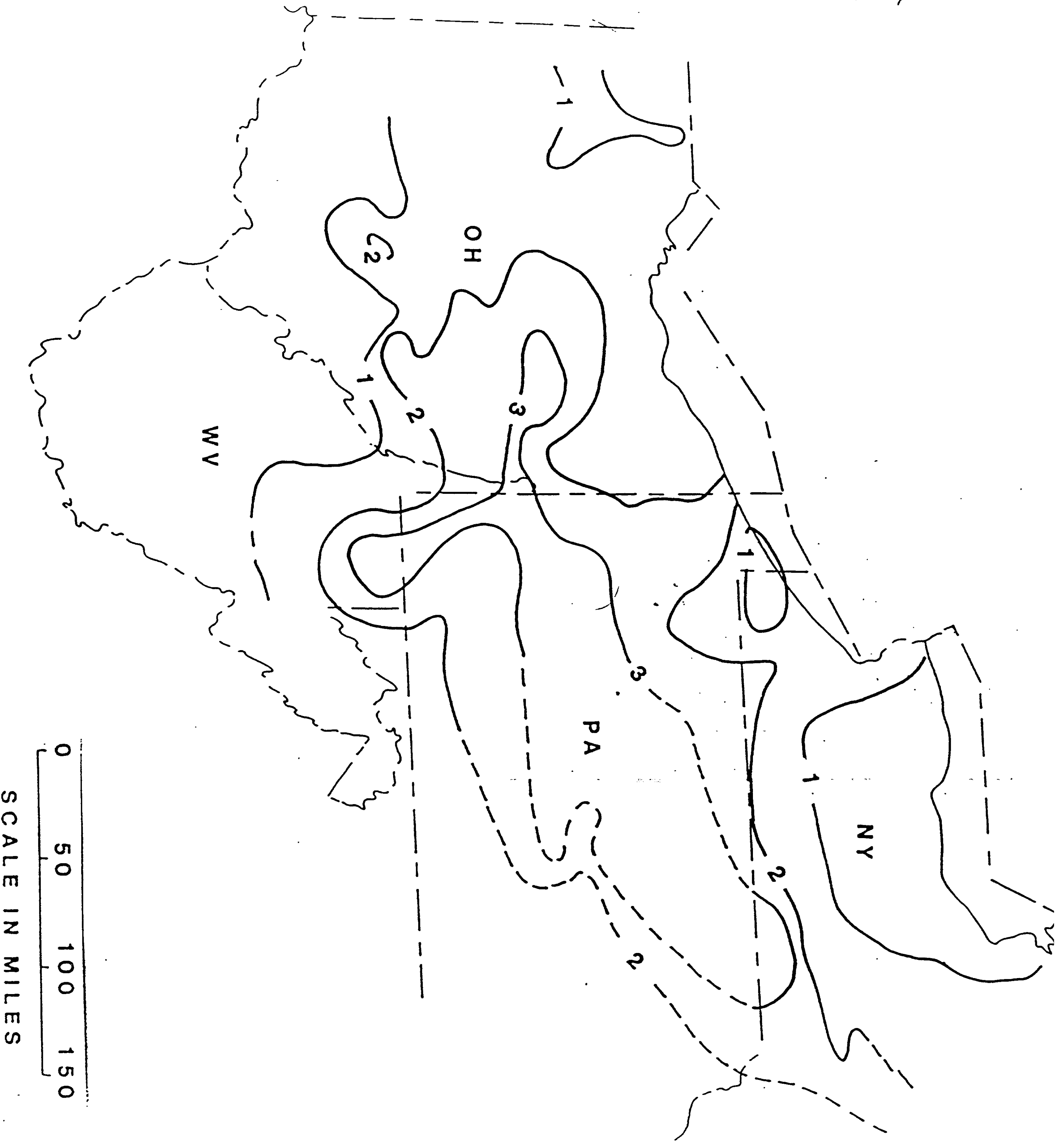


Table 4. Geochemical Parameters Describing Source Rock Generative Potential. Modified from Peters (1986).

Quality	TOC (wt.%)	S_1*S_2*	
Poor	<0.5	0-0.5	0-2.5
Fair	0.5-1	0.5-1	2.5-5
Good	1-2	1-2	5-10
Very good	2+	2+	10+

*S_1 = 1 mg HC/g rock; S_2 = mg HC/g rock

can also be used to evaluate the genetic potential of the rock (see tables 4 and 5 of this report). As previously mentioned, the genetic potential is the amount of petroleum which the kerogen in a given sample is capable of generating. In other words, the genetic potential refers to the potential of the given sample to produce hydrocarbons under conditions of burial heating over geologic time. The values listed in appendix 3 as compared to the criteria of Peters for S_1 and S_2 in table 4 and compared to the criteria of Tissot and Welte for (S_1+S_2) in table 5 indicate a poor genetic potential for future oil production and some potential for gas production in New York, Pennsylvania and West Virginia. About one half of the samples from Ohio, however, show fair to good potential as a moderate source rock. These data, in conjunction with the TOC data indicate that the Utica sequence is presently depleted in hydrogen at the New York, Pennsylvania, and West Virginia localities. About one half of the samples from Ohio shows hydrogen depletion. Hydrogen depletion may be caused by high levels of thermal maturation or by oxidation of the samples.

For thermally postmature samples, poor genetic potential does not preclude the possibility that the unit has produced oil in the past and that this oil could have migrated to cooler reservoirs and could have been preserved. Poor genetic potential only indicates that the unit no longer has significant potential for the generation of hydrocarbons.

QUANTITATIVE RESOURCE EVALUATION

To determine the possible quantity of hydrocarbons that the Utica sequence might have generated, the following volumetric formula was used:

$$Q_r = V \times D \times TOC \times C \times \%R$$

where Q_r is the possible quantity of hydrocarbons trapped in unspecified reservoirs, V is the volume of rock, D is the rock density, TOC is the organic richness, C is the hydrocarbon conversion ratio, and %R is the percent of those hydrocarbons reservoired.

The volume of rock from which hydrocarbons could have been generated is defined by the thickness and areal extent of the Utica sequence within the limits of CAI 1.5 and 4. These CAI values correspond to the middle of the catagenic stage and the beginning of the metagenic stage respectively (fig. 19) and correspond to areas of oil and gas production from Ordovician reservoirs.

We chose CAI values as our maturation indicies even though we realized the limitations of this method for CAI values of less than 1.5. A CAI value of 1.5 lies well within the oil generation window, but CAI values below 1.5 can not be measured. Although a certain quantity of potentially oil productive shale has been eliminated from this evaluation by using CAI values as our maturation indicies, we feel that this quantity is relatively small. A large portion of the shale to the west of the CAI 1.5 isopleth had a PI of less than 0.1 and is therefore just marginally mature.

The volume of rock in the Utica sequence between the CAI of 1.5 and 4 was calculated in cubic meters and converted to metric tons assuming an average shale density of 2.65×10^3 kg/m^3. Next, the weight of organic matter in the Utica sequence was computed by multiplying the weight of the rock in metric tons (4.5879×10^{13}MT), by the average weight percent organic carbon in the rock sequence, 1.34%.

Table 5. Genetic Potential as a Function of S_1 and S_2 (Tissot and Welte, 1978)

$S_1 + S_2$ = Genetic Potential
<2 kg/MT* - no oil source rock, potential for gas
2-6 kg/MT - moderate source rock
6 kg/MT - good source rock

* 1 kg/MT = 1 mg/g

Claypool and others (1978), in evaluating of the hydrocarbon potential of the black shales of the Phosphoria Formation in the western U.S. determined that 20% was an optimistic value for the percentage of organic carbon that was converted to hydrocarbons. For Type I kerogen like the Green River Shales with high HC/TOC, the conversion values reach about 15%, and 10% is a typical value for Type II and III kerogens (Jerry Clayton, USGS, personal comm., 1988). Since we have no data for Ordovician shale samples in the Appalachian basin, we chose to use a minimal value of 10%. The calculated volume of hydrocarbons generated from the Utica sequence was then adjusted to find a potentially trapped amount in unspecified reservoirs.

McDowell (1975), suggested that 10% of the total hydrocarbons generated in a basin may be recoverable but that 3% is a more probable value. McDowell shows that 0 to 50% of the total oil generated (Q), may be expelled from the source rock (Q_E) (fig. 21). Of the total amount of oil expelled from the source rock, 50% may be trapped in reservoirs (Q_R). Therefore, 25% or less of the total oil generated (Q) may be reservoired. The remaining amount of oil has either been dispersed or lost.

For this study we conservatively estimated the amount of oil trapped in reservoirs to be only 3% of the total amount of hydrocarbons generated from the Utica sequence. We do not geologically define any specific reservoirs as to size, location, and physical characteristics. Therefore, we do not suggest that any quantity of the proposed hydrocarbon generated and reservoired is known to be in place and recoverable.

If we use a TOC content of 1.34%, which is our computed average, a hydrocarbon conversion factor (C) of 10% which is one half of Claypool and others (1978) average for the Phosphoria black shale, and a percent reservoired (%R) amount of 3% as suggested by McDowell (1975), the Upper Ordovician dark-gray to black shale may have generated and reservoired 13.26 billion barrels of oil or its equivalent in gas.

SUMMARY

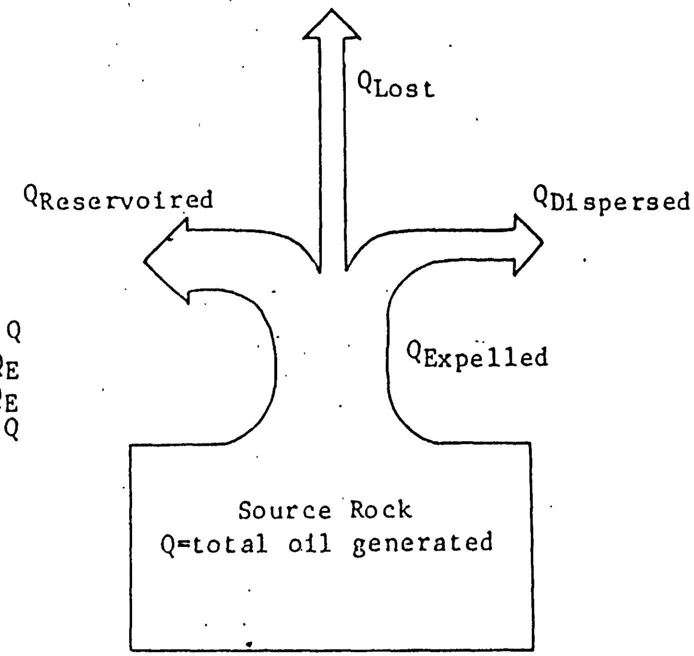
In summary, the Ordovician black shale in the northern part of the Appalachian basin covers a wide area in New York, Pennsylvania, West Virginia, and Ohio. It is 200 ft. thick in Ohio where it is 2,000 ft. below sea level and plunges to 12,000 feet below sea level in Pennsylvania where it reaches a thickness of 600 ft. The shales have undergone a considerable range in maturation from the diagenetic state in the west to the catagenetic stage in the east. Rock-Eval and TOC results indicate a sequence which could have generated considerable hydrocarbons in the past but presently show only a slight generative potential for gas in the deep eastern part of the basin and only moderate potential for oil in the shallow western part of the basin.

Assuming that these rocks produced hydrocarbons which have migrated, and using a TOC content average of 1.34%, a hydrocarbon conversion ratio (C) of 10%, and a percent reservoired (%R) of 3%, the Upper Ordovician sequence could have generated and reservoired 13.26 billion barrels of oil or equivalent.

Figure 21. Hydrocarbons generated, expelled, dispersed, and reservoired (McDowell, 1975).

Fig 21

Q_E = 0 to 50%+ of Q
Q_L = 0 to 10% of Q_E
Q_R = 0 to 50% of Q_E
Q_R = 0 to 25%+ of Q



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APPENDIX 1

Wells used in the construction of cross sections, isopach, drilling depth and structure maps of the Ordovician shale rich in organic matter. Wells marked with an * were used in the study but do not appear on the well location map because of scale limitations.

APPENDIX 1

NEW YORK

1. #1 Sommers & Tuttle
Appalachian Basin Oil & Gas
Sheridan Twp., Chautauqua Co.
7800' N 42°30'; 3300' W 79°15'
Geolog P-1428

2. WPL #1 Lackawanna Plant
Bethlehem Steel Corp.
Hamburg Twp, Erie Co.
N 42°48'01"; W 78°50'40"
Geolog P-1802

3. R. W. Brundage
Duchscherer
Alabama Twp., Genesee Co.
27,725' S 43°10'; 17,000' W 78°15'
Geolog P-1677

4. #1 Bowerman
Duchscherer & Strudwick
Farmington Twp., Ontario Co.
22,750' S 43°05'; 540' W 77°20'
Geolog P-1372

5. #1 E. K. Munroe
Cunningham Natural Gas Co.
Camillus Twp., Onondaga Co.
23,500' S 43°05'; 14,400' W 76°15'
Geolog P-2057

6. #1 J. Danisevich
New York State Natural Gas
Bookfield Twp., Madison Co.,
Sangerfied "H"
13,500' S 42°50'; 7,950' W 75°22'30"
Geolog P-682

7. #1 Robert Olin
New York State Natural Gas
Woodhull Twp., Steuben Co.
7,400' S 42°05'; 3,800' W 77°25'
Geolog P-22

8. #1 L. & N. Richards
Fenix & Scisson
Triangle Twp., Broome Co.
3,600' S 42°20'; 8,430' W 75°55'
Geolog P-1784

9. #1 F. Finch
Gulf Oil Corp.
Sydney Twp., Delaware Co.
5,850' S 42°20'; 18,750' W 75°10'
Geolog P-1418

10. #1 Branagan
New York State Natural Gas
Lebanon Twp., Madison Co.
10,400' S 42°50'; 18,000' W 75°35'
Geolog P-281

11. #1 Edson House
Humble Oil & Refining
Hastings Twp., Oswego Co.
4,400' N 43°20'; 5,300' W 76°05'
Geolog P-486

12. #1 C. Hazen
Weaver Exploration Co.
Hamlin Twp., Monroe Co.
1,350' S 43°20'; 13,150' W 77°55'
Geolog P-661

13. #1 Kellogg
Humble Oil & Refining
Williamstown Twp., Oswego Co.
9,750' N 43°25'; 11,250' W 75°50'
Geolog P-485

14. A. McClurg #N-952
New York State Natural Gas
York Twp., Livingston Co.
14,475' S 42°52'30"; 5,450'W 77°55'
Geolog P-914

15. #1 F. Kelly
Humble Oil & Refining
Barre Twp., Orleans Co.
6,350' S 43°12'30";2,100' W 78°15'
Geolog P-942

16. #1 Wyman
Hammerstone
Farmington Twp., Ontario Co.
4,050' S 43°00'; 7,850' W 77°15'
Geolog P-1348

17. #1 R. Wolfe
Hammerstone
Somerset Twp., Niagara Co.
29,500' S 43°25'; 3,450' W 78°30'
Geolog P-1349

18. #1 H. V. Olson
Duchscherer
Lyons Twp., Wayne Co.
20,050' S 43°10'; 5,500' W 77°00'
Geolog P-1493

19. #1 L. Burkard N-946
New York State Natural Gas & Acme
Maryland Twp., Otsego Co.
19,150' S 42°35'; 13,450' W 74°50'
Geolog P-1581

20. #1 E. S. Hall
Duchscherer
Oswego Twp., Oswego Co.
17,150' S 42°25'; 5,000' W 76°35'
Geolog P-1636

21. #1 Werner
New York State Natural Gas
Orangeville Twp., Wyoming Co.
875' S 42°45'; 8,400' W 78°10'
Geolog P-1700

22. #1 G. C. Frankish
M. C. Hoover
Gorham Twp., Ontario Co.
7,550' S 42°50; 9,750' W 77°10'
Geolog P-1828

23. #2 G. M. Cook
Parsons Brothers
Hume Twp., Allegany Co.
17,000' S 42°30'; 2,050' W 78°10'
Geolog P-240

24. #1 Harrington
Pennzoil
Ellery Twp., Chautauqua Co.
23,900' S 42°15'; 1,300' W 79°20'
Geolog P-601

25. #1710 Ellis
Iroquois Gas
Perrysburg Twp., Cattaraugus Co.
16,150' S 42°30'; 10,975' W 79°00'
Geolog P-689

26. #1 Arthur E. Johnson N-956
New York State Natural Gas
Caledonia Twp., Livingston Co.
Caledonia "B"
9,475'S 42°57'30";2,425'W 77°52'30"
Geolog P-874

27. #1 A. Kennedy
E. Blair & O. D. Weaver
Sparta Twp., Livingston Co.
4,500' S 42°40'; 3,000' W 77°45'
Geolog P-875

28. #1 L. Tyler
E. F. Blair & O. D. Weaver
Byron Twp., Genesee Co.
15,000' S 43°05'; 20,550' W 78°00'
Geolog P-896

29. #1 Celia Wasielewski
Humble
Ira Twp., Cayuga Co.
29,400' S 43°20'; 19,700' W 76°25'
Geolog P-936

30. #1 C. E. Leslie
Gulf Oil Corp.
Franklin Twp., Delaware Co.
9,900' S 42°25'; 12,200' W 75°00'
Geolog P-1377

31. #1 Campbell
Gulf Oil Corp.
Hamden Twp., Delaware Co.
24,700' S 42°15'; 1,450' W 74°55'
Geolog P-1391

32. #1 K. & O. Clough
Delta Drilling Co.
Freetown Twp., Cortland Co.
23,500' S 42°35'; 250' W 76°00'
Geolog P-1406

33. K. & R. Klotzbach
Duchscherer
Alabama Twp., Genesee Co.
500' S 43°02'30"; 4,050'W 78°22'30"
Geolog P-1678

34. #1 A. Victor
Schoellkopf & Victor
Hamburg Twp., Erie Co.
10,000' S 42°45'; 7,600 W 78°55'
Geolog P-1712

35. Kesselring
New York State Natural Gas
Van Etten Twp., Chemung Co.
2.22 mi N 42°10'; 1.89 mi W 76°30'
Fettke, 1961

36. Lanzillota
Gulf Oil & Refining
Roxbury Twp., Delaware Co.
24,600' S 42°20'; 15,200' W 74°35'
Geolog P-1485

37. #2 Schaffer
United Production
Fayette Twp., Seneca Co.
14,750' S 42°55'; 6,750' W 76°50'
Geolog P-511

38. #1 Veith
New York State Natural Gas
Gainesville Twp., Wyoming Co.
17,600' S 42°40'; 21,800' W 78°00'
Geolog P-274

39. #1 Heaphy
Humble Oil & Refining
Palermo Twp., Oswego Co.
5,300' N 43°20'; 3,800' E 76°20'
Geolog P-484

PENNSYLVANIA

1. Pa. Dept. Forest & Waters Blk. 2 #1
New York State Nat. Gas-Kewanee Oil
Lake Erie, Erie Co.
10,900' N $42^{\circ}15'$; 4,700' E $79^{\circ}55'$
Geolog P-39

2. #2 Hammermill Plant
Hammermill Paper Co.
City of Erie, Erie Co.
8,700' S $42^{\circ}10'$; 12,900' W $80^{\circ}00'$
Geolog P-849

3. #1 Shaw
Biery & Johnson
Limestone Twp., Warren Co.
0.91 mi S $41^{\circ}40'$; 1.85 mi W $79^{\circ}20'$
Geolog P-3

4. #1 Fee
Minard Run Oil Co.
Bradford Twp., McKean Co.
12,650' S $41^{\circ}55'$; 8,600' W $78^{\circ}35'$
Geolog P-957

5. Emma McKnight
Melben Oil Co.
Pymatuning Twp., Mercer Co.
.92 mi S $41^{\circ}20'$; 2.01 mi E $80^{\circ}30'$
Wagner, 1958

6. C-1 Pa. Dept. Forest & Waters
Texaco Inc.
Blooming Grove Twp., Pike Co.
15,150' S $41^{\circ}27'$; 4,400' W $75^{\circ}07'30''$
Geolog P-2356

7. #1 Solomon
G. L. Cabot Inc.
Buffalo Twp., Union Co.
7,700' E $77^{\circ}00'$; 6,500' S $41^{\circ}55'$
Geolog P-12

8. #1 J. Kardosh
Benedum Trees & Ark.-La. Gas
Summerhill Twp., Crawford Co.
12,525' S $41^{\circ}25'$; 15,500' W $80^{\circ}15'$
Geolog P-67

9. Pa. Dept. Forest & Waters Blk 1 #1
New York State Nat. Gas
Lake Erie, Erie Co.
5,300' N $42^{\circ}00'$; 7,150' W $80^{\circ}25'$
Geolog P-73

10. #1 Borst
R. McConnell
Conneaut Twp., Erie Co.
1.89 mi N $41^{\circ}50'$; 2.77 mi W $80^{\circ}25'$
Geolog P-112

11. #1 Long
Mobil Oil Co.
Marion Twp., Centre Co.
2,150' S $41^{\circ}00'$; 4,700' W $77^{\circ}35'$
Geolog P-695

12. #1 W. Morton
D. C. Garrett
Bloomfield Twp., Crawford Co.
29,200' S $41^{\circ}55'$; 15,600' W $79^{\circ}50'$
Geolog P-737

13. 1 Shade Mnt.
Shell et. al.
Fayette Twp., Juniata Co.
23,000' S $40^{\circ}45'$; 8,500' W $77^{\circ}15'$
Geolog P-751

14. J. Marzka
D. C. Garrett
Rockdale Twp., Crawford Co.
3,200' S $41^{\circ}50'$; 5,100' W $79^{\circ}55'$
Geolog P-752

15. 1 Mike Miller
James Drilling Co.
Indian Springs Twp., Crawford Co.
22,800' S $41^{\circ}50'$; 17,400' W $80^{\circ}20'$
Geolog P-795

16. #1 T. Miller Shellsburg
Kerr-McGee, et. al.
Napier Twp., Bedford Co.
22,400' S $40^{\circ}10'$; 9,300' W $78^{\circ}35'$
Geolog P-998

17. #2 Benebaugh
Trans American
Beaver Twp., Crawford Co.
3,500' S 41°50'; 14,000' W 80°25'
Geolog P-1077

18. #1 Tyler
Ventura Oil
Beaver Twp., Crawford Co.
22,000' S 41°50'; 3,800' W 80°25'
Geolog P-1094

19. #1 Goodwill-Curley
V. R. Stephens, et. al.
Summit Twp., Erie Co.
13,400' S 42°05'; 6,600' W 80°00'
Geolog P-1207

20. #1 Buchowski
Sun Oil Co.
Cussewago Twp., Crawford Co.
3,600' S 41°50'; 6,200' W 80°10'
Geolog P-1292

21. #1 Pa. Tract 129
Consolidated Gas N-972
Stewardson Twp., Potter Co.
3,900' S 41°30'; 6,550' W 77°45'
Geolog P-1396

22. 2 Amerite
Eldon Funk
Fannette Twp., Franklin Co.
23,600' S 40°15'; 2,900' W 77°40'
Geolog P-1583

23. #1 Nellie C. Martin
Peoples Natural Gas
Wayne Twp., Armstrong Co.
11,500' S 40°55'; 3,700' W 79°20'
Geolog P-1981

24. Jay Childs #1
Ohio Oil Co.
Springfield Twp., Erie Co.
2.23 mi S 42°00'; .95 mi W 80°30'
Fettke, 1961

25. #1 Leonard Svetz
Amoco & PNG
Middle Creek Twp., Somerset Co.
8,100' S 40°00'; 150' W 79°20'
Geolog P-3203

WEST VIRGINIA

1. #1 Grover Arrington
United Fuel Gas
Clendenia Dist., Mason Co.
2.50 mi S 38°45'; 4.12 mi W 82°05'
Geolog P-14

2. Ray Sponaugle
United Fuel Gas Well #800T
Circleville Dist. Pendleton Co.
2.43 mi S 38°35'; 0.69 mi W 79°30'
Geolog P-110

3. #1 U.S. Forest Service
Tidwater and S. Penn Tr. 357
Huntersville Dist., Pocohantas Co.
5,050' S 38°10'; 3,300' W 80°00'
Geolog P-560

4. J. W. Heinzman
United Fuel #4053
Curtis Dist., Roane Co.
3.42 mi S 38°50'; 0.34 mi W 81°30'
Geolog P-571

5. #1 Duckworth
Shell Oil Co.
Springfield Dist., Hampshire Co.
2,100' S 39°30'; 17,500' W 78°35'
Geolog P-621

6. #1 R. R. Finch
Phillips
Winfield Dist., Marion Co.
4.76 mi S 39°30'; 0.64 mi W 80°00'
Geolog P-625

7. #1 S. Minesinger (42172)
Humble Oil
Clay Dist., Hancock Co.
2.98 mi S 40°35'; 2.86 mi W 80°30'
Geolog P-1392

8. #10707A (HNG)
Phillips Petroleum
Walker Dist., Wood Co.
25,400' S 39°20'; 6,800' W 81°15'
Geolog P-1419

9. #3 Greenland Lodge 10768
Shell Oil Co.
Union Dist., Grant Co.
7,300' S 39°10'; 9,800' W 79°10'
Geolog P-1770

10. E. Kingery Unit #1
Cyclops
Union Dist., Cabell Co.
4.19 mi S 38°35'; 0.72 mi W 82°15'
Geolog P-2220

11. #1 John Burley
Occidental
Liberty Dist., Marshall Co.
25,600' S 39°50'; 8,450' W 80°30'
Geolog P-1960

12. HNG Co. #9634
Power Oil Co.
Walker Dist., Wood Co.
5.40 mi S 39°20'; 1.14 mi W 81°15'
Price and others, 1959

13. 9674T
Columbia Gas
Harvey Dist., Mingo Co.
.78 mi S 37°55'; .21 m W 82°10'
Geolog P-2888

14. 20659 S. D. Todd
Columbia Gas
Malden Dist., Kanawha Co.
2.47 mi S 38°20'; 2.01 mi W 81°20'
Geolog P-4611

APPENDIX 2

Sample localities in New York, Ohio, Pennsylvania, and West Virginia

APPENDIX 2

NEW YORK

Sample No.	Sample Location
NY1	#1 Sommers & Tuttle Appalachian Basin Oil & Gas Sheridan Twp., Chautauqua Co. 7,800' N $42^{\circ}30'$; 3,300' N $79^{\circ}15'$
NY2	#1 Harrington Pennzoil Ellery Twp., Chautauqua Co. 23,900' S $42^{\circ}15'$; 1,300' W $79^{\circ}20'$
NY3	Fee #2 J. F. Weinheimer Inc. Tonowanda Twp., Erie Co. 1,600' N $43^{\circ}00'$; 2,350' E $78^{\circ}50'$
NY4	#1 R. Wolfe Hammerstone Somerset Twp., Niagara Co. 29,500' S $43^{\circ}25'$; 3,450' W $78^{\circ}30'$
NY5	#1 F. Kelly Humble Oil & Refining Barre Twp., Orleans Co. 6,350' S $43^{\circ}12'30''$; 2,100' W $78^{\circ}15'$
NY6	#1 L. Tyler E. F. Blair & O. D. Weaver Byron Twp., Genesee Co. 15,000' S $43^{\circ}05'$; 20,550' W $78^{\circ}00'$
NY7	#1 Veith New York State Natural Gas Gainesville Twp., Wyoming Co. 17,600' S $42^{\circ}40'$; 21,800' W $78^{\circ}00'$
NY8	#2 G. M. Cook Parsons Brothers Hume Twp., Allegany Co. 17,000' S $42^{\circ}30'$; 2,050' W $78^{\circ}10'$
NY9	#1 C. Hazen Weaver Exploration Co. Hamlin Twp., Monroe Co. 1,350' S $43^{\circ}20'$; 13,150' W $77^{\circ}55'$
NY10	#1 A. Kennedy E. Blair & O. D. Weaver Sparta Twp., Livingston Co. 4,500' S $42^{\circ}40'$; 3,000' W $77^{\circ}45'$
NY11	#1 Robert Olin New York State Natural Gas Woodhull Twp., Steuben Co. 7,400' S $42^{\circ}05'$; 3,800' W $77^{\circ}25'$
NY12	#1 H. V. Olson Duchscherer Lyons Twp., Wayne Co. 20,050' S $43^{\circ}10'$; 5,500' W $77^{\circ}00'$
NY13	#1 Bowerman Duchscherer & Strudwick Farmington Twp., Ontario Co. 22,750' S $43^{\circ}05'$; 540' W $77^{\circ}20'$
NY14	Kesselring New York State Natural Gas Van Etten Twp., Chemung Co. 2.22 mi N $42^{\circ}10'$; 1.89 mi W $76^{\circ}30'$
NY15	#2 Schaffer United Production Fayette Twp., Seneca Co. 14,750' S $42^{\circ}55'$; 6,750' W $76^{\circ}50'$
NY16	Shepard, John N.Y.S. Natural Gas Danby Twp., Tompkins Co. 1,750' S $42^{\circ}22'30''$; 1,700' W $76^{\circ}30'$
NY17	C. C. Lobdell #1 Bradley Prod. Corp. Columbus Twp., Chenango Co. 9,700' N $42^{\circ}40'$; 3,150' W $75^{\circ}20'$
NY18	#1 Celia Wasielewski Humble Ira Twp., Cayuga Co. 29,400' S $43^{\circ}20'$; 19,700' W $76^{\circ}25'$
NY19	#1 Kellogg Humble Oil & Refining Williamstown Twp., Oswego Co 9,750' N $43^{\circ}25'$; 11,250' W $75^{\circ}50'$
NY20	#1 J. Danisevich New York State Natural Gas Brookfield Twp., Madison Co. 13,500'S $42^{\circ}50'$; 7,950'W $75^{\circ}22'30''$

NY21 #1 L. & N. Richards
Fenix & Scisson
Triangle Twp., Broome Co.
3,600' S 42°20'; 8,430' W 75°55'

NY22 #1 K. & O. Clough
Delta Drilling Co.
Freetown Twp., Cortland Co.
23,500' S 42°35'; 250' W 76°00'

NY23 Gould Paper Co. #1
Humble Oil & Ref.
High Market Twp., Lewis Co.
21,800' S 43°40'; 4,200' W 75°35'

NY24 Puskarenko #1
Devonian Gas & Oil Co
Stark Twp., Herkimer Co.
2,700' S 42°55'; 500' W 74°50'

NY25 Lanzillota
Gulf Oil & Refining
Roxbury Twp., Delaware Co.
24,600' S 42°20'; 15,200' W 74°35'

NY26 #1 L. Burkard N-946
New York State Natural Gas & Acme
Maryland Twp., Otsego Co.
19,150' S 42°35'; 13,450' W 74°50'

NY27 Gans, Maurice #1
United Prod. Co.
Windham Twp., Greene Co.
100' N 42°20'; 5,200' E 74°15'

NY28 Amsterdam 15' Quad.
Schenectady Co., NY
6.3 mi S 43°00'; 3.8 mi W 74°00'

NY29 Amsterdam 15' Quad.
Schenectady Co., NY
6.35 mi S 43°00'; 3.8 mi W 74°00'

NY30 Randall 7 1/2' Quad.
Montgomery Co.
3.65 mi S 43°00'; 1.75 mi E 74°25'

NY31 Carlisle 7 1/2' Quad.
Montgomery Co.
2.4 mi N 42°50'; 2.5 mi E 74°30'

NY32 Canajoharie 7 1/2' Quad.
Montgomery Co.
7.1 mi S 43°00'; 3.5 mi W 74°30'

NY33 Fort Plain 7 1/2" Quad.
Montgomery Co.
4.4 mi S 43°00'; 2.9 mi E 74°45'

NY34 Boonville 7 1/2' Quad.
Oneida Co.
5.85 mi S 43°30'; 3.85 mi W 75°15'

NY35 Glenfield 7 1/2 Quad.
Lewis Co.
7.05 mi S 43°45'; 3.5 mi E 75°30'

NY36 Rodman 7 1/2' Quad.
Jefferson Co.
1.75 mi N 43°50'; 4.4 mi E 76°00'

NY37 Barnes Corner 7 1/2' Quad.
Jefferson Co.
8.25 mi N 43°45'; 4.9 mi W 75°45'

NY38 Glenfield 7 1/2' Quad.
Lewis Co.
3.5 mi S 43°45'; 1.65 mi E 75°30'

NY39 Fort Plain 7 1/2' Quad.
Montgomery Co.
4.5 mi S 43°00'; 2.85 mi E 74°45'

NY40 Van Hornesville 7 1/2' Quad.
Herkimer Co.
1 mi S 43°00'; 2.9 mi W 74°45'

OHIO

Sample No.	Sample Location
OH1	Kenneth D. & Pauline MacBurden Frank Dever Auglaize Twp., Allen Co. 230' FSL; 260' FEL; SW 1/4, Sec. 29
OH2	Kemmer Unit Quaker State Refining Co. Jefferson Twp., Ashtabula Co. 1,148' FSL; 880' FWL; Lot 134
OH3	D & B Hoelscher Comm. West Ohio Gas Co. St. Mary's Twp., Auglaize Co. .25 mi N 40°30'; 1 mi W 84°22'30"
OH4	#1 Clark et al. Unit Stocker & Sitler, Inc. Brown Twp., Carroll Co. 1,590' FNL; 22' FWL; NW 1/4, Sec. 36
OH5	Van Pelt Kewanee Oil Co. Wayne Twp., Clinton Co. 11,200' W 83°35'; 12,800' S 39°25'
OH6	#1 Maynard Barnes National Gas & Oil Co. Deerfield Twp., Morgan Co. 700' FWL; 400' FSL; NE 1/4, Sec. 12
OH7	Nathan Wickham National Oil & Gas Salt Creek Twp., Muskingum Co. 528' FWL; 660' FSL; NE, Sec. 10
OH8	Eldon E. Denny 2468 East Ohio Gas Co. Knox Twp., Columbiana Co. 1,153'FSL; 1,675'FWL; SW 1/4, Sec. 12
OH9	#1 Benley-A Phillips Petroleum Crawford Twp., Coshocton Co. 207' FNL; 800' FWL; SW 1/4, Sec. 16
OH10	Donald F. & Clara E. Higbea Sohio Pet. Co. Adams Twp., Defiance Co. 330' FNL; 330' FEL; SE 1/4, Sec. 18
OH11	Melvin P. Sayler et al. Ohio Fuel Gas 10209 Florence Twp., Erie Co. 1,350'FNL;1,200'FWL;4th Qtr.,Lot 48
OH12	#1 Rosa Thomas Heirs Clark Oil & Refining Co. Clear Creek Twp., Fairfield Co. 430' FSL; 330' FWL; NE 1/4, Sec. 15
OH13	Maynard Hoppes Kewanee Oil Co. Perry Twp., Fayette Co. 11,500' W 83°25'; 9,000' N 39°25'
OH14	#1 Marble Cliff Quarries Marble Cliff Quarries Franklin Twp., Franklin Co. 2,500'S Trabue Rd;3,100'W Sciota Rv
OH15	Noble W. Erbskorn McClure Oil Co. Gorham Twp., Fulton Co. 990'FNL; 4,600'FWL; NW 1/4, Sec. 19
OH16	#1 Mae & Charles Vessels Ridge Oil Co., Inc. Westland Twp., Guernsey Co. 1,520' FNL; 2,603' FEL; 3rd Qtr.
OH17	D & D Jones Norman Edmund Jackson Twp., Hardin Co. 660' FNL; 660' FEL; SW Sec. 30
OH18	#1 M. F. & H. Hockman E. J. Dunigan Jr. Starr Twp., Hocking Co. 660' FSL; 570' FWL; NE/R Sec. 31
OH19	Elizabeth Geib Amerada Petroleum Corp. Berlin Twp., Holmes Co. 660' FEL; 500' FSL; SE 1/4, Lot 12
OH20	George D. & Ina Wood Worthington Oil Co., Inc. Frankin Twp., Jackson Co. 790'FSL; 730'FEL; SW 1/4, Sec. 23

Sample No.	Sample Location
OH21	#1 Charles G. Huffman Kin-Ark Oil Hilliar Twp., Know Co. 500' FNL; 985' FWL; 3rd. Qtr., Lot 21
OH22	#1 Calhio Chemical Inc. Calhio Chemicals Inc. Perry Twp., Lake Co. 1,527' FSL; 435' FEL; Lot 47
OH23	#1 K. F. & M. I. White Southern Triangle Oil Co. Granville Twp., Licking Co. 2,030' FWL; 6,800' FNL; Lot 6
OH24	#1 A. & A. Born 2155 East Ohio Gas Henrietta Twp., Lorain Co. 1,150' FEL; 700' FSL; Lot 8
OH25	Ketring Unit Liberty Pet. Corp. Harding Twp., Lucas Co. 300' FSL; 500' FEL; SE 1/4, Sec. 9
OH26	#1 J. R. Hume Amerada Petroleum Corp. Fairfield Twp., Madison Co. 710' FSWL; 1,980' FNLW' Lot 9717
OH27	M. E. Warner Ohio Fuel Gas Co. Granger Twp., Medina Co. 786' FWL; 540' FNL; Lot 42
OH28	H. V. Thomas Buckeye Management Co. Beaverfield Twp., Perry Co. 1,100' FSL; 1,250' FEL; SW 1/4, Sec. 1
OH29	#1 Mable McCoy Croman McMahon-Billington Jackson Twp., Pickaway Co. 2,700' S 39°40'; 2,400' W 83°05'
OH30	#1 D. Wittmer B.B.M. Drilling Co. Springfield Twp., Richland Co. 955' FSL; 289' FWL; SE 1/4, Sec. 33

Sample No.	Sample Location
OH31	#1 O. & O. Clark Crest Oil Co. Concord Twp., Ross Co. 8,200' FWL; 3,200' FSL
OH32	#1 Ayers E. J. Dunegan, Jr. Washington Twp., Sandusky Co. 230'FNL;330'FEL;SE 1/4, Sec. 31-N
OH33	4-A Erma Sponseller M.B. Oil & Gas & Prudent Resources Canton Twp., Stark Co. 645' FSL; 645' FWL; SW 1/4, Sec. 25
OH34	Carl Matheny Unit Guernsey Pet. Corp. Lawrence Twp., Washington Co. 500'FSL; 1,175'FEL; NE 1/4, Sec. 15
OH35	B. W. Williams Shure Oil Co. Sunfish Twp., Pike Co. 13,800' FSL; 1,500' FEL
OH36	R. R. Shultz R.I.G. Drilling, Inc. Concord Twp., Champaign Co. 660' FSL; 660' FWL; SE 1/4 Sec. 22
OH37	A. & H. Bauer Bauer Bros. Polk Twp., Crawford Co. 676' FNL; 333' FEL; NE 1/4, Sec. 4

PENNSYLVANIA

Sample No.	Sample Location
P1	#2 Hammermill Plant Hammermill Paper Co. City of Erie, Erie Co., PA 8,700' S 42°10'; 12,900' W 80°00'
P2	Jay Childs #1 Ohio Oil Co. Springfield Twp., Erie Co, PA 2.23 mi S 42°00'; .95 mi W 80°30'
P3	1 Mike Miller James Drilling Co. Indian Springs Twp., Crawford Co., PA 22,800' S 41°50'; 17,400' W 80°20'
P4	#1 W. Morton D. C. Garrett Bloomfield Twp., Crawford Co., PA 29,200' S 41°55'; 15,600' W 79°50'
P5	Emma McKnight Meben Oil Co. Pymatuning Twp., Mercer Co., PA .92 mi S 41°20'; 2.01 mi E 80°30'
P6	Jessie Hockenberry Manufacturers Light & Heat Mercer Twp., Butler Co., PA 1.60 mi N 41°05'; 2.13 mi W 80°00'
P7	#1 Shaw Biery & Johnson Limestone Twp., Warren Co., PA .91 mi S 41°40'; 1.85 mi W 79°20'
P8	#1 Fee Minard Run Oil Co. Bradford Twp., McKean Co., PA 12,650' S 41°55'; 8,600' W 78°35'
P9	#1 Nellie C. Martin Peoples Natural Gas Wayne Twp., Armstrong Co., PA 11,500' S 40°55'; 3,700' W 79°20'
P10	#1 Leonard Svetz Amoco & PNG Middle Creek Twp., Somerset Co., PA 8,100' S 40°00'; 150' W 79°20'

Sample No.	Sample Location
P11	#1 T. Miller Shellsburg Kerr-McGee, et al. Napier Twp., Bedford Co., PA 22,400' S 40°10'; 9,300 W 78°35'
P12	1 Shade Mnt. Shell et al Fayette Twp., Juniata Co., PA 23,000' S 40°45'; 8,500' W 77°15'
P13	# Solomon G. L. Cabot Inc. Buffalo Twp., Union Co., PA 7,700' E 77°00'; 6,500' S 41°55'
P14	#1 Long Mobile Oil Co. Marion Twp., Centre Co., PA 2,150' S 41°00' 4,700' W 77°35'
P15	Mingoville 7 1/2' Quadrangle Centre Co., PA 1 mi E 77°45'; 3.8 mi S 41°00'
P16	Mill Hall 7 1/2' Quadrangle Clinton Co., PA 4.6 mi E 77°30'; 4.7 mi N 41°00'
P17	Linden 7 1/2' Quandrangle Lycoming Co., PA 1.5 mi E 77°15'; 5.9 mi S 41°15'
P18	Millheim 7 1/2' Quadrangle Clinton Co., PA 3.8 mi E 77°30'; 1.1 mi S 40°00'
P19	Burnham 7 1/2' Quandrangle Mifflin Co., PA 5.4 mi W 77°30'; 5.8 mi S 40°45'

APPENDIX 3

ANALYSIS OF ORDOVICIAN SHALES RICH IN ORGANIC MATTER

Sample ID	Organic Carbon	S_1 Mg/gm	S_2 Mg/gm	S_3 Mg/gm	T°C	Hydrogen Index	Oxygen Index	Production Index	Depth (ft) Surface (S)	Formation
						NEW YORK				
*NY 1a	1.25	0.48	1.14	0.49	422	91	39	0.30	3619-28	Utica Sh.
1b	0.59	0.24	1.09	0.78	548	184	132	0.18	3526-36	Utica Sh.
*NY 2a	0.72	0.52	1.10	0.48	---	152	66	0.32	5940-50	Utica Sh.
2b	0.68	0.45	1.44	0.53	441	211	77	0.24	5810-20	Utica Sh.
*NY 3a	1.11	0.35	1.26	0.46	429	113	41	0.22	2370-85	Utica Sh.
3b	0.37	0.09	0.52	0.36	443	140	97	0.15	2304-16	Utica Sh.
*NY 4a	0.58	0.22	1.07	0.55	444	184	94	0.17	1240-50	Utica Sh.
4b	0.34	0.07	0.46	0.30	454	135	88	0.13	1160-70	Utica Sh.
*NY 5a	0.46	0.14	0.45	0.37	450	97	80	0.24	1991-2005	Utica Sh.
5b	0.27	0.06	0.24	0.18	479	83	66	0.20	1926-36	Utica Sh.
*NY 6a	0.43	0.19	1.12	0.42	501	260	97	0.15	2440-50	Utica Sh.
6b	0.47	0.22	1.20	0.43	463	255	91	0.15	2350-60	Utica Sh.
*NY 7a	0.78	0.29	1.00	0.40	507	128	51	0.23	5290-5300	Utica Sh.
7b	0.73	0.69	2.25	0.59	---	308	80	0.23	5200-10	Utica Sh.
*NY 8a	0.92	0.18	0.43	0.33	507	46	35	0.30	6060-79	Utica Sh.
8b	0.38	0.09	0.39	0.39	533	102	102	0.19	5872-98	Utica Sh.
*NY 9a	0.87	0.33	0.90	0.47	---	103	54	0.27	1139-49	Utica Sh.
9b	0.38	0.13	0.46	0.38	430	121	100	0.22	1127-39	Utica Sh.
*NY 10a	0.56	0.16	0.74	0.58	491	132	103	0.18	4470-80	Utica Sh.
10b	0.59	0.21	0.77	0.46	---	130	77	0.21	4370-80	Utica Sh.
*NY 11	1.99	0.63	1.02	0.52	---	51	26	0.38	9640-60	Utica Sh.
*NY 12a	0.36	0.07	0.34	0.22	496	94	61	0.17	2470-80	Utica Sh.
12b	0.32	0.05	0.28	0.35	481	87	109	0.16	2390-2400	Utica Sh.
*NY 13a	0.60	0.30	0.88	0.60	---	146	100	0.25	2800-10	Utica Sh.
13b	0.60	0.22	0.85	0.49	460	141	81	0.21	2740-50	Utica Sh.
*NY 14	3.19	0.71	1.00	0.79	---	31	24	0.42	8881-98	Utica Sh.
*NY 15a	0.30	0.11	0.43	0.19	523	143	63	0.20	3520-40	Utica Sh.
15b	0.16	0.08	0.14	0.15	474	87	93	0.36	3460-80	Utica Sh.
*NY 16	1.46	0.48	1.33	0.71	465	91	48	0.27	7720-50	Utica Sh.
*NY 17	2.04	0.51	0.44	0.55	---	21	26	0.54	4230-75	Utica Sh.

*Basal Utica

Sample ID	Organic Carbon	S_1 Mg/gm	S_2 Mg/gm	S_3 Mg/gm	T°C	Hydrogen Index	Oxygen Index	Production Index	Depth (ft) Surface (S)	Formation
*NY 18a	0.95	0.14	0.26	0.26	428	27	27	0.35	1902-1914	Utica Sh.
18b	0.99	0.16	0.36	0.34	452	36	34	0.31	1846-61	Utica Sh.
*NY 19	1.00	0.18	0.35	0.33	419	35	33	0.35	822-35	Utica Sh.
*NY 20a	1.25	0.19	0.34	0.47	---	27	37	0.37	3900-10	Utica Sh.
20b	1.38	0.35	0.31	0.55	---	22	39	0.53	3700-13	Utica Sh.
*NY 21a	1.31	0.22	0.31	0.59	---	23	45	0.42	7660-65	Utica Sh.
21b	2.04	0.39	0.64	1.02	---	31	50	0.38	7550-60	Utica Sh.
*NY 22a	1.62	0.13	0.67	1.10	---	41	67	0.16	6880-90	Utica Sh.
22b	1.06	0.18	0.32	0.42	---	30	39	0.36	6730-40	Utica Sh.
*NY 23	1.41	0.28	0.73	0.49	---	51	34	0.28	1026-35	Utica Sh.
*NY 24	1.17	0.27	0.71	0.59	---	60	50	0.28	1721-47	Utica Sh.
*NY 25a	1.65	0.45	0.40	0.52	---	24	31	0.54	6740-50	Utica Sh.
25b	1.95	0.35	0.62	0.48	---	31	24	0.36	6500-10	Utica Sh.
*NY 26a	2.11	0.33	0.96	0.98	---	45	46	0.26	4295-4304	Utica Sh.
26b	1.34	0.24	0.25	0.42	---	18	31	0.50	4003-14	Utica Sh.
*NY 27	1.77	0.36	0.29	0.41	---	16	23	0.56	6000-18	Utica Sh.
NY 28	1.56	0.09	0.02	0.54	481	1	34	0.90	S	Utica Sh.
NY 29	0.87	0.05	0.06	0.40	---	6	45	0.50	S	Utica Sh.
NY 30	1.50	0.03	0.08	0.36	576	5	24	0.30	S	Utica Sh.
NY 31	0.40	0.01	0.06	0.29	---	15	72	0.17	S	Utica Sh.
NY 32	2.55	0.06	0.33	0.58	585	12	22	0.16	S	Utica Sh.
NY 33	1.70	0.04	0.20	0.28	576	11	16	0.17	S	Utica Sh.
NY 34	1.28	0.03	0.05	0.33	416	3	25	0.37	S	Utica Sh.
NY 35	1.67	0.05	0.21	0.45	482	12	26	0.19	S	Utica Sh.
NY 36	0.66	0.06	0.12	0.53	497	18	80	0.33	S	Utica Sh.
NY 37	1.57	0.43	0.76	0.31	456	48	19	0.36	S	Utica Sh.
NY 38	1.33	0.09	0.21	0.16	483	15	12	0.30	S	Utica Sh.
NY 39	1.53	0.05	0.21	0.44	560	13	28	0.19	S	Utica Sh.
NY 40	2.00	0.06	0.36	0.23	559	18	11	0.14	S	Utica Sh.

*Basal Utica

ANALYSIS OF ORDOVICIAN SHALES
RICH IN ORGANIC MATTER

Sample ID	Organic Carbon	S_1 Mg/gm	S_2 Mg/gm	S_3 Mg/gm	T^oC	Hydrogen Index	Oxygen Index	Production Index	Depth (ft) Surface (S)	Formation
							OHIO			
O 1	1.29	0.61	3.73	0.53	440	289	41	0.14	1438-40	Cincinnatian Series
O 2a	2.43	3.01	4.45	0.62	439	183	25	0.40	4980-5000	Utica Sh.
*O 2b	1.37	1.56	2.10	0.56	444	153	40	0.43	5150-60	Utica Sh.
*O 3	1.36	0.58	4.06	0.87	444	298	63	0.12	1040-50	Reedville Sh.
O 4a	0.32	0.18	0.75	0.55	---	234	171	0.20	6860-80	Utica Sh.
*O 4b	2.83	1.15	1.56	0.80	466	55	28	0.43	7300-20	Utica Sh.
O 5a	0.29	0.04	0.39	0.45	430	134	155	0.10	970-80	Cincinnatian Series
*O 5b	0.66	0.20	2.17	0.37	439	328	56	0.08	1090-95	Pt. Pleasant Fm.
O 6a	2.30	1.15	5.03	0.83	441	218	36	0.19	5655-70	Utica Sh.
*O 6b	1.08	0.49	2.27	0.63	440	210	58	0.18	5705-19	Utica Sh.
O 7a	0.69	0.29	0.95	0.61	433	137	88	0.23	5544-61	Utica Sh.
*O 7b	1.81	1.96	3.42	0.81	443	188	44	0.36	5741-48	Utica Sh.
O 8a	0.40	0.19	0.54	0.40	425	135	100	0.26	6880-6910	Cincinnatian Series
*O 8b	1.68	0.65	1.66	0.59	461	98	35	0.28	6970-7000	Utica Sh.
O 9a	0.54	0.12	0.71	0.54	439	131	100	0.15	5130-40	Cincinnatian Series
*O 9b	2.86	1.58	6.40	0.79	440	223	27	0.20	5410-20	Utica Sh.
*O 10	1.82	0.88	4.26	0.69	435	234	37	0.17	1840-45	Utica Sh.
O 11a	0.97	0.16	2.24	0.57	435	230	58	0.07	2804-2813	Cincinnatian Series
*O 11b	1.55	0.55	4.56	0.79	434	294	50	0.11	3141-52	Utica Sh.
*O 12	2.02	0.69	10.00	1.63	436	495	80	0.06	2940-60	Utica Sh.
*O 13	0.72	0.11	3.10	0.63	432	430	87	0.03	1260-80	Utica Sh.
*O 14	1.38	0.51	4.86	1.03	440	352	74	0.10	1700-10	Utica Sh.
*O 15	1.80	0.75	3.95	0.68	440	219	37	0.16	2412-27	Utica Sh.
*O 16	2.27	2.03	4.33	0.89	438	190	39	0.32	6300-10	Utica Sh.
*O 17	0.99	0.16	2.86	0.66	439	288	66	0.05	1220-30	Utica Sh.
*O 18	0.28	0.06	0.33	0.65	437	117	232	0.16	4280-90	Utica Sh.
*O 19	2.70	1.03	5.56	1.07	438	205	39	0.16	5670-80	Utica Sh.

Sample ID	Organic Carbon	S_1 Mg/gm	S_2 Mg/gm	S_3 Mg/gm	T^oC	Hydrogen Index	Oxygen Index	Production Index	Depth (ft) Surface (S)	Formation
*O 20	0.19	0.04	0.25	0.57	439	131	300	0.14	3470-80	Utica Sh.
*O 21	1.29	0.69	3.31	1.45	448	256	112	0.17	2980-3000	Utica Sh.
*O 22	1.37	0.54	1.55	0.73	---	113	53	0.26	4680-90	Utica Sh.
*O 23	1.86	1.04	4.58	1.87	449	246	100	0.19	3410-15	Utica Sh.
*O 24	1.58	0.44	4.77	0.89	446	301	56	0.08	3280-87	Utica Sh.
*O 25	0.93	0.37	2.85	0.68	438	306	73	0.11	1905-22	Utica Sh.
*O 26	1.03	0.34	4.54	1.27	439	440	123	0.07	1650-1710	Utica Sh.
*O 27	1.98	0.27	2.06	1.38	439	104	69	0.12	4960-5030	Utica Sh.
*O 28	0.90	0.29	2.10	0.70	438	233	77	0.12	5160-70	Utica Sh.
*O 29	0.68	0.13	2.42	0.76	433	355	111	0.05	1720-30	Utica Sh.
*O 30	2.64	1.15	10.39	2.62	443	393	99	0.10	3370-80	Utica Sh.
*O 31	0.66	0.36	2.53	0.88	432	383	133	0.12	1680-1705	Utica Sh.
*O 32	1.51	0.27	5.00	1.09	442	331	72	0.05	1230-35	Utica Sh.
*O 33	3.71	2.69	5.76	1.63	454	155	43	0.32	6500-20	Utica Sh.
*O 34	0.24	0.03	0.10	0.49	418	41	204	0.25	8500-10	Reedsville Sh.
*O 35	0.43	0.08	1.06	0.49	431	246	113	0.07	1763-73	Cincinnatian Series
*O 36	1.82	0.81	4.81	1.78	447	264	97	0.14	1340-50	Cincinnatian Series
*O 37	1.94	0.84	8.00	2.00	443	412	103	0.10	2785-2839	Cincinnatian Series

*Basal Utica

Sample ID	Organic Carbon	S_1 Mg/gm	S_2 Mg/gm	S_3 Mg/gm	T°C	Hydrogen Index	Oxygen Index	Production Index	Depth (ft) Surface (S)	Formation
PENNSYLVANIA										
*P 1a	0.97	0.46	1.77	0.45	440	182	46	0.21	4320-30	Utica Sh. (Antes)
P 1b	1.01	0.50	1.55	0.52	440	153	51	0.25	4180-90	Utica Sh. (Antes)
P 1c	0.18	0.04	0.21	0.38	447	116	211	0.17	3860-70	Reedsville Sh.
P 1d	1.04	0.43	1.49	0.37	439	143	35	0.22	4180-4350	Utica Sh. (Antes)
P 2a	0.34	0.20	1.08	0.54	426	317	158	0.16	3973-82	Reedsville Sh.
P 2b	2.02	0.79	3.79	0.68	434	187	33	0.17	4305-18	Utica Sh. (Antes)
*P 2c	2.40	1.73	5.51	0.80	436	229	33	0.24	4372-82	Utica Sh. (Antes)
P 3a	0.54	0.18	0.73	0.78	453	135	144	0.20	5126-36	Reedsville Sh.
P 3b	1.81	0.83	2.37	0.65	432	130	35	0.26	5246-56	Utica Sh. (Antes)
*P 3c	2.18	1.45	3.14	0.82	436	144	37	0.32	5551-61	Utica Sh. (Antes)
P 4a	0.19	0.03	0.30	0.30	494	157	157	0.09	5980-90	Reedsville Sh.
P 4b	2.10	0.68	1.80	0.43	449	85	20	0.27	6380-90	Utica Sh. (Antes)
*P 4c	1.53	0.41	1.47	0.66	447	96	43	0.22	6570-80	Utica Sh. (Antes)
P 5a	0.33	0.07	0.31	0.80	---	93	242	0.18	6470-80	Reedsville Sh.
P 5b	1.96	0.73	1.96	0.87	442	100	44	0.27	6680-90	Utica Sh. (Antes)
*P 5c	1.33	0.47	1.36	0.77	442	102	57	0.26	6720-30	Utica Sh. (Antes)
P 6a	0.14	0.02	0.12	0.33	---	85	235	0.14	8112-27	Reedsville Sh.
P 6b	1.30	0.08	0.44	0.44	526	33	33	0.15	8504-13	Utica Sh. (Antes)
*P 6c	2.97	0.24	0.44	0.37	524	14	12	0.35	8770-84	Utica Sh. (Antes)
P 7a	1.07	0.10	0.29	0.51	418	27	47	0.26	8057-66	Reedsville Sh.
P 7b	1.56	0.12	0.37	0.33	446	23	21	0.25	8103-08	Utica Sh. (Antes)
*P 7c	1.81	0.28	0.68	0.62	---	37	34	0.29	8272-82	Utica Sh. (Antes)
P 8a	0.35	0.08	0.57	0.41	553	162	117	0.12	8600-10	Reedsville Sh.
P 8b	0.74	0.25	1.08	0.36	602	145	48	0.19	8730-40	Utica Sh. (Antes)
*P 8c	2.78	0.61	1.37	0.55	---	49	19	0.31	9000-10	Utica Sh. (Antes)
P 9a	0.19	0.02	0.18	0.24	493	94	126	0.10	11560-70	Reedsville Sh.
P 9b	2.07	0.18	0.42	0.51	515	20	24	0.30	11800-10	Utica Sh. (Antes)
*P 9c	3.89	0.42	0.27	0.67	---	6	17	0.62	12070-80	Utica Sh. (Antes)
P 9d	2.88	0.23	0.47	0.61	---	16	21	0.33	11950-12110	Utica Sh. (Antes)
P 10a	0.26	0.03	0.25	0.38	578	96	146	0.11	14610-20	Reedsville Sh.
P 10b	0.38	0.05	0.33	0.41	563	86	107	0.13	14800-10	Utica Sh. (Antes)

*Basal Utica

Sample ID	Organic Carbon	S_1 Mg/gm	S_2 Mg/gm	S_3 Mg/gm	T°C	Hydrogen Index	Oxygen Index	Production Index	Depth (ft) Surface (S)	Formation
*P 10c	1.93	0.56	0.90	0.95	---	46	49	0.38	15400-10	Utica Sh. (Antes)
P 10d	1.61	0.16	0.42	0.51	497	26	31	0.28	15150-15470	Utica Sh. (Antes)
P 11a	0.73	0.16	1.33	0.58	----	182	79	0.11	6800-10	Reedsville Sh.
P 11b	0.71	0.09	0.83	0.55	---	116	77	0.10	7100-10	Utica Sh. (Antes)
*P 11c	2.18	0.24	1.05	0.82	---	48	37	0.19	7620-30	Utica Sh. (Antes)
P 12a	1.98	0.24	0.68	0.56	---	34	28	0.26	3230-40	Utica Sh. (Antes)
P 12b	3.48	0.41	0.93	0.63	---	26	18	0.31	3510-20	Utica Sh. (Antes)
*P 12c	2.36	0.36	1.01	0.75	---	42	31	0.26	3780-90	Utica Sh. (Antes)
P 13a	0.36	0.17	0.32	0.43	412	88	119	0.35	5103-12	Utica Sh. (Antes)
P 13b	0.80	0.16	0.33	0.28	---	41	35	0.33	5286-5301	Utica Sh. (Antes)
*P 13c	1.32	0.28	0.47	0.40	---	35	30	0.38	5408-19	Utica Sh. (Antes)
P 13d	1.59	0.50	0.53	0.43	---	33	27	0.49	5584-95	Trenton Gp.
P 14a	0.19	0.06	0.32	0.73	---	168	384	0.16	13440-50	Reedsville Sh.
P 14b	1.00	0.37	0.41	0.41	---	41	41	0.47	13980-90	Utica Sh. (Antes)
*P 14c	2.66	0.43	0.42	0.52	---	15	19	0.51	14210-20	Utica Sh. (Antes)
P 15a	2.65	0.48	3.16	0.14	452	119	5	0.13	S	Utica Sh. (Antes)
P 15b	0.17	0	0	0.06	---	0	35	0	S	Utica Sh. (Antes)
P 15c	0.13	0	0.03	0.06	---	23	46	0	S	Reedsville Sh.
P 16	2.46	0.06	0.10	0.41	595	4	16	0.37	S	Utica Sh. (Antes)
P 17	2.02	0.03	0.08	0.24	585	3	11	0.30	S	Utica Sh. (Antes)
P 18	0.26	0	0	0.04	---	0	15	0	S	Utica Sh. (Antes)
P 19	2.49	0.06	0.13	0.47	597	5	18	0.33	S	Utica Sh. (Antes)

*Basal Utica

ANALYSIS OF ORDOVICIAN SHALES
RICH IN ORGANIC MATTER

Sample ID	Organic Carbon	S_1 Mg/gm	S_2 Mg/gm	S_3 Mg/gm	T°C	Hydrogen Index	Oxygen Index	Production Index	Depth (ft) Surface (S)	Formation
						WEST VIRGINIA				
WV 1a	0.21	0.11	0.68	0.75	---	323	357	0.14	5300-50	Martinsburg Sh.
*WV 1b	0.21	0.11	0.54	0.72	427	257	342	0.17	5660-5710	Utica Sh.
WV 2a	1.62	0.45	0.57	0.83	507	35	51	0.44	8680-8710	Martinsburg Sh.
WV 2b	3.36	1.08	1.86	3.35	---	55	99	0.37	8930-60	Utica Sh.
WV 2c	2.10	0.45	0.52	0.92	419	24	43	0.47	8800-10	Utica Sh.
WV 3a	0.30	0.07	0.22	0.50	437	73	166	0.25	12680-710	Utica Sh.
*WV 3b	3.85	0.99	1.06	1.74	---	27	45	0.49	13040-60	Utica Sh.
WV 4a	0.17	0.14	0.45	0.45	465	264	264	0.24	12140-360	Utica Sh.
*WV 4b	1.54	0.26	0.43	0.50	---	27	32	0.38	12780-870	Utica Sh.
*WV 5a	0.35	0.03	0.09	0.25	---	25	71	0.25	11750-70	Martinsburg Sh.
WV 5b	0.23	0.05	0.14	0.47	---	60	204	0.28	10930-80	Martinsburg Sh.
WV 6a	0.25	0.07	0.11	0.34	---	44	136	0.39	8310-30	Utica Sh.
*WV 6b	0.25	0.05	0.05	0.34	---	20	136	0.50	8460-70	Utica Sh.
*WV 7a	2.25	0.32	0.41	0.57	---	18	25	0.44	13970-90	Utica Sh.
WV 7b	0.26	0.02	0.05	0.42	---	19	161	0.33	13500-30	Utica Sh.
WV 8a	0.22	0.10	0.18	0.38	437	81	172	0.36	8505-25	Martingsburg Sh.
*WV 8b	0.40	0.13	0.27	0.37	---	67	92	0.32	8845-65	Utica Sh.
WV 8c	0.44	0.14	0.19	0.44	---	43	100	0.44	8785-8815	Utica Sh.

*Basal Utica