Evidence for Cambrian Petroleum Source Rocks in the Rome Trough of West Virginia and Kentucky, Appalachian Basin

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Open-File Report 05-1443

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Introduction

The Utica-Lower Paleozoic total petroleum system in the Appalachian basin as defined by Milici and others (2003a,b) is moderately well documented by geochemical evidence (Drozd and Cole, 1994; Ryder and others, 1998). The Middle Ordovician Utica Shale is the source rock in the petroleum system and very likely accounts for oil and gas trapped in such reservoirs as the Cambrian Knox Dolomite, Cambrian Rose Run Sandstone, Lower Ordovician Beekmantown Dolomite, and Middle Ordovician Black River/Trenton Limestones (fig. 1). Probable, but less certain, oil and gas accumulations associated with the Utica Shale source rock are those trapped in the Upper Ordovician Bald Eagle Sandstone/Queenston Shale, Lower Silurian "Clinton/Medina/Tuscarora sandstones, and Upper Silurian Lockport Dolomite (fig. 1).

Hypothetical migration pathways for Utica-derived petroleum were suggested by Ryder and others (1998) along a regional geologic cross section through eastern Ohio and western West Virginia (fig. 2). In addition, this cross section of Ryder and others (1998) showed natural gas occurrences in Cambrian strata of the deep Rome trough of West Virginia (Exxon No.1 McCoy and Exxon No.1 Gainer-Lee wells) that cannot be explained by derivation from a Utica source rock (fig. 2). Rome trough petroleum occurrences in West Virginia and Kentucky include: 1) the Exxon No. 1 McCoy well, Jackson County, West Virginia, where gas from the Cambrian Maryville Limestone of the Conasauga Group initially produced natural gas at 6 to 9 million cu ft per day (Harris and Drahavzal, 1996); 2) the Exxon No. 1 Gainer-Lee well, Calhoun County, West Virginia, where 13.4 barrels of gas-cut mud were produced during a drill stem test from the Maryville Limestone; 3) the Inland No. 529 White well, Boyd County, Kentucky, where 10,000 barrels of oil and associated gas were produced from the Cambrian Tomstown (Maryville Limestone) (Weaver and McGuire, 1977); 4) the Homer field, Elliott County, Kentucky, where gas and oil is produced from the Cambrian Rome Formation and Conasauga Group (Lynch and others, 1999; Harris and others, 2004); and 5) the Miller No. 1 Bailey well, Wolfe County, Kentucky, where good gas and condensate shows occurred in the Cambrian Rome Formation (fig. 3). Although Cambrian source rocks were suspected for these Rome trough gas and oil occurrences, most rock samples analyzed from the Lower Ordovician-Cambrian interval in the trough had a total organic carbon content in weight percent (TOC) that was too low for an effective source rock (Ryder and others, 1998).

New geochemical evidence presented by Ryder and others (2003) indicated that Cambrian source rocks are present in the Rome trough and they correlate favorably with oils in nearby Cambrian reservoirs. This evidence confirms a new petroleum system in the Rome trough of Kentucky and West Virginia that involves a source rock in the Cambrian Conasauga Group and reservoirs in the Cambrian Rome Formation and Conasauga Group (Milici and others, 2003a,b). This report provides the supporting documentation for the Ryder and others (2003) presentation.

Conasauga-Rome/Conasauga Petroleum System

Source Rock Characteristics of Cambrian Rocks: Several deep wells drilled into the Rome trough by Exxon Corporation in the 1970s were cored in the Cambrian Conasauga Group and Rome Formation (fig. 4). Of these cores, selected ones were sampled, analyzed, and total organic carbon and RockEval analyses were reported by Ryder and others (1998). For example, Ryder and others (1998) reported that core samples collected from the Rome Formation and the Maryville Limestone of the Conasauga Group in the Exxon No. 1 McCoy well (figs. 4, 5; table 1) yielded TOC values ranging from 0.09 to 0.11% in the Rome Formation and 0.19 to 0.59% in the Maryville Limestone (figs. 6, 7; table 1). A higher TOC value of 0.84% was reported from cuttings in the Rome Formation in the No. 1 McCoy well (fig. 7; table 1; Richard W. Beardsley, written communication March 1993). Additional samples were collected by Ryder and others (1998) from a core in the Columbia Gas No. 9674T Mineral Tract well, Mingo County, West Virginia (figs. 4, 8, 9) where TOC contents in the Rome Formation ranged from 0.15 to 0.58% (figs. 9; table 1). Although these analyses (Ryder and others,1998) indicated that organic carbon is present in the Cambrian section of the Rome trough, the TOC values are generally very low and are considered to be below the lower limit for an effective petroleum source rock (Peters and Moldowan, 1993).

In early 2001, additional cores from the deep Exxon drill holes were shipped to Lexington, Kentucky, for sampling and analysis. Among these cores were the Exxon No. 1 Smith drill hole, Wayne County, West Virginia (figs. 4, 10): (core 1) lower part of the Rome Formation, (core 2) upper part of the Rome Formation, (core 3) Rogersville Shale of the Conasauga Group, and (core 4) Maryville Limestone of the Conasauga Group (fig. 11). New TOC analyses for the Rome Formation in the two deepest cores (1 and 2) yielded low values ranging from 0.13 to 0.22% (figs. 12, 13; table 1) that are consistent with analyses reported by Ryder and others (1998). Much higher TOC values, ranging from 1.20 to 4.40%, were obtained from four samples of the Rogersville Shale (figs. 14, 15; table 1). These high TOC values indicate a good to very good potential source rock that, based on the density log, may be about 123 ft thick (fig. 14). To test for contamination by migrated liquid petroleum, the shale sample with the highest TOC value was extracted and then reanalyzed. The resultant post-extraction TOC value of 3.16% compared with the original value of 4.40% suggests that the high TOC values are credible and that the extractable bitumen was probably locally derived from the shale (fig. 14; table 1). Photographs and descriptions of the core indicate that the Rogersville Shale at this locality is a slightly fossiliferous, dark gray shale of marine origin which commonly contains thin laminae of siltstone/very fine grained sandstone and burrows filled with siltstone/very fine grained sandstone (figs. 15, 16).

S_1 yields (0.81 to 2.71 mgHC/g orgC), T_{max} values (460-469 ^{o}C; 414 ^{o}C value is probably anomalous), S_2 yields (0.75-2.58 mgHC/g orgC), and PI values (0.51-0.58) in the Rogersville samples (table 1) suggest that they have reached the late stage of thermal maturity for oil and the early stage for gas (Peters and Moldowan, 1993).

The relatively high percentage (≈25%) of extractable bitumen in the Rogersville Shale (11,161.5 ft; table 1) is unusual for rocks of this thermal maturity and could be the result of solid bitumen (with an extractable component) introduced into the sandstone/siltstone laminae and burrows from a different source rock. Moreover, the lithologic character of the Rogersville Shale in the core is inconsistent with known source rocks. Commonly, gray shale with sandstone/siltstone laminae and burrows have a TOC content of <0.5%. Despite these bothersome possibilities, we propose that the Rogersville Shale in the No. 1 Smith well is a credible source rock that was capable of generating petroleum in the Rome trough. The generation and introduction of solid bitumen from another source rock is discounted here because there is no visual evidence for it in the core, such as black, opaque coatings along laminae, pores, and burrows. We suggest that the high percentage of extractable bitumen in the Rogersville is a remnant of the original petroleum generated *in situ* from the source rock. Although the lithologic character of the Rogersville is atypical for an excellent source rock, it may represent a variety of poorly documented source rocks that are intermediate in organic richness.

Oil-Source Rock Correlations: A gas chromatogram (GC) of the bitumen extract (core depth=11,161.5 ft) is characterized by a full spectrum of *n*-alkanes from n-C_{11} through n-C_{30} but with a reduced n-C_{20+} fraction, strong odd predominance of *n*-alkanes in the n-C_{13} through n-C_{19} range, and very small amounts of pristane (pr) and phytane (ph) (fig. 17). These three characteristics are diagnostic of organic matter predominantly composed of the alga *Gloeocapsomorpha prisca* whose age is commonly associated with Ordovician source rocks (Longman and Palmer, 1987; Jacobson and others, 1988). The character of this gas chromatogram presents compelling evidence that *G. prisca* or a *G. prisca* precursor was living at least as early as Middle Cambrian time, approximately 50 million years before the Ordovician organism. To our knowledge, the only other reported occurrence of *G. prisca* from Cambrian rocks is from a Middle Cambrian alginite in the Canadian Northwest Territories (Wielens and others, 1990).

We compared the geochemistry of the bitumen extract from the Rogersville Shale in the No. 1 Smith drill hole, Wayne County, West Virginia (figs. 4, 10), with the geochemistry of oil produced from a Cambrian carbonate reservoir in the Inland No. 529 White well, Boyd County, Kentucky (fig. 3). Drilled in the mid-1960s, this well yielded the first commercial oil production from Cambrian rocks in the Rome trough (Weaver and McGuire, 1977). The No. 529 White well is located about 12 mi northwest and updip of the No. 1 Smith drill hole (figs. 3, 4). Gas chromatograms for the Rogersville Shale bitumen extract in the No. 1 Smith well and the Cambrian-reservoir oil in the No. 529 White well have very similar characteristics and thus provide strong evidence for an oil-source rock correlation (fig. 18). This evidence implies that the Cambrian-reservoired oil in Boyd County, Kentucky, was derived from a source rock similar in composition to the Cambrian Rogersville Shale in Wayne County, West Virginia. Additional compelling evidence for a Cambrian source rock-Cambrian oil linkage is provided by the mud log for the No. 1 Smith well that shows excellent hydrocarbon shows above and below the Rogersville Shale core (fig. 19). Based on the mud log we suggest that petroleum was generated from the Rogersville Shale source rock and migrated vertically into the 100-ft-thick overlying sandstone unit in the Rogersville. The cross section shown in figure 20 illustrates our interpretation that oil was generated in the Rogersville Shale in the vicinity of the No. 1 Smith drill hole, migrated 10- to 15-miles updip along a sandstone carrier bed in the Rogersville, and was trapped in a structural feature that involved the Maryville Limestone near the No. 529 White well.

G. prisca geochemical characteristics were noted in other oils from the Cambrian Rome Formation in eastern Kentucky: 1) the Homer field, Elliott County, Kentucky, discovered by Carson Associates (fig. 3); 2) the Blue Ridge No. 1 Jewell Greene well, Elliott County, Kentucky, (Moldowan and Jacobson, 2000); and 3) the Miller No. 1 Bailey well, Wolfe County, Kentucky (fig. 3). The Homer field oil (fig. 21) correlates most closely with the Rogersville Shale extract (Wayne County, West Virginia) (figs. 17, 18) and Marysville Limestone oil (Boyd County, Kentucky) (fig. 18) because of its higher API gravity. Although condensate from the No. 1 Greene and No. 1 Bailey wells show a C_{20+} *n*-alkane distribution that is more attenuated than the oil from the Homer field the characteristic odd-predominance of *n*-alkanes in the n-C_{13} through n-C_{19} range is still present (fig. 21). Very likely, all the oils/condensates shown in figure 21 were generated from organic matter in the Rogersville Shale or from other compositionally similar shales in the Conasauga Group or Rome Formation. There is no evidence that Ordovician source rocks in eastern Kentucky and adjoining western West Virginia could have generated these oils.

At the western end of the Rome trough, a thin, dark gray to black shale was sampled for this investigation from the Cambrian Rome Formation in the Texaco No. 1 Kirby well, Garrard County, Kentucky (fig. 4). This well yielded shows of oil and low-Btu gas from sandstone units in the Rome Formation (Harris and Baranoski, 1996). TOC values of the shale ranged from 0.70 to 3.26% (fig. 22). A core photograph shows that the shale is less than an inch thick and associated with burrowed sandstone and conglomeratic sandstone (fig. 23). The moderate RockEval S1 yield for the Rome Formation shale samples, ranging from 0.30 to 0.55 mg HC/g sample (table 1), was sufficiently high for a bitumen extraction. The gas chromatographic signature that characterizes this bitumen extract (core depth=4,628.8 ft) is very similar to the one obtained from the Rogersville Shale (fig. 24) and, thus, further corroborates the presence of the alga *G. prisca* or a predecessor in Cambrian rocks of the Rome trough. Based on sparse hydrogen index (HI) and oxygen index (OI) data from RockEval analyses (fig. 25), the kerogen in the Rome shales probably can be characterized as Type I organic matter. However, because of its relatively high thermal maturity, kerogen in the Rogersville Shale plots near the origin of the HI vs OI plot where the type of original organic matter is indeterminant (fig. 25). Judging from its marine origin, the kerogen in the Rogersville Shale most likely consists of Type II organic matter. Although this thin shale in the No. 1 Kirby well has a moderately high organic carbon content, it probably is only a local source rock. However, its presence does indicate that organic material accumulated in the Rome Formation and suggests the possibility that thicker accumulations of organic matter may exist in the Rome Formation elsewhere in the Rome trough.

Results and Discussion: Based on these new TOC/RockEval analyses and initial oil-source rock correlation we are able to identify a new petroleum system in the Appalachian basin. Organic-matter-rich shale units in the Middle and Upper Cambrian Conasauga Group are the source rocks in the petroleum system and very likely account for known oil and gas accumulations trapped in sandstone reservoirs in the Cambrian Rome Formation and Conasauga Group (fig. 26). Source rocks in the Rome Formation are considered to be local. In eastern and central Kentucky and western West Virginia, oil and gas in the Cambrian and Ordovician Knox Dolomite, Ordovician St. Peter Sandstone, and Ordovician Trenton Limestone also may belong to this petroleum system having migrated vertically, along fractures from Conasauga Group source rocks (fig. 26). This petroleum system possibly extends into central and northern West Virginia and perhaps Pennsylvania where there are potential gas-bearing reservoirs in the Conasauga Group and equivalent units (fig. 26). Younger potential gas-bearing reservoir units in central and northern West Virginia and Pennsylvania, such as the Knox Dolomite, Copper Ridge Dolomite/sandstone member, Beekmantown Dolomite/Group, and Trenton Limestone, are assigned to the Utica-lower Paleozoic petroleum system (fig. 1). Although unlikely, the possibility exists that some deep gas in the Utica-lower Paleozoic petroleum system may be mixed with gas that has leaked upsection from the Conasauga-Conasauga/Rome petroleum system.

Preliminary burial and temperature history models for the Exxon No. 1 Smith (figs. 4, 10) and the Exxon No. 1 Gainer-Lee (fig. 5) wells suggest that oil generated from

Cambrian rocks in the central and southern West Virginia parts of the Rome trough was actively migrating no later than Late Silurian to Early Devonian time (figs. 27, 28). These models further suggest that gas generated from Cambrian rocks in central West Virginia was actively migrating by the Late Devonian (fig. 28) and that gas generated from Cambrian rocks in southern West Virginia was actively migrating in the Early Permian (fig. 27). The predicted Late Devonian timing of gas generation/active migration in central West Virginia resulted from the abrupt thickening of Upper Devonian overburden formed during Catskill delta sedimentation (fig. 28), whereas the predicted Early Permian timing in southern West Virginia resulted from an incremental burial history with fewer periods of abrupt overburden thickening (fig. 27). Probably the timing of oil/gas generation and migration in the Rome trough of Kentucky is very similar to the timing in southern West Virginia.

An events chart for the Conasauga-Conasauga/Rome petroleum system indicates that all the key elements appear to be present such as source rock, reservoir, seal, traps, and favorable timing of petroleum generation and trap formation (fig. 29).

Although the Rome trough has known petroleum source rocks and known oil/gas accumulations much uncertainty remains. Unanswered questions include:

1. What is the thickness and extent of the Cambrian source rocks? Are they widespread throughout the Rome trough or only locally distributed?

2. What is the nature of the available traps during optimum petroleum migration? Are structural traps the most important or are stratigraphic traps also important?

3. What kinds of reservoirs exist in the deep Rome trough? Are there sandstones with intergranular porosity?; carbonates with intercrystalline and (or) vuggy porosity?; and do open fractures exist in these potential reservoirs?

4. What is the extent and integrity of the seals? Are they leaky or tight? They must hold petroleum for about three hundred million years, possibly under geopressures that are greater than hydrostatic.

5. What additional geochemical studies are needed to further the tentative oil-source rocks shown here?

Conclusions

A 123-ft-thick Cambrian marine dark gray shale from a core between 11,150-11,195 ft in the Exxon No. 1 Smith well in Wayne County, West Virginia, has good source rock potential that, combined with favorable oil-source rock correlations, demonstrates a new petroleum system in the Rome trough. This dark gray shale occurs in the Middle Cambrian Rogersville Shale of the Conasauga Group. Total organic carbon (TOC) contents of 4 samples that range from 1.2 to 4.4%, average 2.6%, are the highest reported to date in the pre-Knox section of the Rome trough. Thermally the samples are in the zone of late oil/early gas generation based on T_{max} values of about 465 ^{o}C. S_1 values of 0.81 to 2.71 indicate that they contain free extractable hydrocarbons. The gas chromatogram of a whole bitumen extract is characterized by *n*-alkanes from C_{11} through C_{30}, strong odd-carbon predominance in the C_{15} to C_{19} range, and small amounts of pristane and phytane. The strong odd-predominance is diagnostic of organic matter composed of the alga *G. prisca* whose age is usually restricted to the Ordovician. These *G. prisca* characteristics have not been previously identified in Cambrian-age source rocks in the Appalachian basin. Thin black shale in the Lower to Middle Cambrian Rome Formation in the Texaco No. 1 Kirby well in Garrard County, Kentucky, which have TOC contents as high as 3.2%, HI as high as 417, and extract GC signatures similar to the Rogersville Shale, may be a secondary source rock interval in the petroleum system. The GC signatures of the bitumen extract from the Rogersville Shale correlate closely with oils from Cambrian reservoirs in eastern Kentucky. These oils are from the Homer field in Elliott County, Kentucky; Inland No. 529 White well in Boyd County, Kentucky; and Miller No. 1 Bailey well in Wolfe County, Kentucky. The new petroleum system, named the Conasauga-Conasauga/Rome probably extends along the Rome trough from eastern Kentucky to at least central West Virginia.

Acknowledgements

We thank Richard W. Beardsley, Triana Energy (formerly with Columbia Natural Resources), Charleston, West Virginia, who has been very supportive of the U.S. Geological Survey's petroleum source investigations in the Appalachian basin. Mud logs for the Exxon No.1 Smith and Exxon No. 1 McCormick wells were donated to the U.S. Geological Survey by Exxon Corporation U.S.A..

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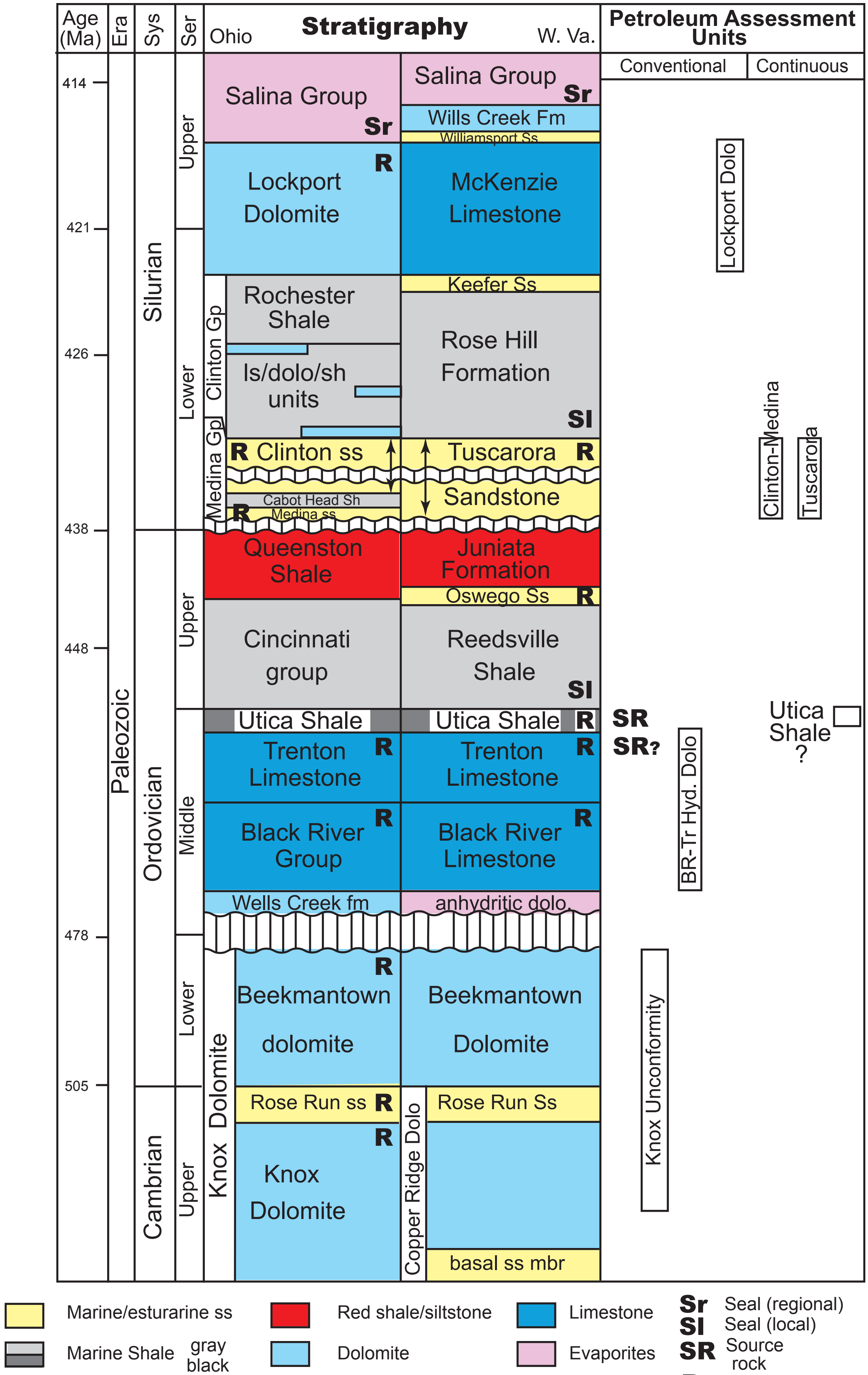
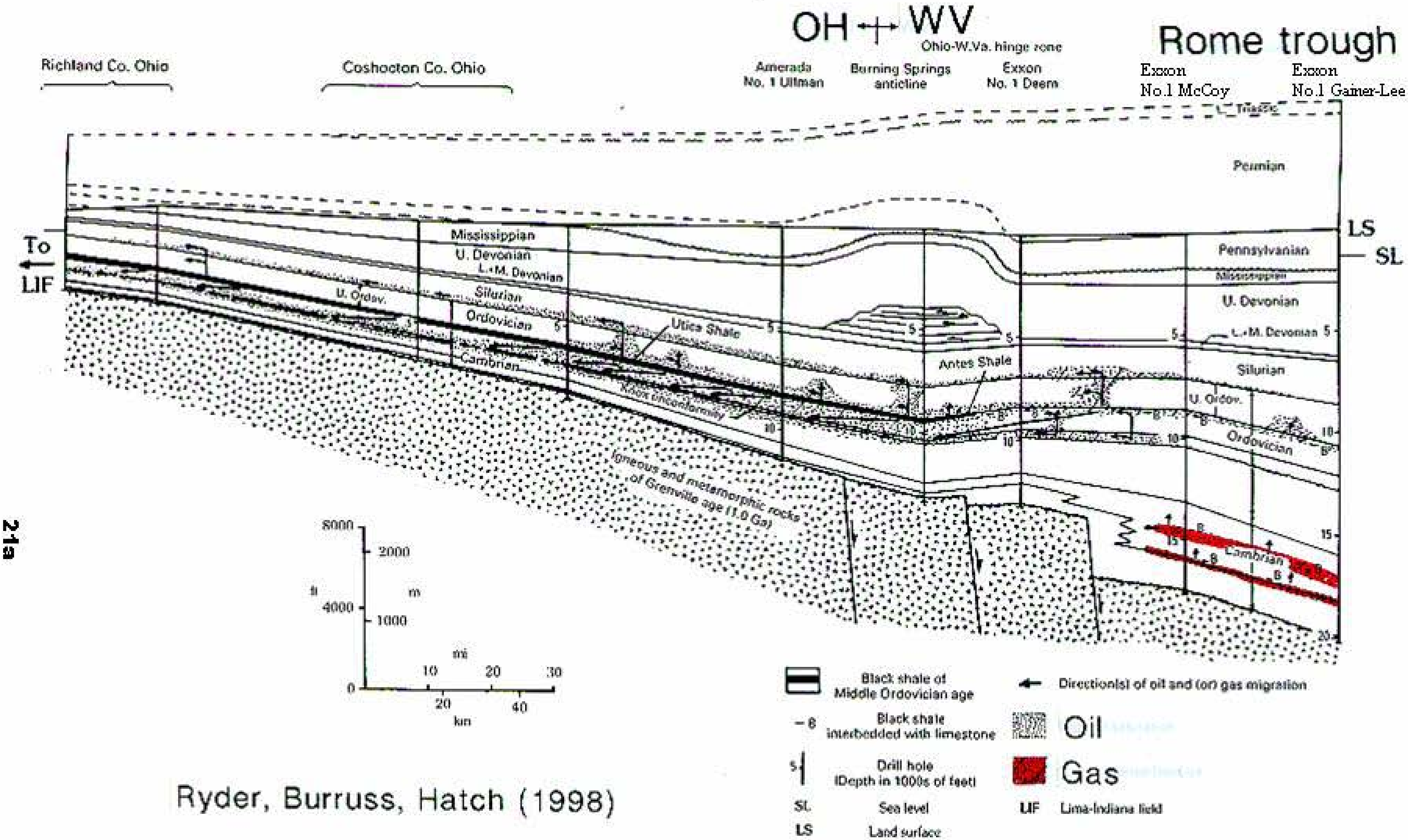
Figure 1. Correlation chart showing the stratigraphic units of the Utica-Lower Paleozoic Petroleum System and reservoirs, seal, and source rock. Abbreviations: dolo, dolomite; ls, limestone; Sh(sh); shale; Ss(ss), sandstone; Fm(fm), formation; Gp, Group; Mbr(mbr), member; BR, Black River; Tr, Trenton; Hyd., Hydrothermal.



Utica-Lower Paleozoic Total Petroleum System

Figure 2. Generalized geologic cross section from central Ohio to central West Virginia showing proposed migration routes of oil and gas generated from the Ordovician Utica Shale and Cambrian Conasauga Group. The cross section is from Ryder, Burruss, and Hatch (1998). See figure 4 for line of section.



Ryder, Burruss, Hatch (1998)

Figure 3. Map of the Conasauga-Rome/ Conasauga Petroleum System showing the location of selected wells in the Rome trough with oil and gas production and shows.

Selected Gas and Oil Shows in the Rome Trough

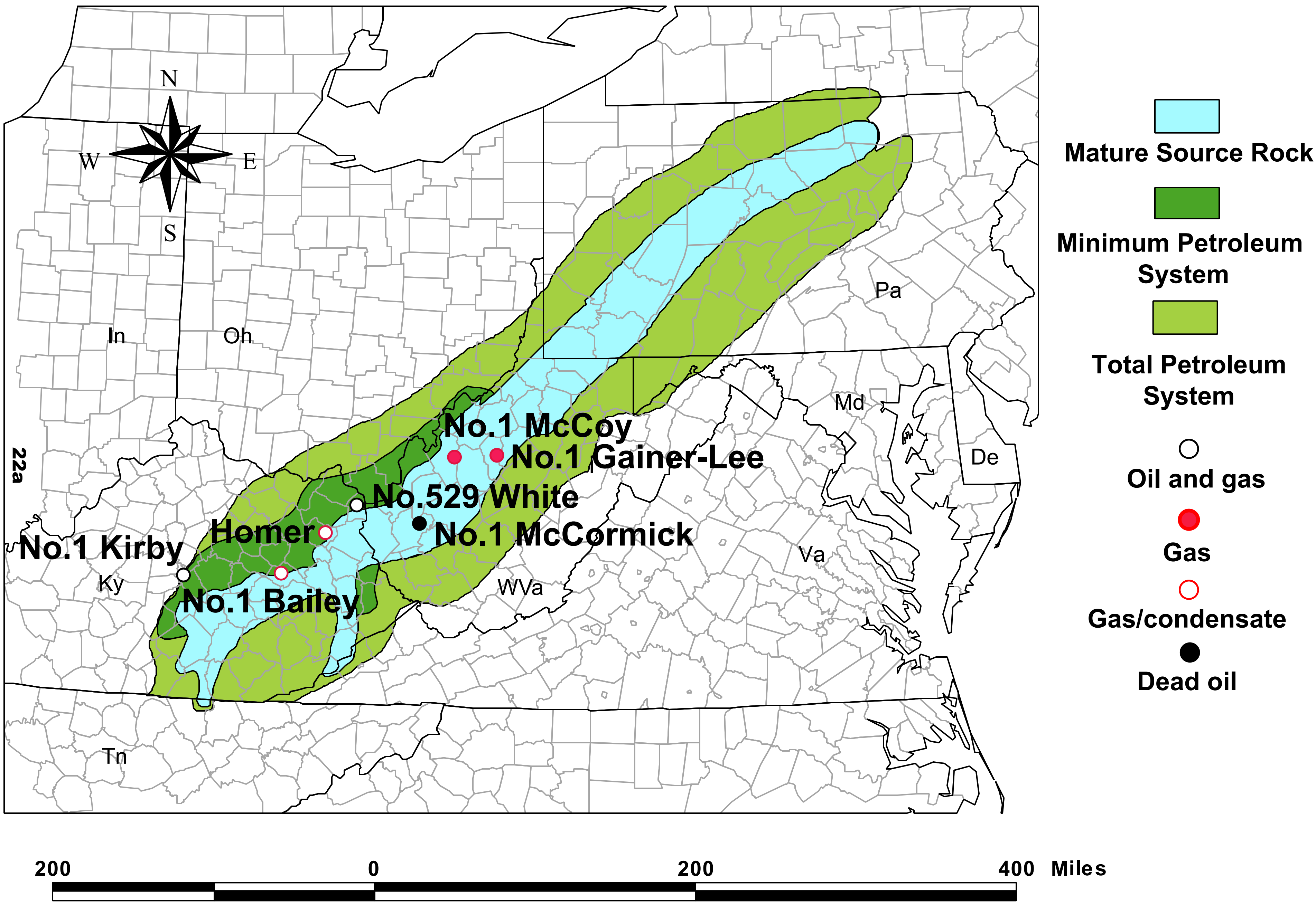


Figure 4. Map of the Conasauga-Rome/Conasauga Petroleum System showing the location of regional cross sections E-E' and G-G' and wells in the Rome trough sampled for source rocks. Also, this map shows the location of the cross sections shown in figures 2 and 20.

Selected Wells Sampled for Source Rocks in the Rome Trough

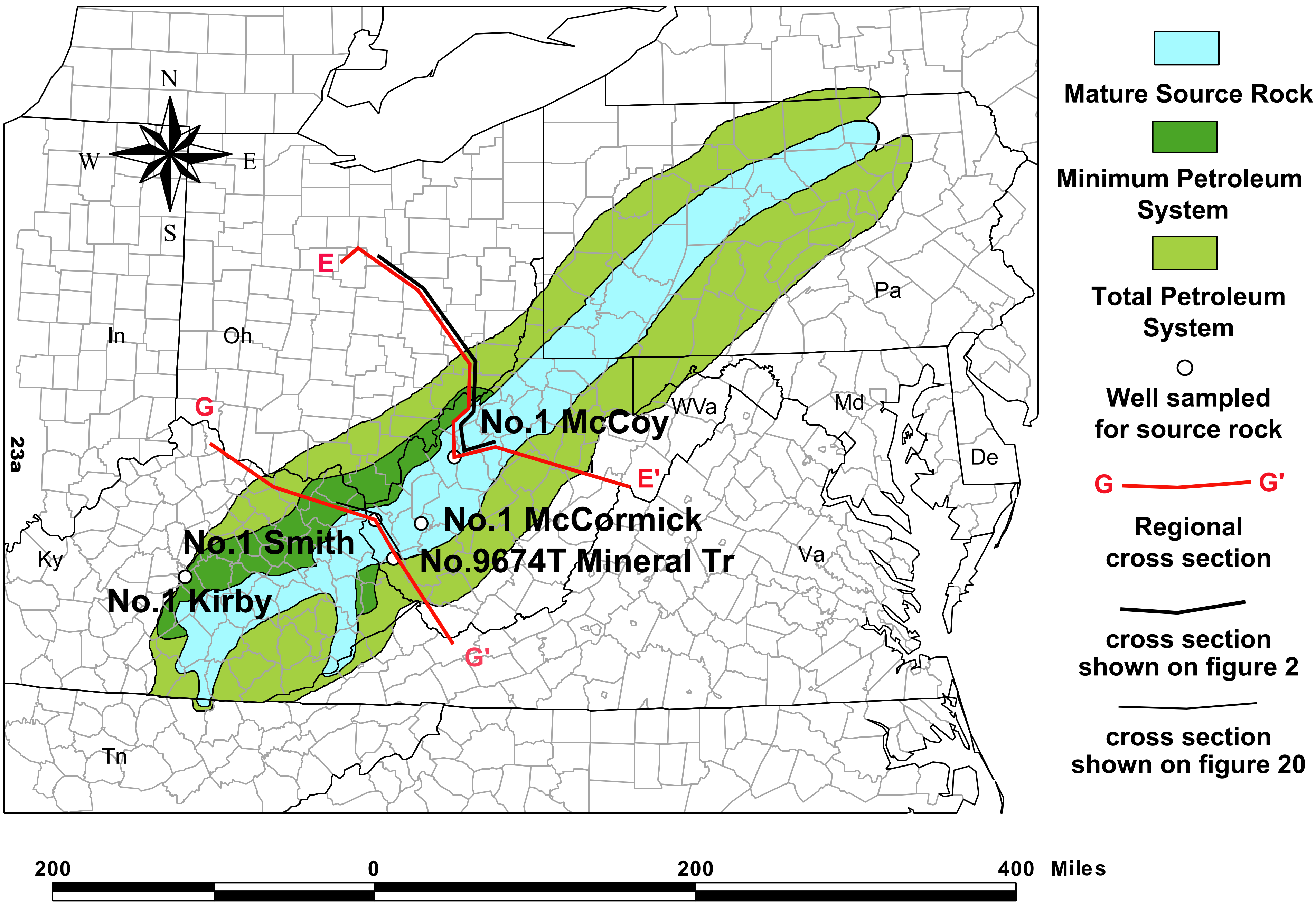


Figure 5. Appalachian basin cross section E-E' through Cambrian and Ordovician strata, Ohio and West Virginia, showing the Exxon No. 1 McCoy and No. 1 Gainer-Lee wells and source rock sample locations. The cross section is from Ryder (1992).

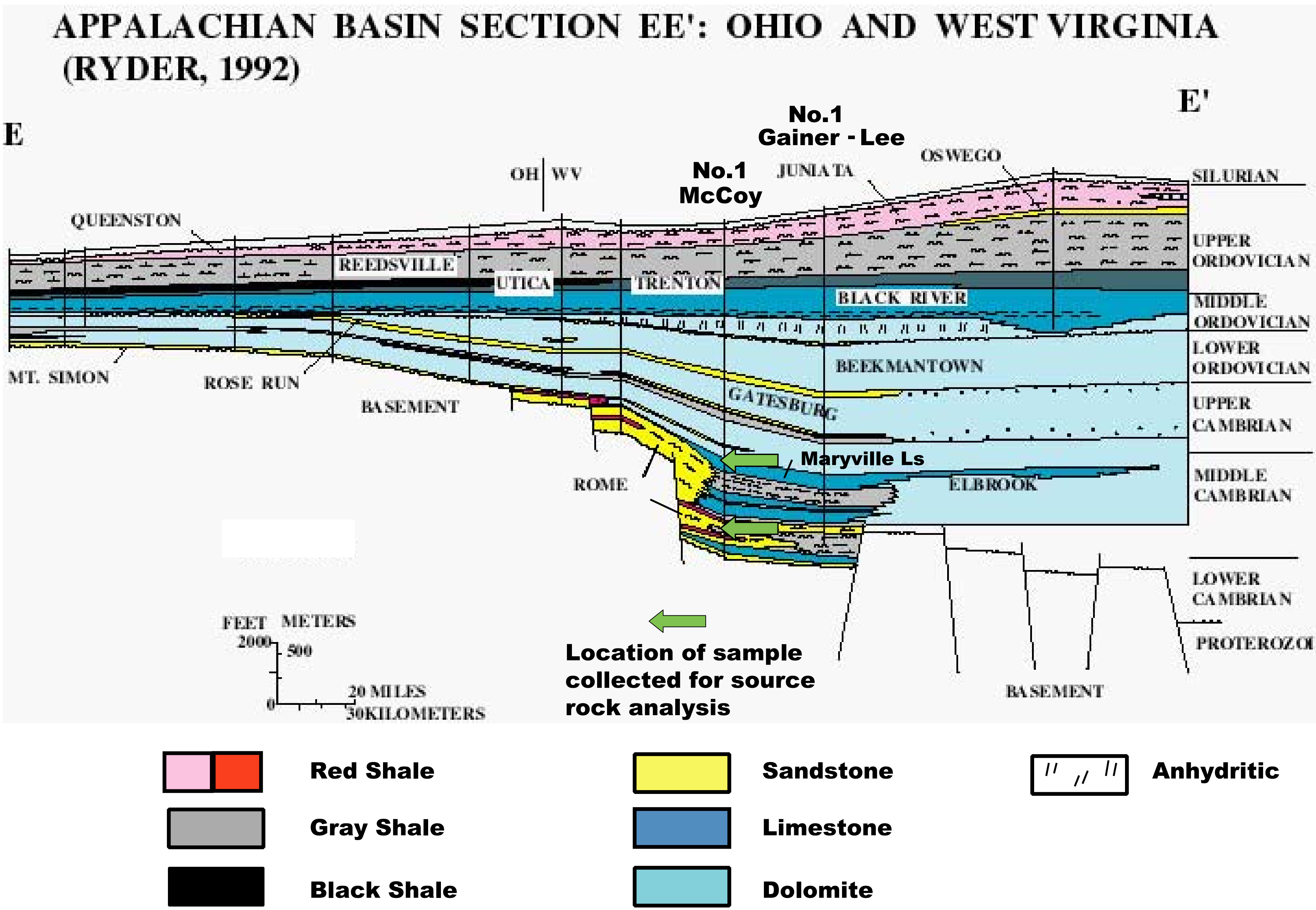
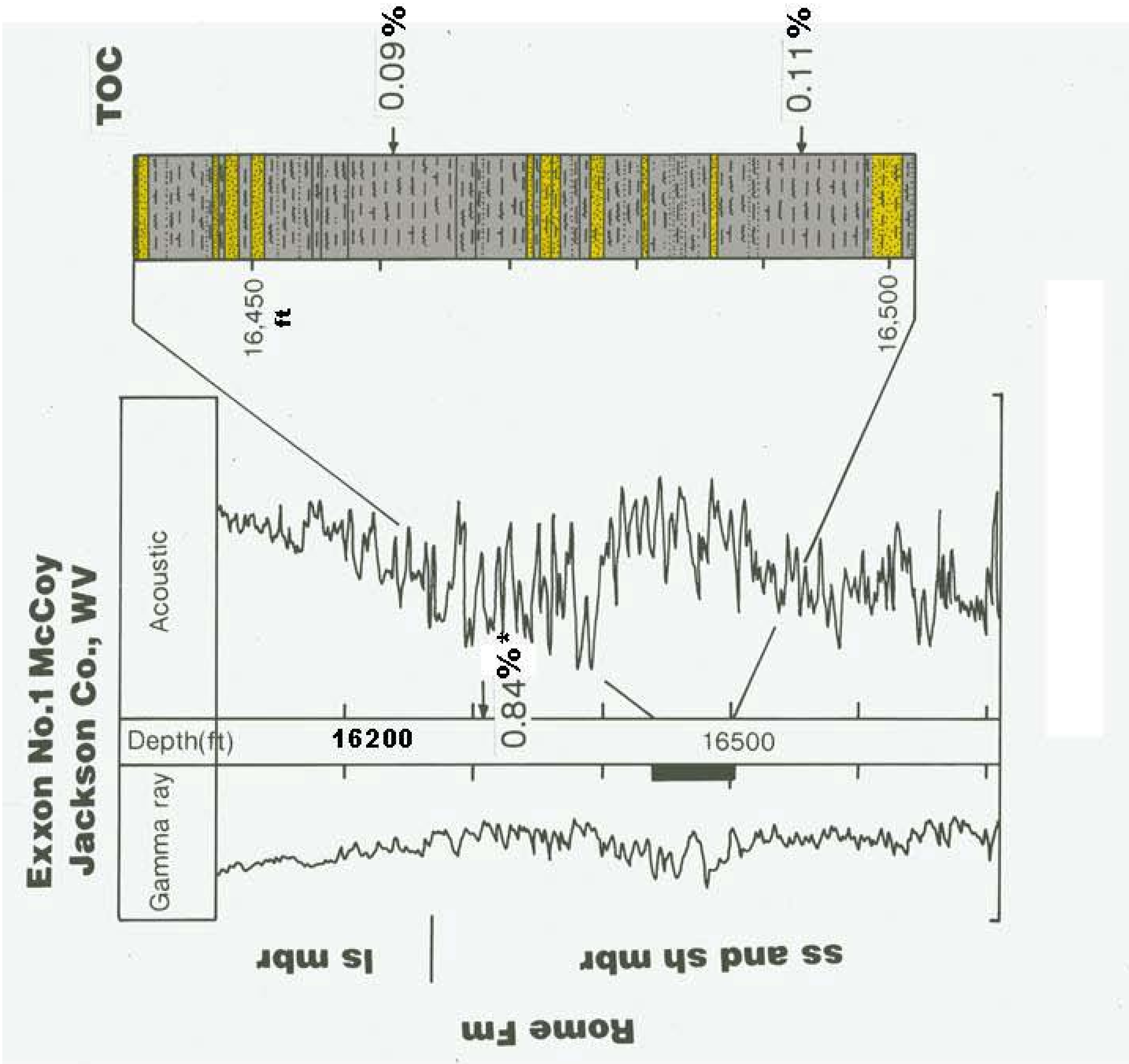

APPALACHIAN BASIN SECTION EE': OHIO AND WEST VIRGINIA
(RYDER, 1992)
E
E'
No.1
Gainer - Lee
No.1
McCoy
OH
WV
QUEENSTON
JUNIATA
OSWEGO
REEDSVILLE
UTICA
TRENTON
BLACK RIVER
BEEKMANTOWN
GATESBURG
Maryville Ls
ELBROOK
ROME
MT. SIMON
ROSE RUN
BASEMENT
SILURIAN
UPPER ORDOVICIAN
MIDDLE ORDOVICIAN
LOWER ORDOVICIAN
UPPER CAMBRIAN
MIDDLE CAMBRIAN
LOWER CAMBRIAN
PROTEROZOIC
FEET METERS
2000
500
0
20 MILES
30KILOMETERS
Location of sample collected for source rock analysis
Red Shale
Gray Shale
Black Shale
Sandstone
Limestone
Dolomite
Anhydritic

Figure 6. Results of total organic carbon (weight %) (TOC) analyses for three samples from the Cambrian Rome Formation, Exxon No. 1 McCoy well, Jackson County, West Virginia. The core location is indicated by the solid black bar. See figures 3 and 4 for the location of the well. * data from Richard W. Beardsley (written communication, March 1993). See Ryder (1992) for a brief discussion of the sandstone and shale member and limestone member of the Rome Formation. Abbreviations: Fm, formation; ls, limestone; mbr, member; sh, shale; ss, sandstone.



Exxon No.1 McCoy
Jackson Co., WV
Rome Fm
ls mbr
ss and sh mbr
Gamma ray
Depth(ft)
16200
16500
Acoustic
0.84%*
16,450
ft
16,500
TOC
0.09%
0.11%

Figure 7. Results of total organic carbon (weight %) (TOC) analyses for four samples from the Cambrian Maryville Limestone of the Conasauga Group, Exxon No. 1 McCoy well, Jackson County, West Virginia. The core location is indicated by the solid black bar. See figures 3 and 4 for the location of the well. See Ryder (1992) for a brief discussion of the Maryville Limestone of the Conasauga Group. Abbreviations: Gp, group; Ls, limestone.

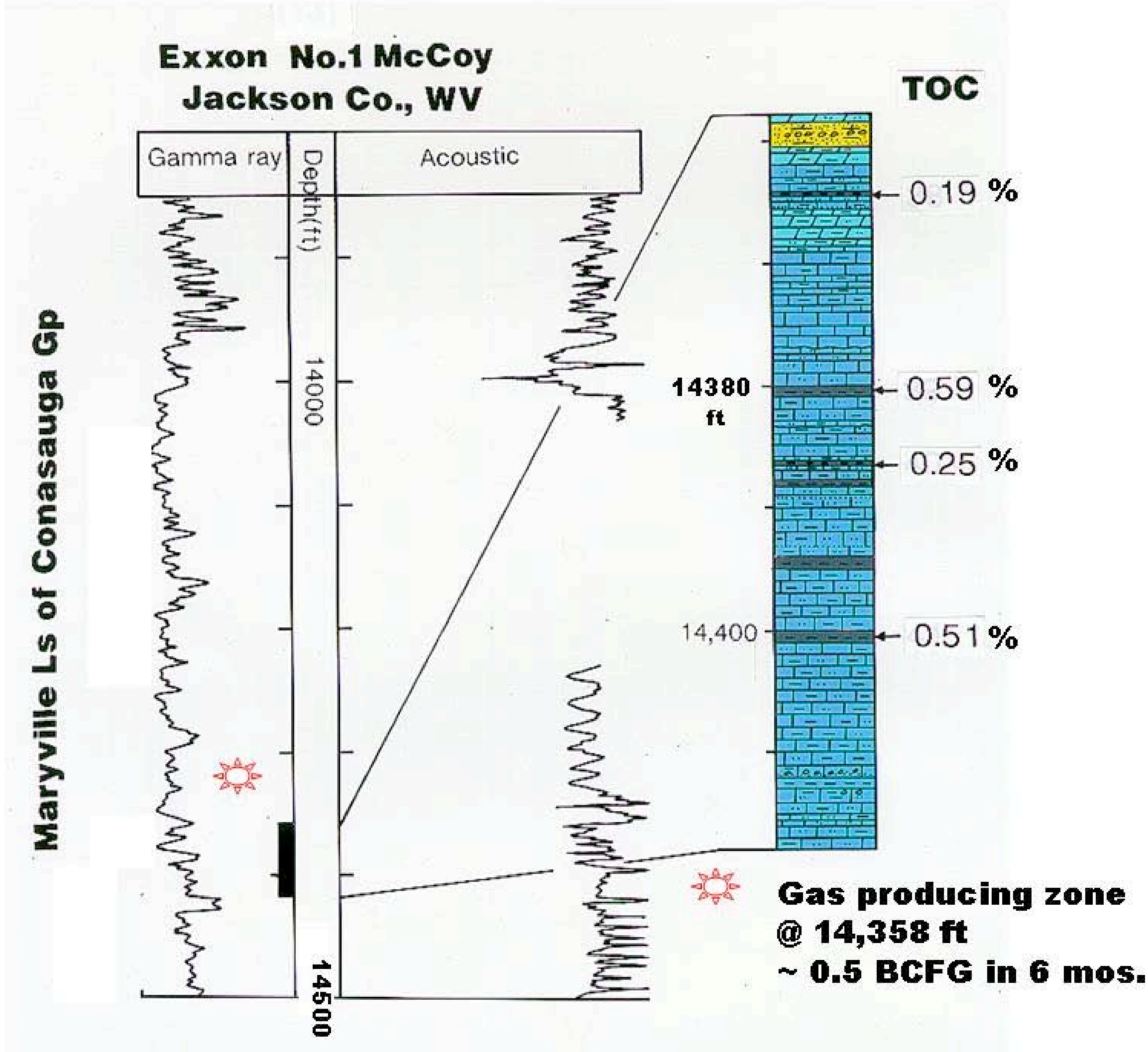

Exxon No.1 McCoy
Jackson Co., WV
Gamma ray
Depth(ft)
Acoustic
14000
14500
TOC
0.19 %
0.59 %
0.25 %
0.51 %
14380 ft
14,400
Gas producing zone
@ 14,358 ft
~ 0.5 BCFG in 6 mos.
Maryville Ls of Conasauga Gp

Figure 8. Appalachian basin cross section G-G' through Cambrian and Ordovician strata, Kentucky, West Virginia, and Virginia, showing the Columbia Gas No. 9674T Mineral Tract well and source rock sample location. The cross section is from Ryder, Repetski, and Harris (1997). See figure 5 for an explanation of the major lithologic units.

APPALACHIAN BASIN SECTION G - G': KENTUCKY, WEST VIRGINIA AND VIRGINIA (RYDER AND OTHERS 1997)

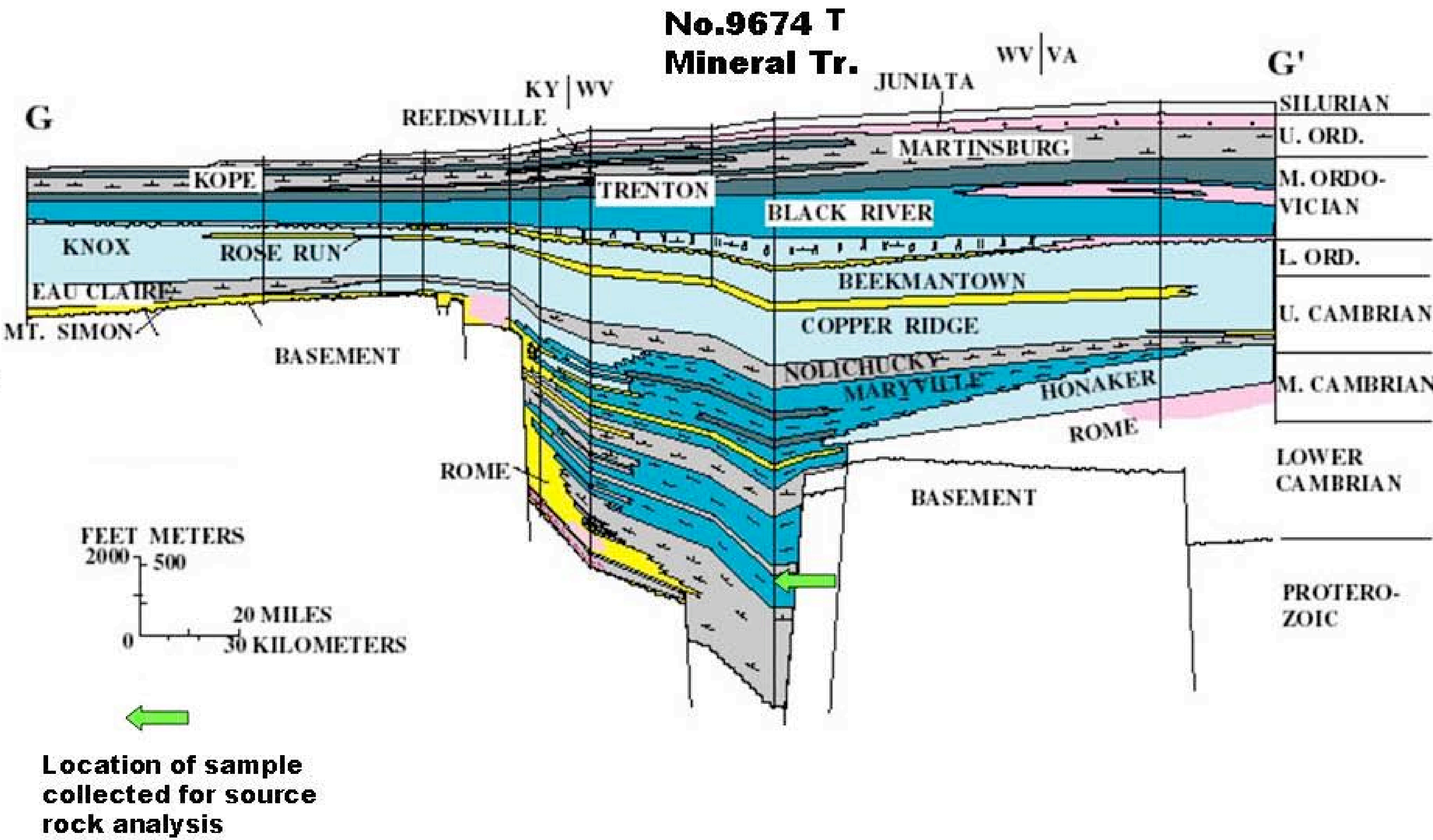


Figure 9. Results of total organic carbon (weight %) (TOC) analyses for three samples from the Cambrian Rome Formation, Columbia Gas No. 9674T Mineral Tract well, Mingo County, West Virginia. The core location is indicated by the solid black bar. See figure 4 for the location of the well. See Ryder (1992) for a brief discussion of the limestone member of the Rome Formation and the Pumpkin Valley Shale of the Conasauga Group. Abbreviations: Fm, formation; Gp, group; ls, limestone; mbr, member; Sh, shale; Tr, tract.

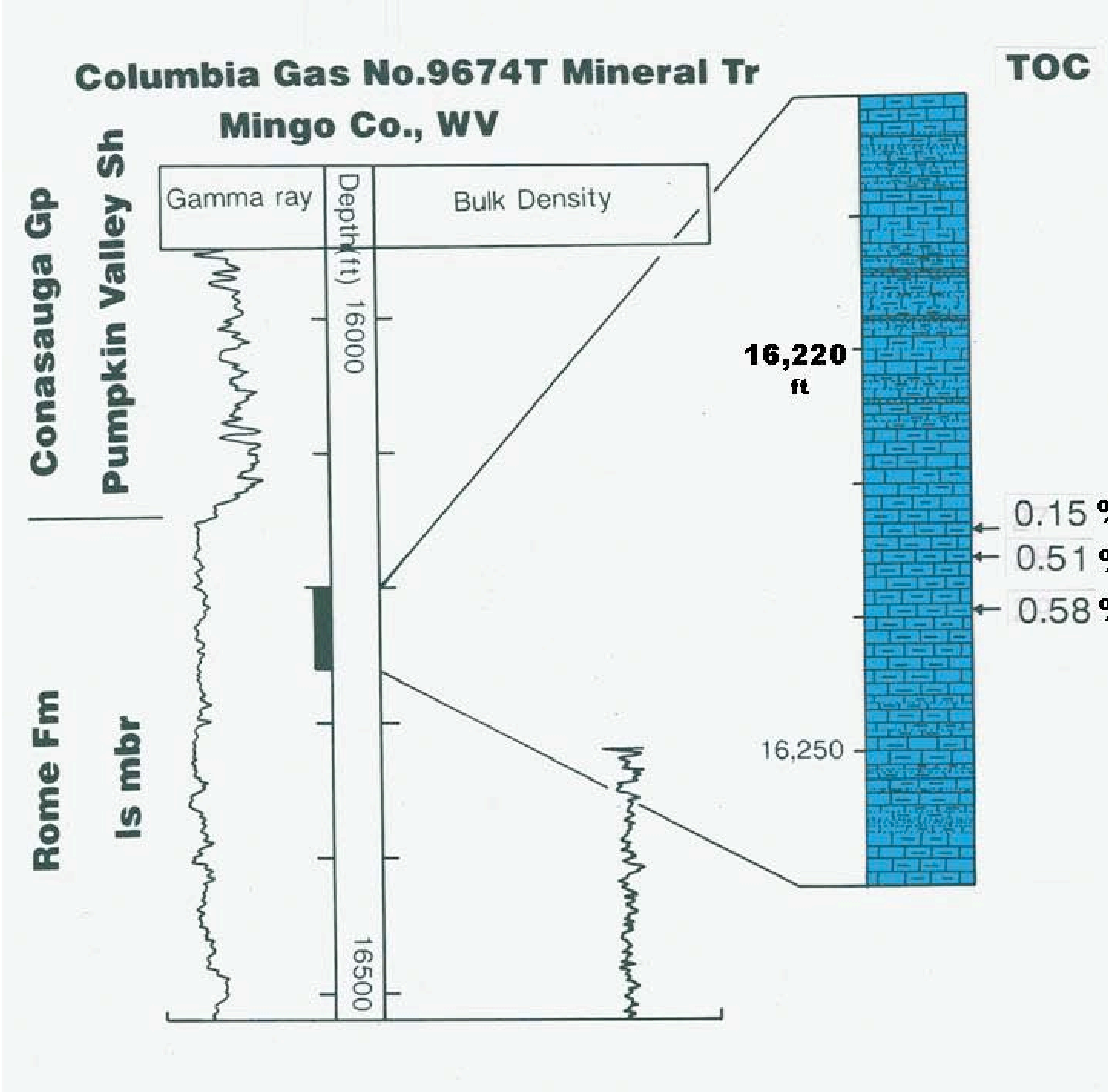

Columbia Gas No.9674T Mineral Tr
Mingo Co., WV
TOC
Conasauga Gp
Pumpkin Valley Sh
Rome Fm
ls mbr
Gamma ray
Depth (ft)
Bulk Density
16000
16500
16,220 ft
16,250
0.15 %
0.51 %
0.58 %

Figure 10. Appalachian basin cross section G-G' through Cambrian and Ordovician strata, Kentucky, West Virginia, and Virginia, showing the Exxon No. 1 Smith well and source rock sample locations. The cross section is from Ryder, Repetski, and Harris (1997). See figure 5 for an explanation of the major lithologic units.

APPALACHIAN BASIN SECTION G - G': KENTUCKY, WEST VIRGINIA AND VIRGINIA (RYDER AND OTHERS 1997)

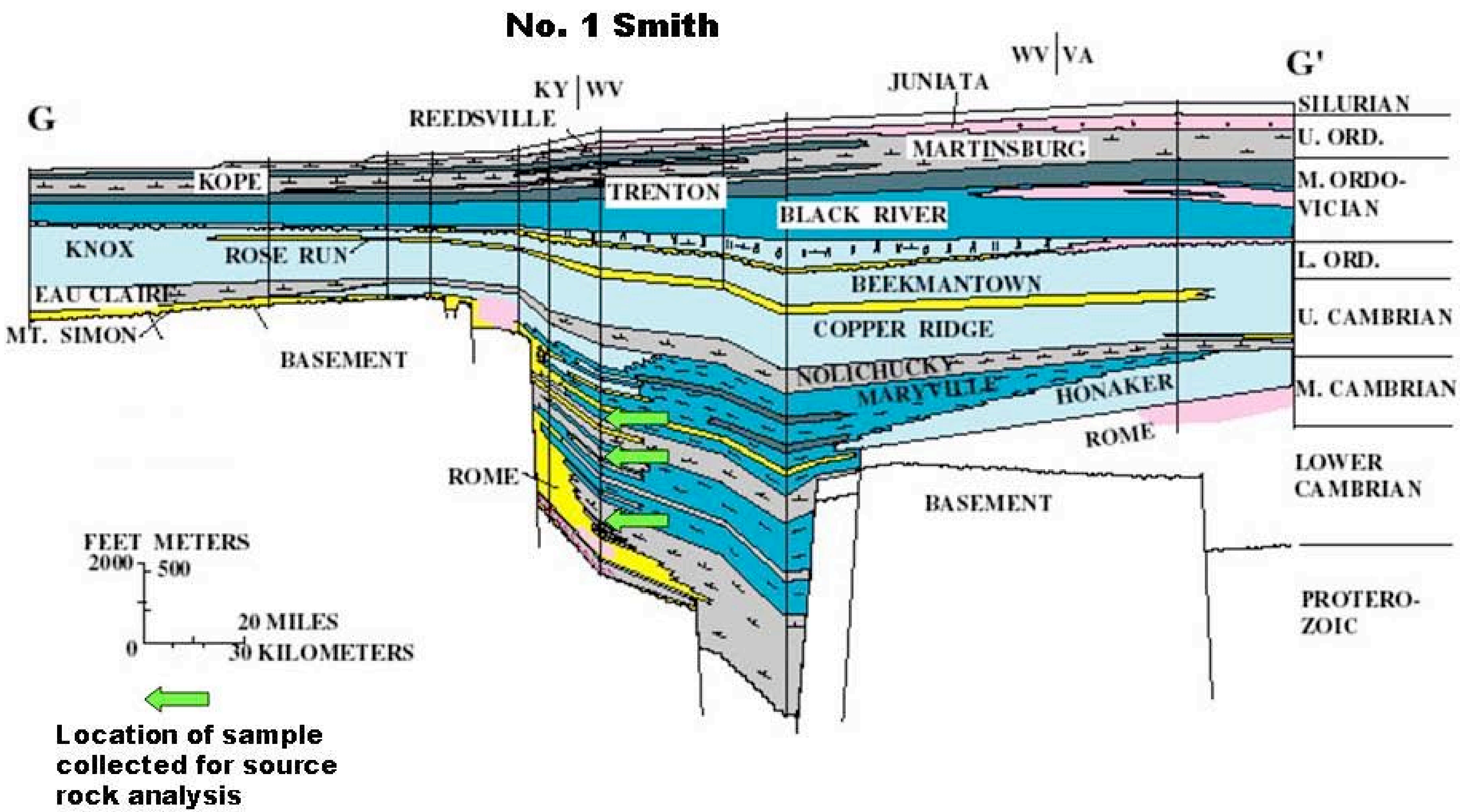


Figure 11. Gamma-ray, caliper, and density logs from lower Paleozoic strata in the Exxon No. 1 Smith well, Wayne County, West Virginia. See figure 4 for the location of the well. Abbreviations: Dol., dolomite; Fm., formation; Ls., limestone; Strat., stratigraphy; XTL, crystalline rocks.

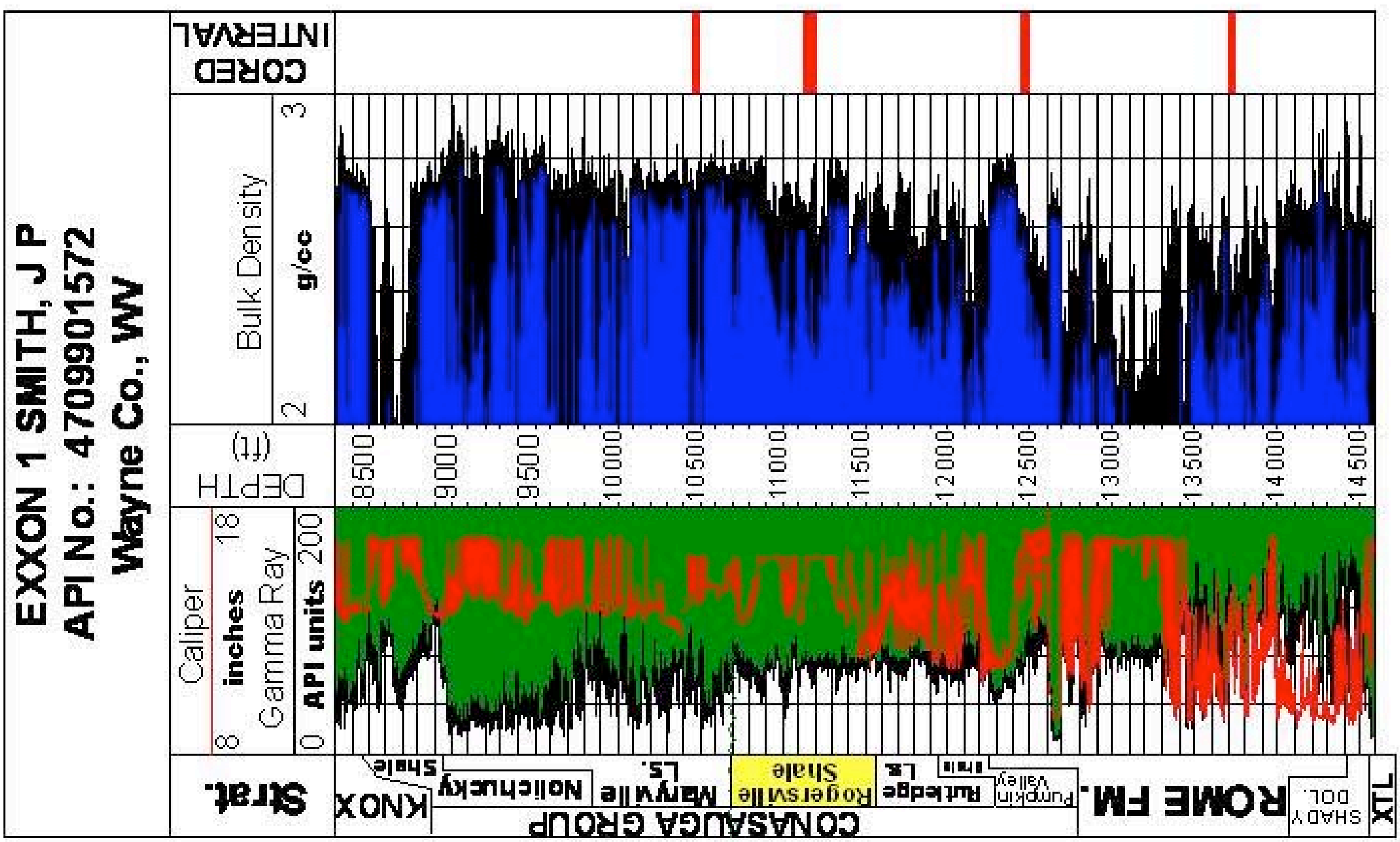

EXXON 1 SMITH, J P
API No.: 4709901572
Wayne Co., WV
Strat.
Caliper
8
inches
18
Gamma Ray
0
API units
200
DEPTH
(ft)
8500
9000
9500
10000
10500
11000
11500
12000
12500
13000
13500
14000
14500
Bulk Density
g/cc
2
3
CORED
INTERVAL
KNOX
Shale
Nolichucky
Maryville
LS.
Rogersville
Shale
Rutledge
LS.
Pumpkin
Valley
CONASAUGA GROUP
ROME FM.
SHADY
DOL.
XTL

Figure 12. Gamma-ray, caliper, and density logs and total organic carbon (weight %) content for two samples from the lower part of the Cambrian Rome Formation in the Exxon No. 1 Smith well, Wayne County, West Virginia. See figure 4 for the location of the well. Abbreviations: Fm., formation.

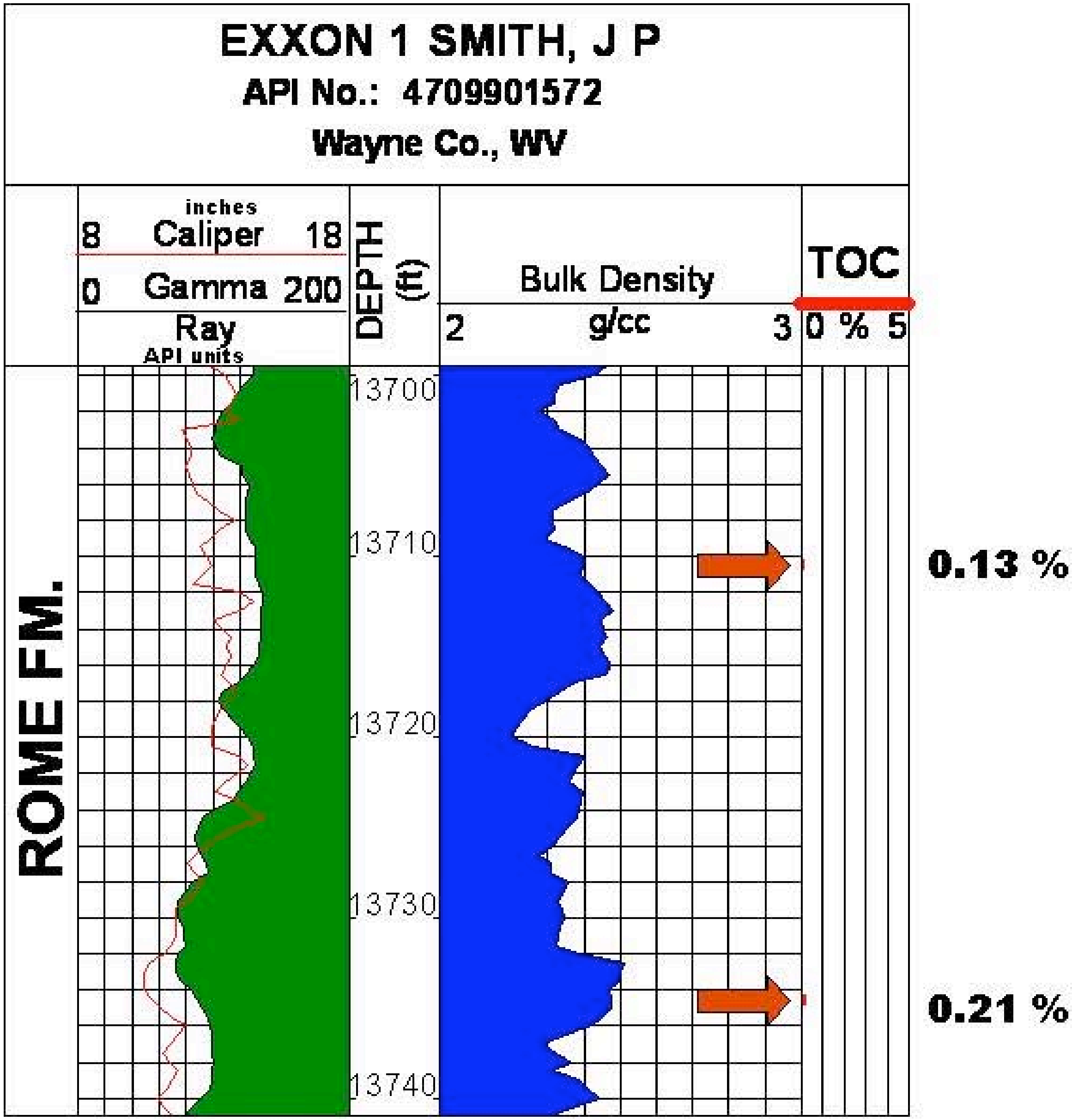
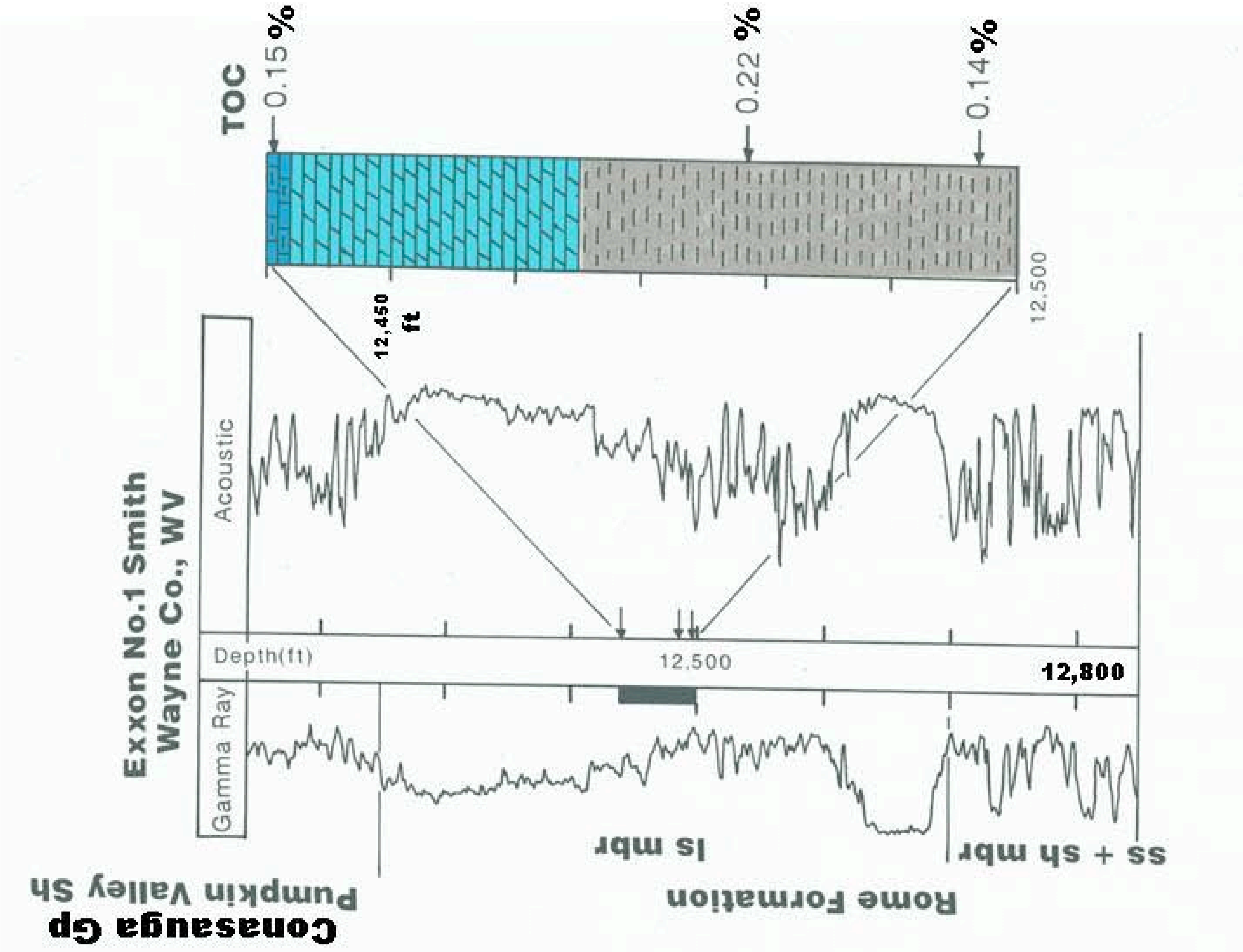

EXXON 1 SMITH, J P
API No.: 4709901572
Wayne Co., WV
inches
8 Caliper 18
0 Gamma 200
Ray
API units
DEPTH (ft)
Bulk Density
2 g/cc 3
TOC
0 % 5
ROME FM.
13700
13710
13720
13730
13740
0.13 %
0.21 %

Figure 13. Results of total organic carbon (weight %) (TOC) analyses for three samples from the upper part of the Cambrian Rome Formation Exxon No. 1 Smith well, Wayne County, West Virginia. The core location is indicated by the solid black bar. See figure 4 for the location of the well. See Ryder (1992) and Ryder and others (1997) for a brief discussion of the limestone member of the Rome Formation and the Pumpkin Valley Shale of the Conasauga Group. Abbreviations: Gp, group; ls, limestone; mbr, member; Sh(sh), shale; ss, sandstone.



Exxon No.1 Smith
Wayne Co., WV
TOC
0.15%
0.22%
0.14%
12,450
ft
12,500
Acoustic
Depth(ft)
12,500
12,800
Gamma Ray
ls mbr
ss + sh mbr
Rome Formation
Pumpkin Valley Sh
Conasauga Gp

Figure 14. Results of total organic carbon (weight %) (TOC) analyses for five samples from the Cambrian Rogersville Shale of the Conasauga Group, Exxon No. 1 Smith well, Wayne County, West Virginia. The core location is indicated by the solid black bar. See figure 4 for the location of the well. See Ryder (1992) and Ryder and others (1997) for a brief Discussion of the Rogersville Shale of the Conasauga Group. Abbreviations: Gp, group; Sh, shale.

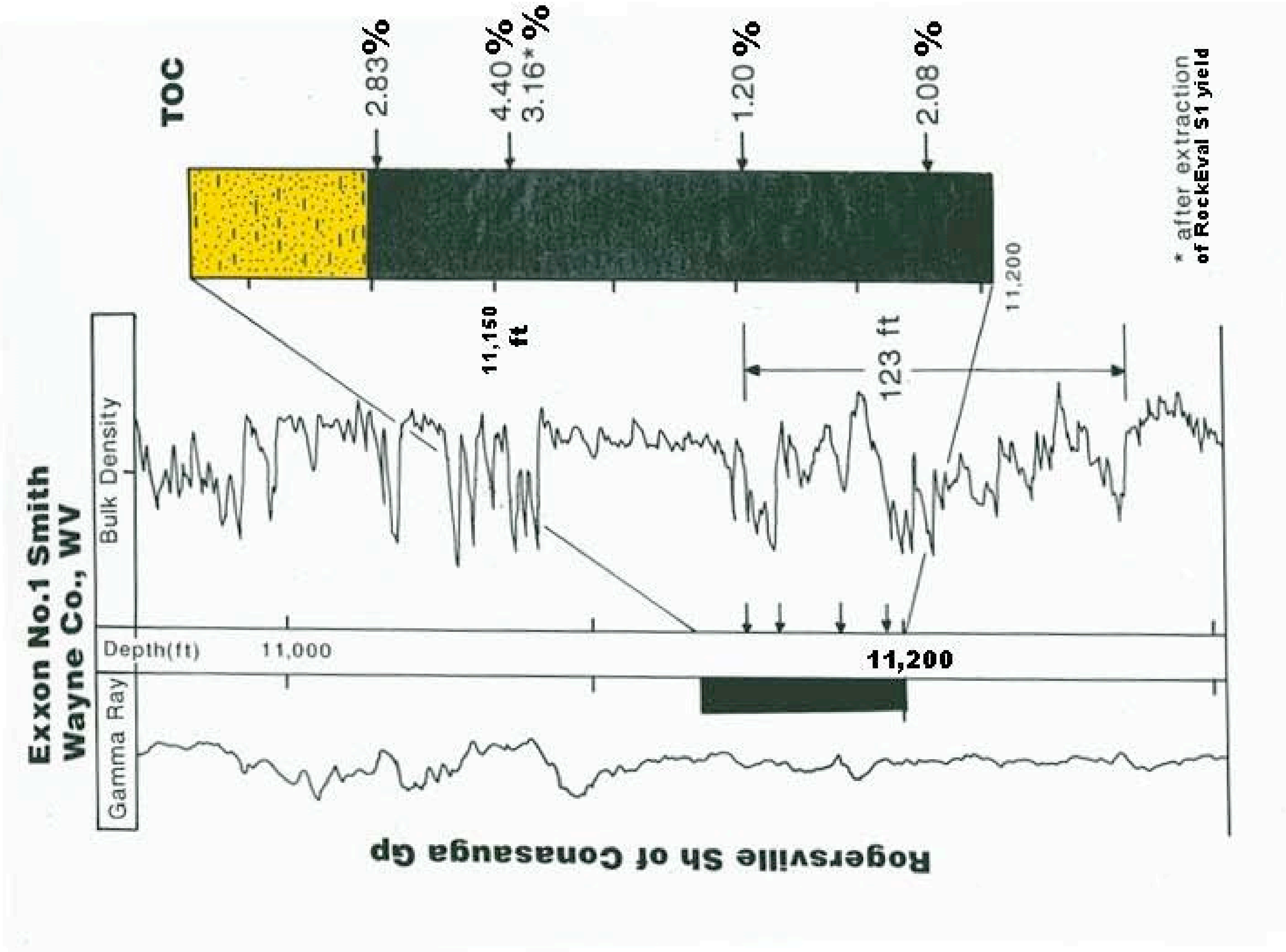
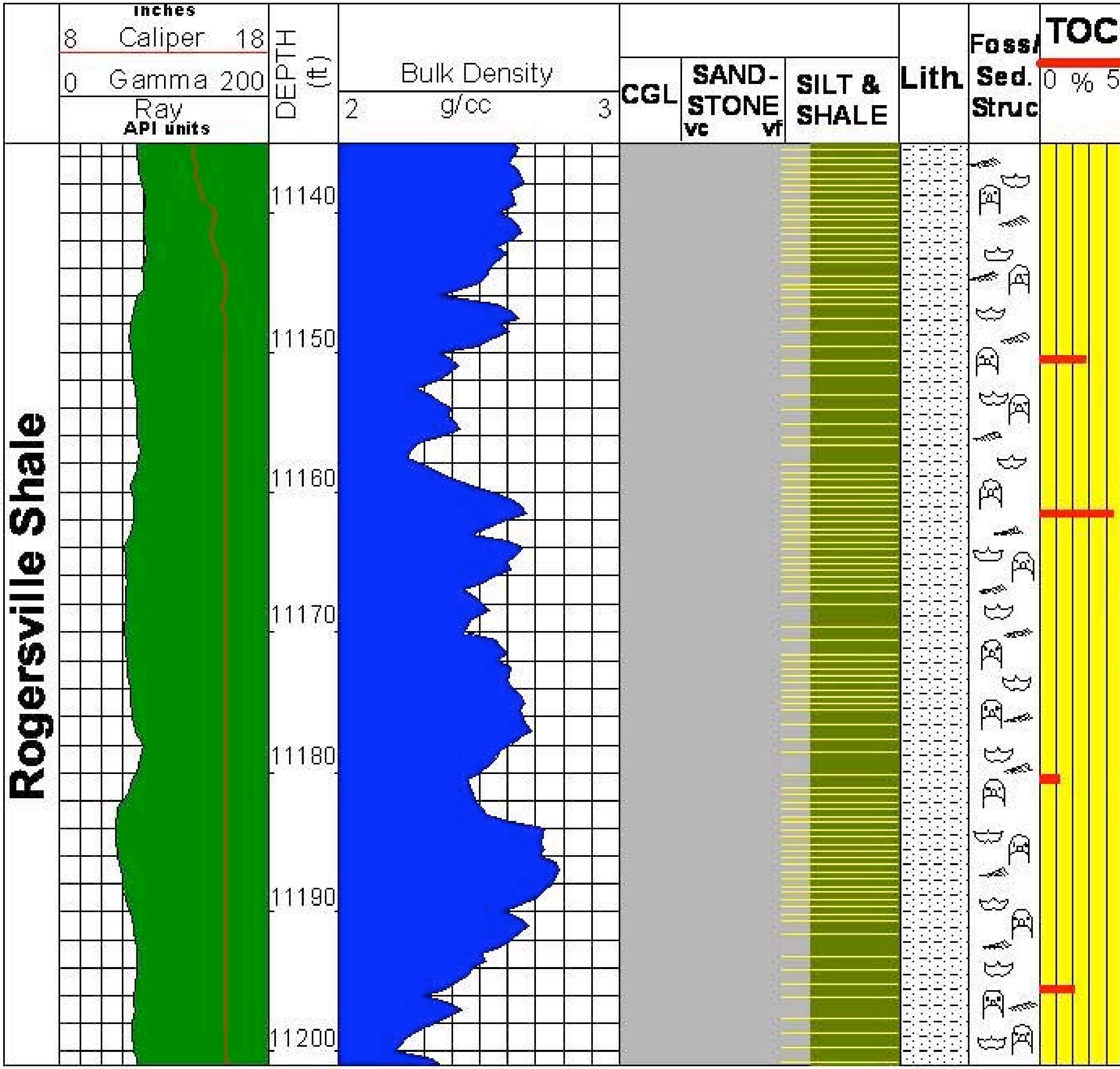

Exxon No.1 Smith
Wayne Co., WV
Gamma Ray
Depth(ft)
Bulk Density
11,000
11,200
TOC
2.83%
4.40 %
3.16* %
1.20 %
2.08 %
11,150
ft
11,200
123 ft
* after extraction
of RockEval S1 yield
Rogersville Sh of Conasauga Gp

Figure 15. Summary data for cored interval of the Cambrian Rogersville Shale of the Conasauga Group, Exxon No. 1 Smith well, Wayne County, West Virginia. The scale bar is in 1 cm increments. See figure 4 for the location of the well. Abbreviations: brachs, brachiopods; cmt, cement; CGL, conglomerate; Foss, fossils; Lith., lithology; Sed. Struc, sedimentary structures; TOC, total organic carbon in weight percent; v. fn. gr, very fine grained

Rogersville Shale Cored Interval with Total Organic Carbon (TOC)



Shale, dark gray, with thin **Sandstone**, (1 mm to 5 cm) v. fn. gr, calcite cmt., trilobite and lingulid brachs common. Burrowed to bioturbated, with flaser and ripple cross-lamination.

Figure 16. Core photograph of the Cambrian Rogersville Shale of the Conasauga Group at 11,150.5 ft, Exxon No. 1 Smith well, Wayne County, West Virginia. The scale bar is in 1 cm increments. See figure 4 for the location of the well.


Exxon #1 Smith
Rogersville Shale
11,150.5 ft
Shale
Very fine grained
sandstone laminae
Burrows filled with
very fine grained sandstone

Figure 17. Gas chromatogram of a whole bitumen extract from the Cambrian Rogersville Shale of the Conasauga Group at 11,161.5 ft, Exxon No. 1 Smith well, Wayne County, West Virginia. The *n*-alkanes and the isoprenoids including pristane (pr) and phytane (ph) are identified. See figure 4 for the location of the well.

Whole bitumen extract – Rogersville Shale
No. 1 Smith
Wayne Co., WV
11,161.5 ft

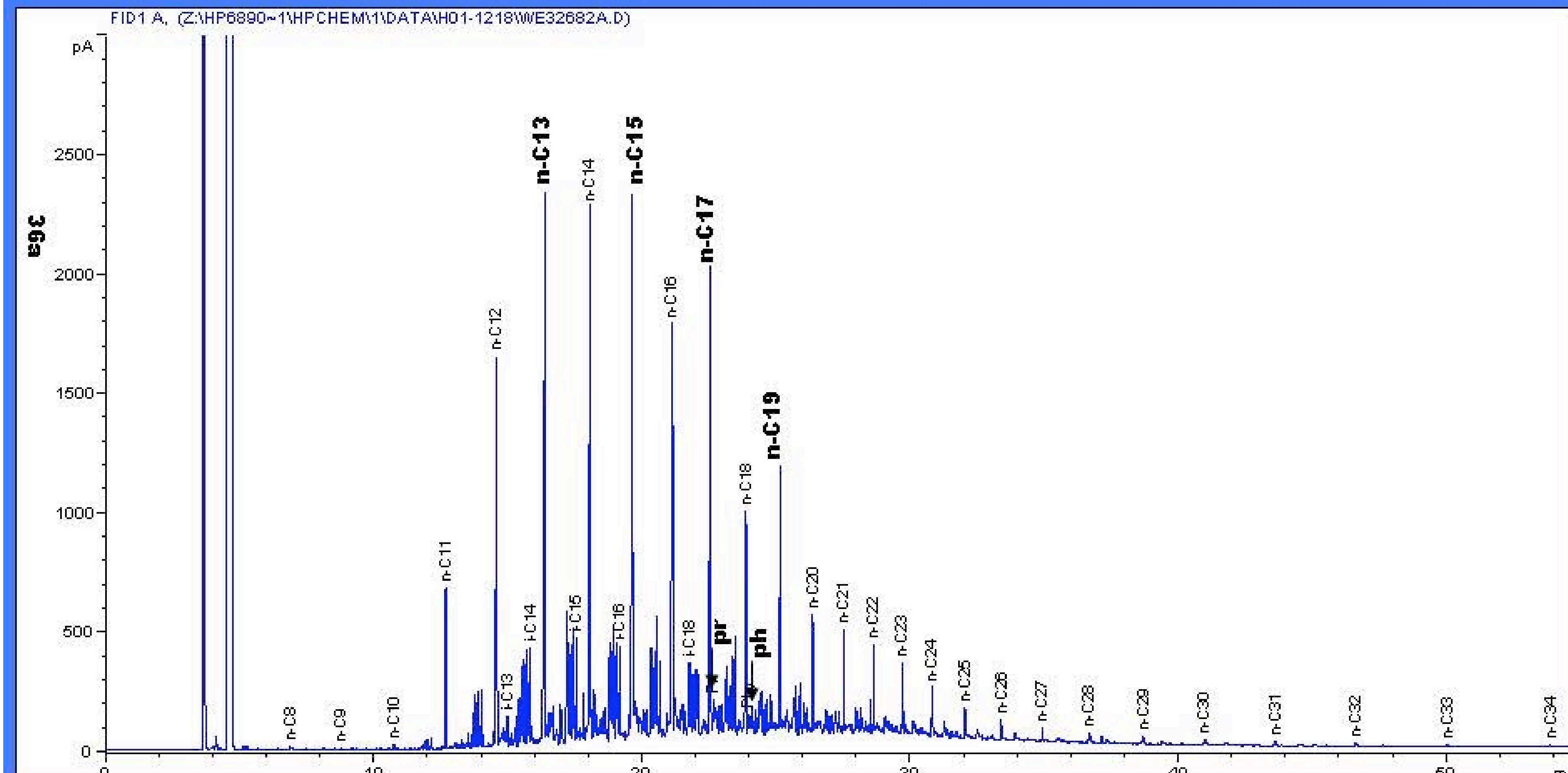
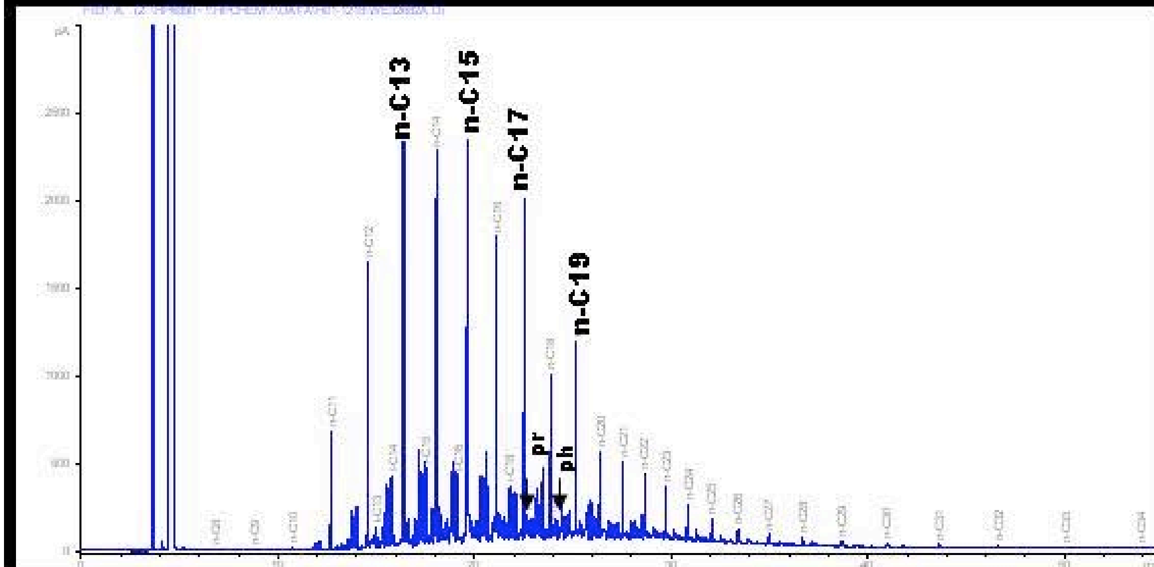
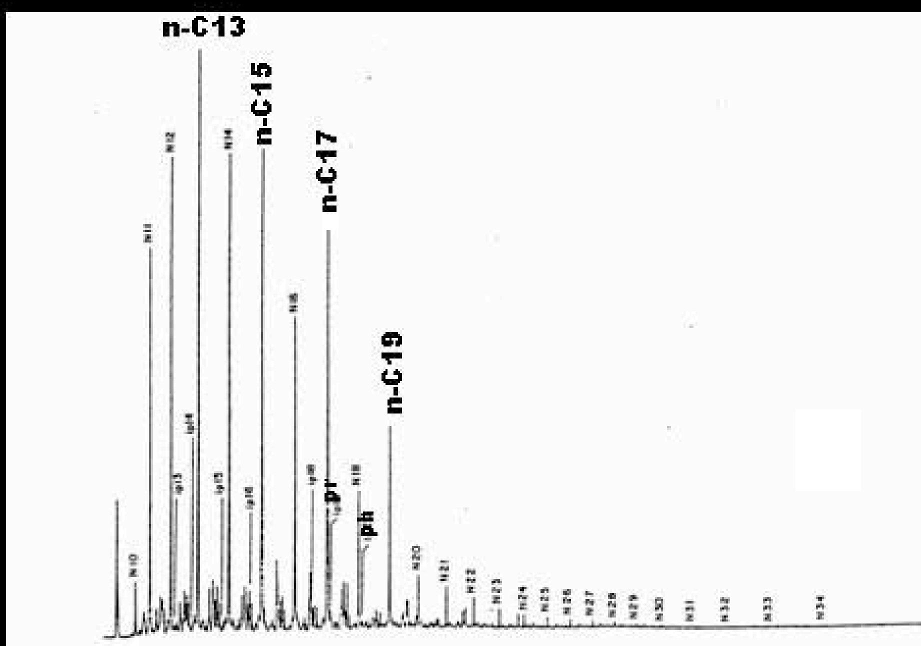


Figure 18. Gas chromatograms showing the oil-source rock correlation between a whole bitumen extract from the Rogersville Shale at 11,161.5 ft, in the No. 1 Smith well, Wayne County, West Virginia, and an oil from the Maryville Limestone at 7,574-7,598 ft in the No. 529 White, Boyd County, Kentucky. The *n*-alkanes and the isoprenoids including pristane (pr) and phytane (ph) are identified. See figure 4 for the location of the well. * oil data provided by Richard W. Beardsley (written communication, December 1995)

Oil – Source Rock Correlation



Whole Bitumen Extract - Rogersville Shale No. 1 Smith Wayne Co., WV 11,161.5 ft



Oil*– Maryville Limestone

No. 529 White

Boyd Co., Ky

7,574 – 7,598 ft

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Figure 19. Mud log of the Conasauga Group (part) interval showing a high gas concentration in the cored Rogersville Shale Exxon No. 1 Smith well, Wayne County, West Virginia. The core location is indicated by the solid black bar. Lithology: sandstone = stippled pattern; shale = dashed lines; limestone = brick pattern/ vertical lines; dolomite = brick pattern/ diagonal lines. See figure 4 for the location of the well. Hotwire gas is the initial concentration of gas detected in the drilling fluid (mud) by a heated platinum filament that forms one arm of a wheatstone bridge circuit. The drilling fluid (mud) is further analyzed by a chromatograph to determine the concentration of individual gases (C_1-C_4) in ppm.

Exxon No.1 Smith
Wayne Co., WV

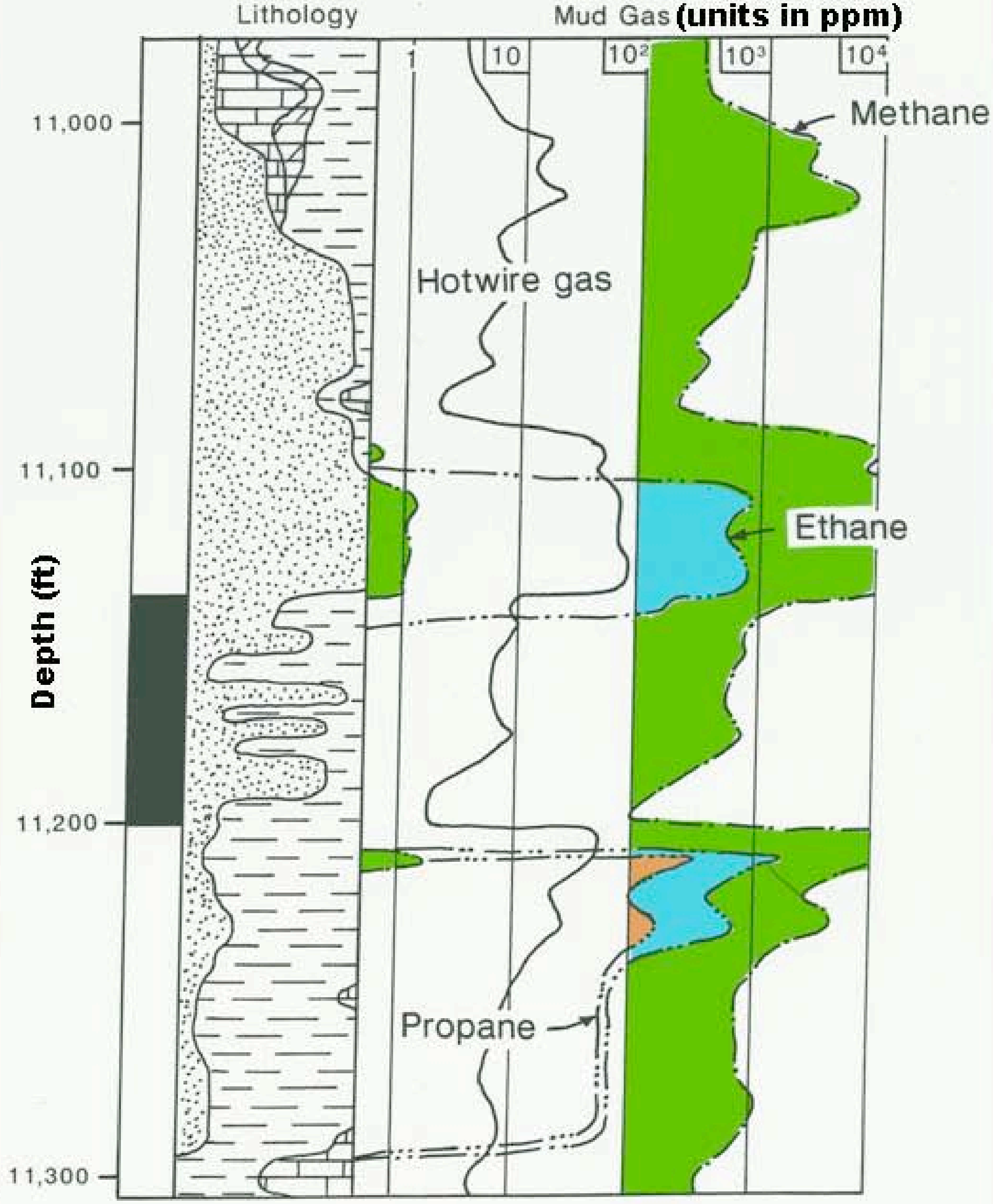


Figure 20. Cross section through the northern margin of the Rome trough showing the proposed oil migration route from the Rogersville Shale source rock in the Exxon No.1 Smith well, Wayne County, West Virginia, to the Maryville Limestone reservoir in the Inland No. 529 White well, Boyd County, Kentucky. This cross section is modified from Ryder and others (1997). See figures 3 and 4 for the location of the wells and the line of section. See figure 5 for an explanation of the major lithologic units.

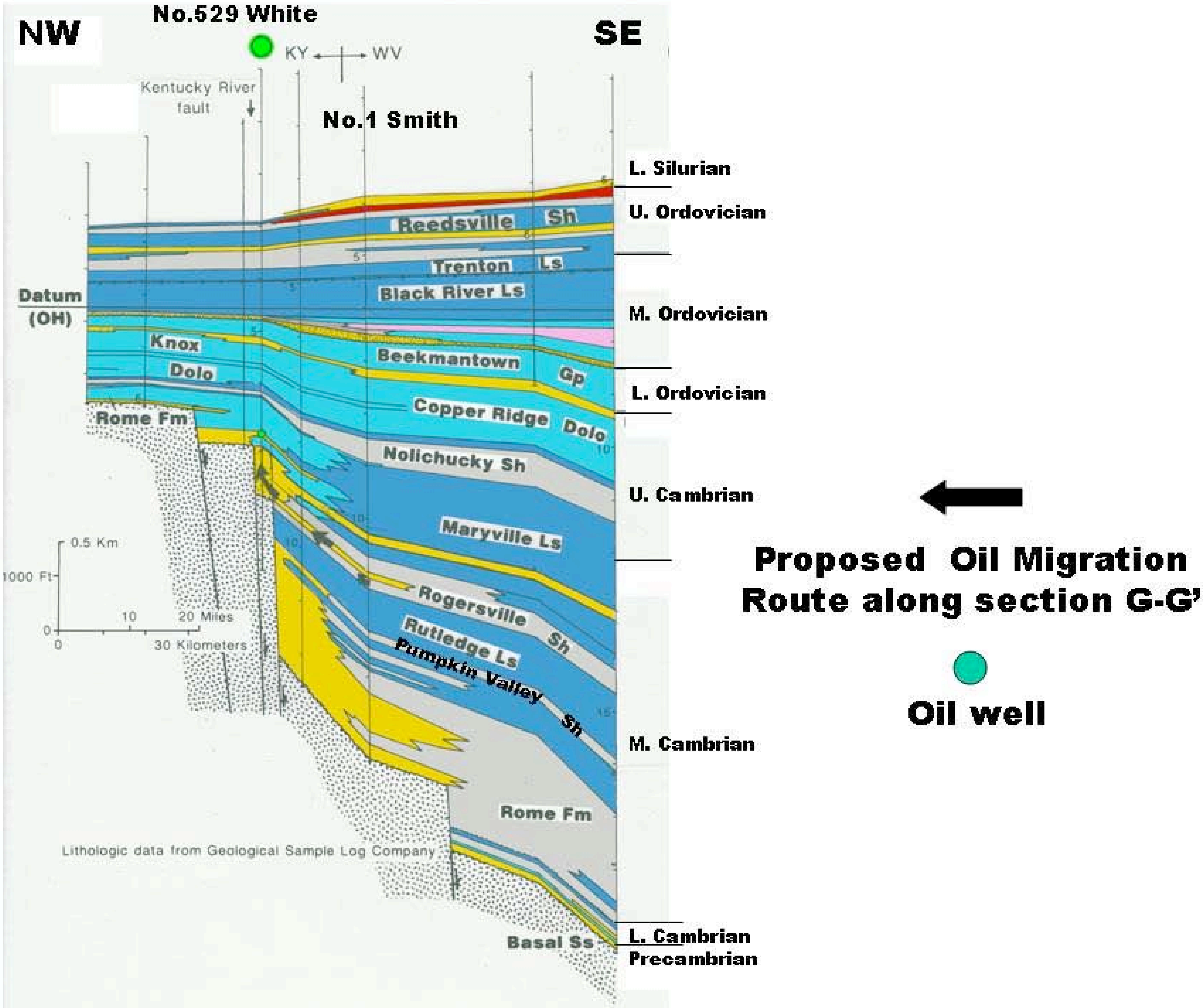
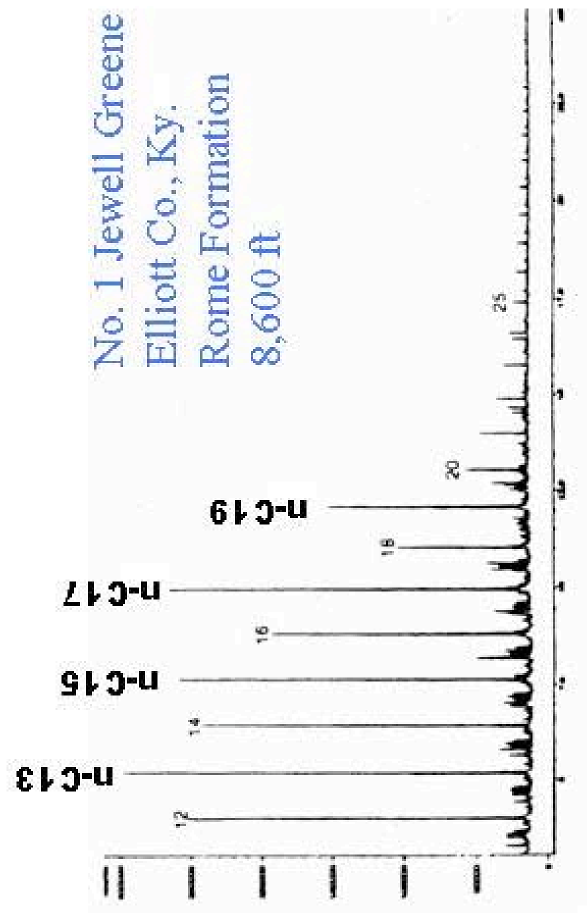
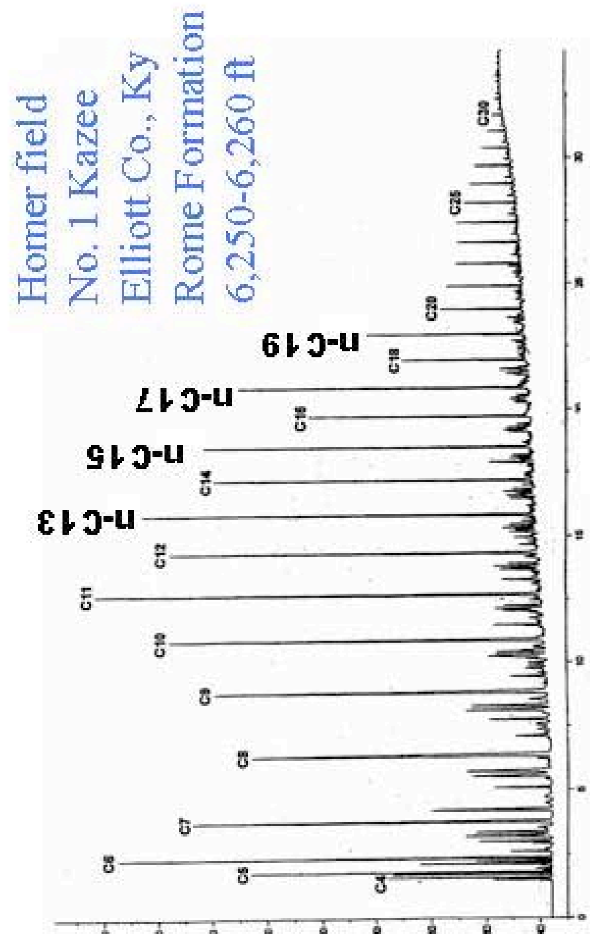

NW
No.529 White
KY
WV
SE
Kentucky River fault
No.1 Smith
L. Silurian
U. Ordovician
Reedsville Sh
Trenton Ls
Black River Ls
Datum (OH)
M. Ordovician
Knox Dolo
Beekmantown Gp
L. Ordovician
Rome Fm
Copper Ridge Dolo
Nolichucky Sh
U. Cambrian
Maryville Ls
0.5 Km
1000 Ft
0
10
20 Miles
30 Kilometers
Rogersville Sh
Rutledge Ls
Pumpkin Valley Sh
M. Cambrian
Rome Fm
Lithologic data from Geological Sample Log Company
Basal Ss
L. Cambrian
Precambrian
Proposed Oil Migration Route along section G-G'
Oil well

Figure 21. Gas chromatograms from selected oils/condensates in Cambrian reservoirs in eastern Kentucky wells. The oil/condensates are from the Miller Oil and Gas No. 1 Bailey well, Wolfe County, Kentucky, 6,956-6,960 ft; the Blue Ridge Group No. 1 Jewell Greene well, Elliott County, Kentucky, 8,600 ft (Moldowan and Jacobson, 2000); and the Carson Associates No. 1 Kazee well, Elliott County, Kentucky, 6,250-6,260 ft. The gas chromatograms for the No. 1 Bailey and No. 1 Kazee oils/condensates are whole oil gas chromatograms. The type of gas chromatogram for the No. 1 Jewell Greene oil/condensate is unspecified. The *n*-alkanes are identified. See figure 3 for the location of the No. 1 Bailey well and the Homer field.


No. 1 Jewell Greene
Elliott Co., Ky.
Rome Formation
8,600 ft
n-C13
n-C15
n-C17
n-C19
12
14
16
18
20
25


Homer field
No. 1 Kazee
Elliott Co., Ky
Rome Formation
6,250-6,260 ft
n-C13
n-C15
n-C17
n-C19
C4
C5
C6
C7
C8
C9
C10
C11
C12
C14
C16
C18
C20
C25
C30

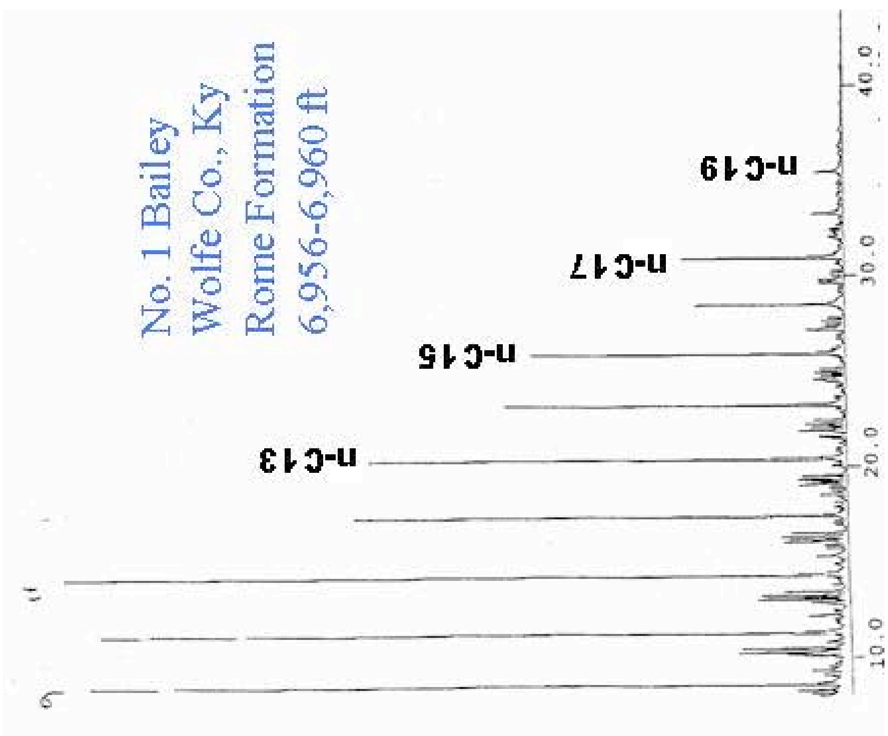
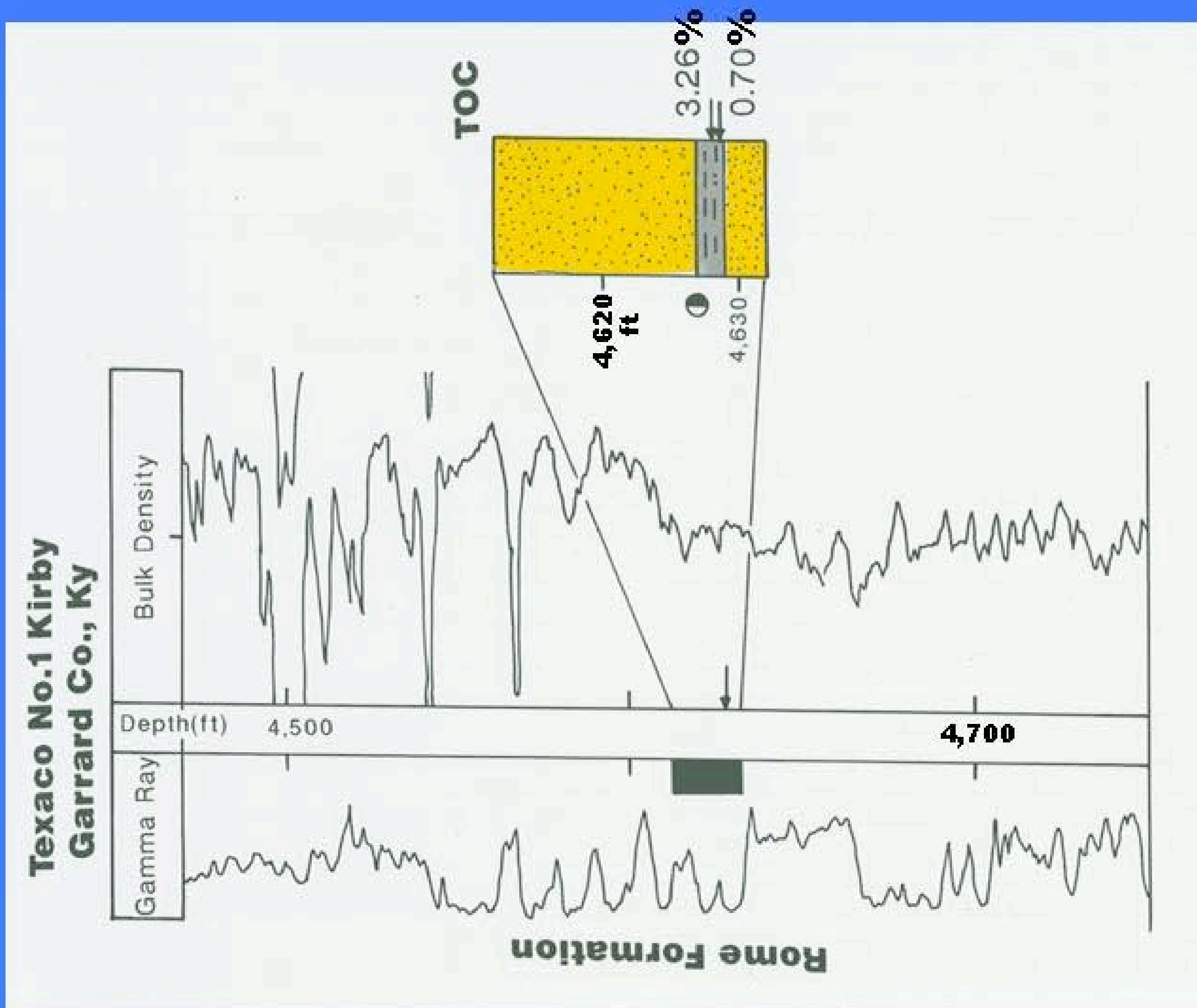

No. 1 Bailey
Wolfe Co., Ky
Rome Formation
6,956-6,960 ft
n-C13
n-C15
n-C17
n-C19
10.0
20.0
30.0
40.0

Figure 22. Results of total organic carbon (weight %) (TOC) analyses for two samples from of the Cambrian Rome Formation, Texaco No. 1 Kirby well, Garrard County, Kentucky. The core location is indicated by the solid black bar. See figures 3 and 4 for the location of the wells.

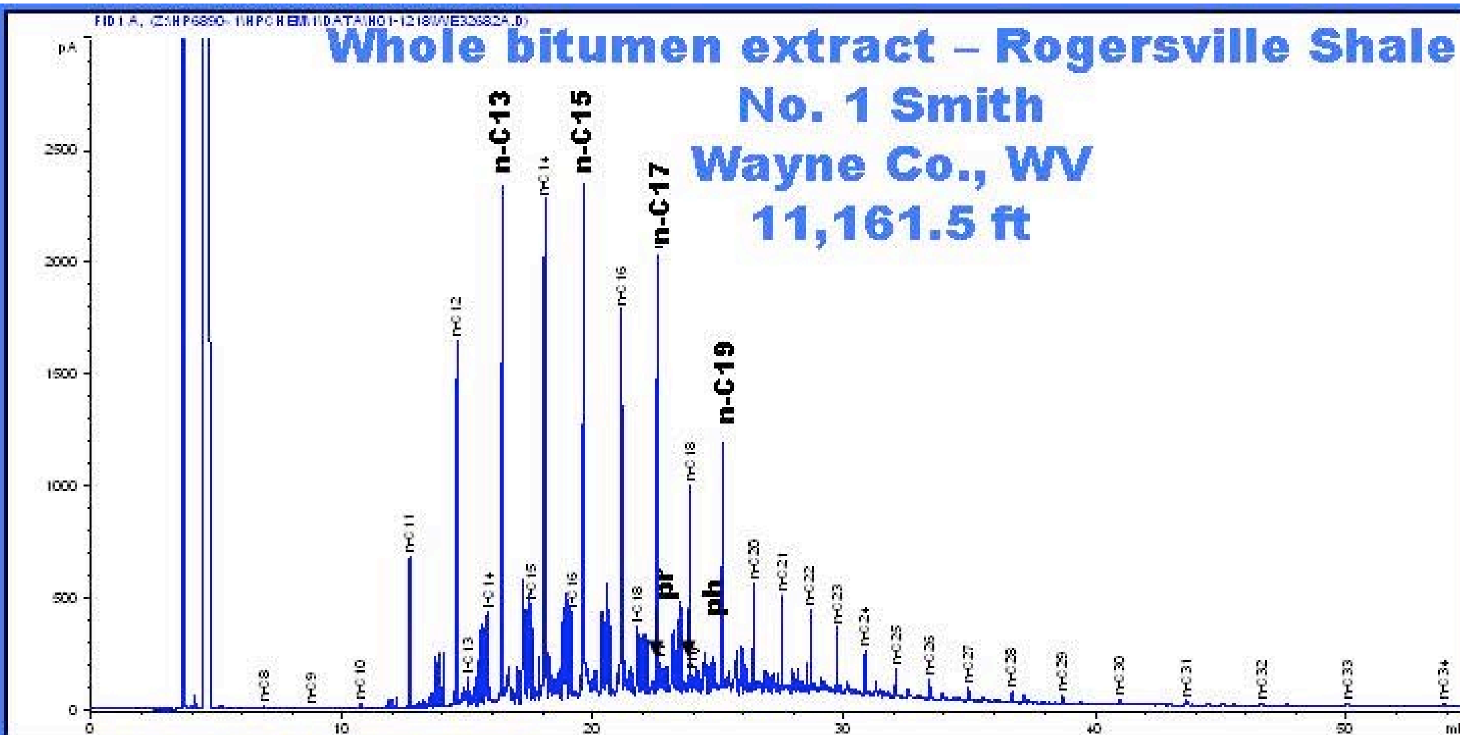


Texaco No.1 Kirby
Garrard Co., Ky
Bulk Density
Depth(ft)
4,500
4,700
Gamma Ray
TOC
3.26%
0.70%
4,620 ft
4,630
Rome Formation

Figure 23. Core photograph of a black shale in the Cambrian Rome Formation, Texaco No. 1 Kirby well at 4,628.8 ft, Garrard County, Kentucky. The scale bar is in 1 cm increments. See figures 3 and 4 for the location of the well.

Texaco #1 Kirby
Garrard Co., Ky.
Rome Fm.

Figure 24. Gas chromatograms of whole bitumen extracts in the Rogersville Shale, No. 1 Smith well, Wayne County, West Virginia, and in the Rome Formation, No. 1 Kirby well, Garrard County, Kentucky. The *n*-alkanes and the isoprenoids including pristane (pr) and phytane (ph) are identified. See figure 4 for the location of the wells.


Whole bitumen extract – Rogersville Shale
No. 1 Smith
Wayne Co., WV
11,161.5 ft
n-C13
n-C15
n-C17
n-C19
pr
ph

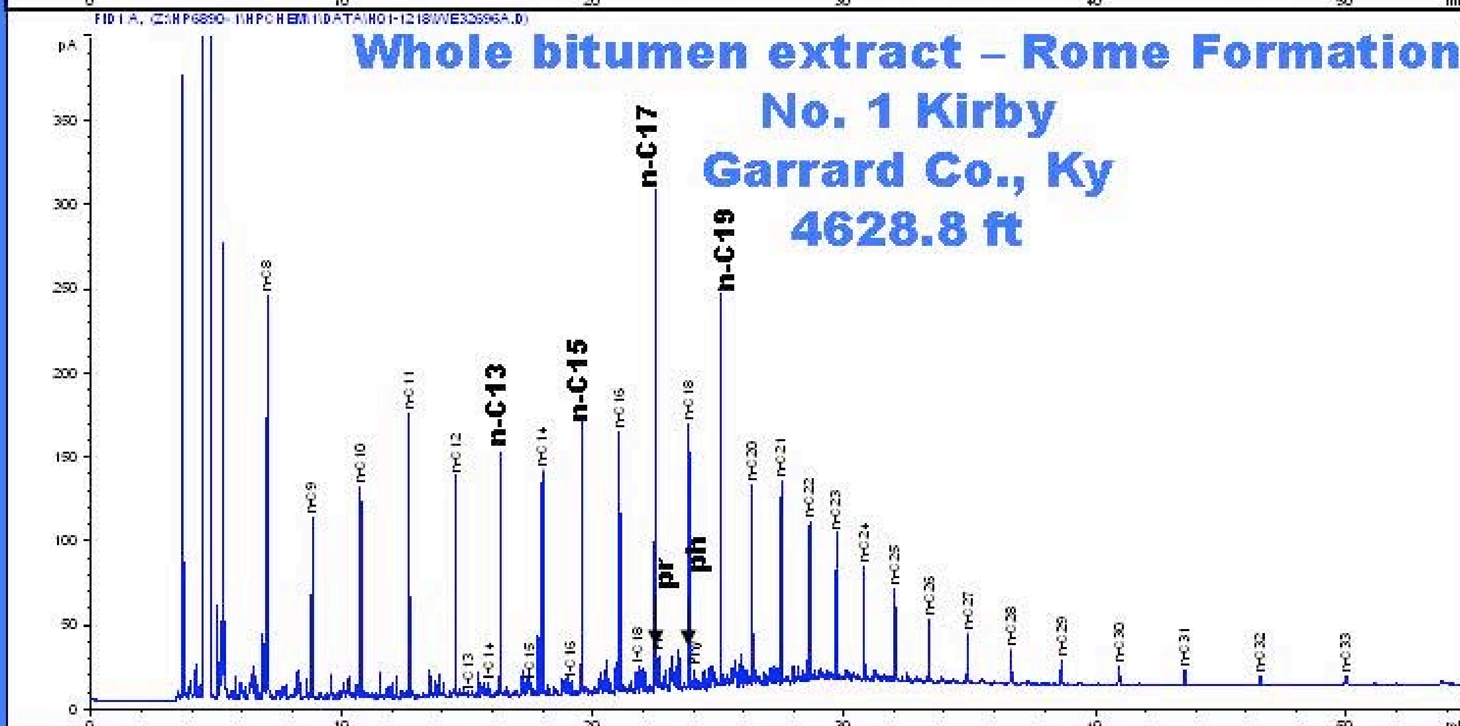

Whole bitumen extract – Rome Formation
No. 1 Kirby
Garrard Co., Ky
4628.8 ft
n-C13
n-C15
n-C17
n-C19
pr
ph

Figure 25. Hydrogen index (HI) verses Oxygen index (OI) plot for Cambrian source rocks in the Rome trough. See figure 4 for the location of the No. 1 Kirby and No. 1 Smith wells.

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Hydrogen Index (HI) vs. Oxygen Index (OI) plot for Rome trough source rocks

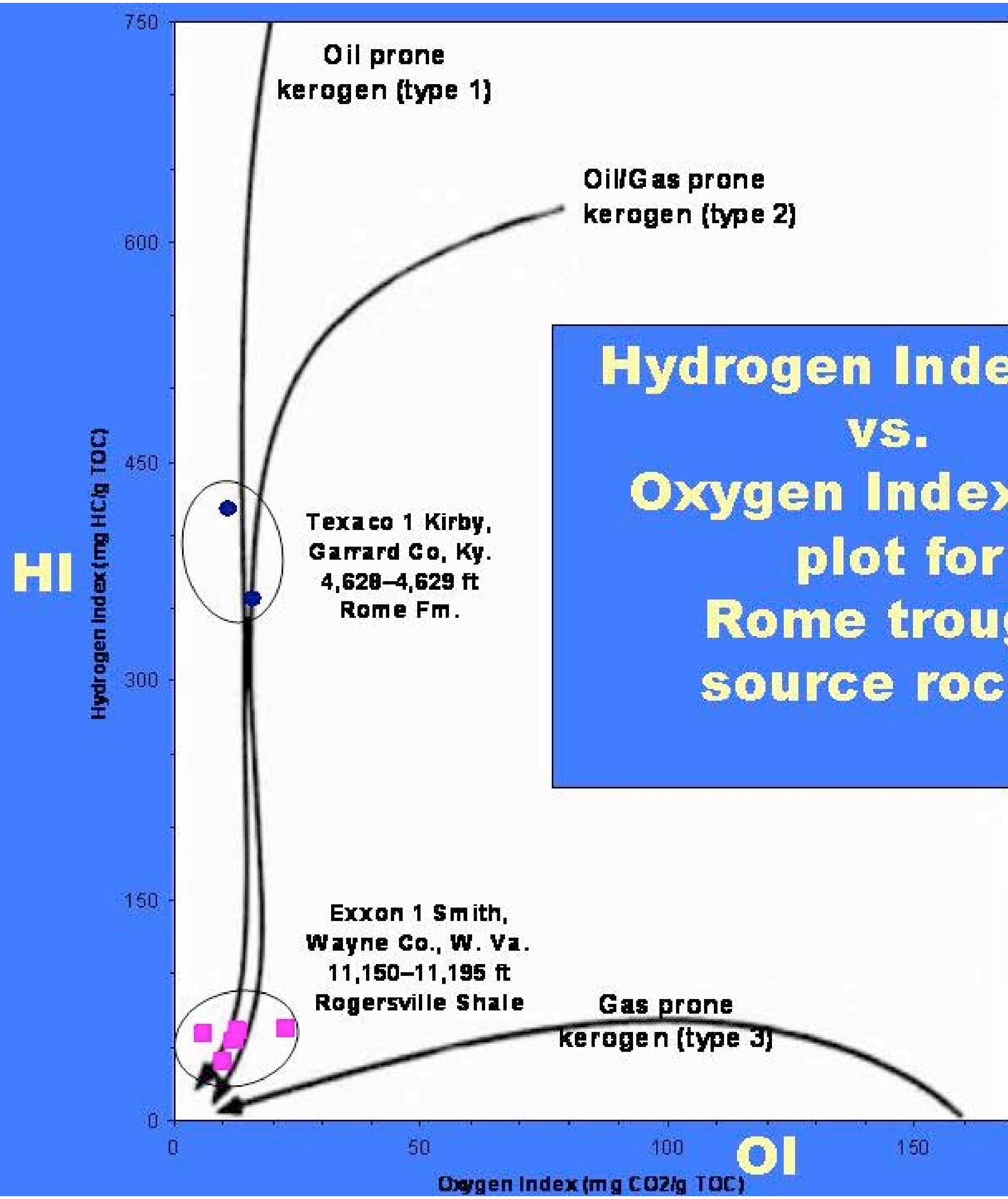
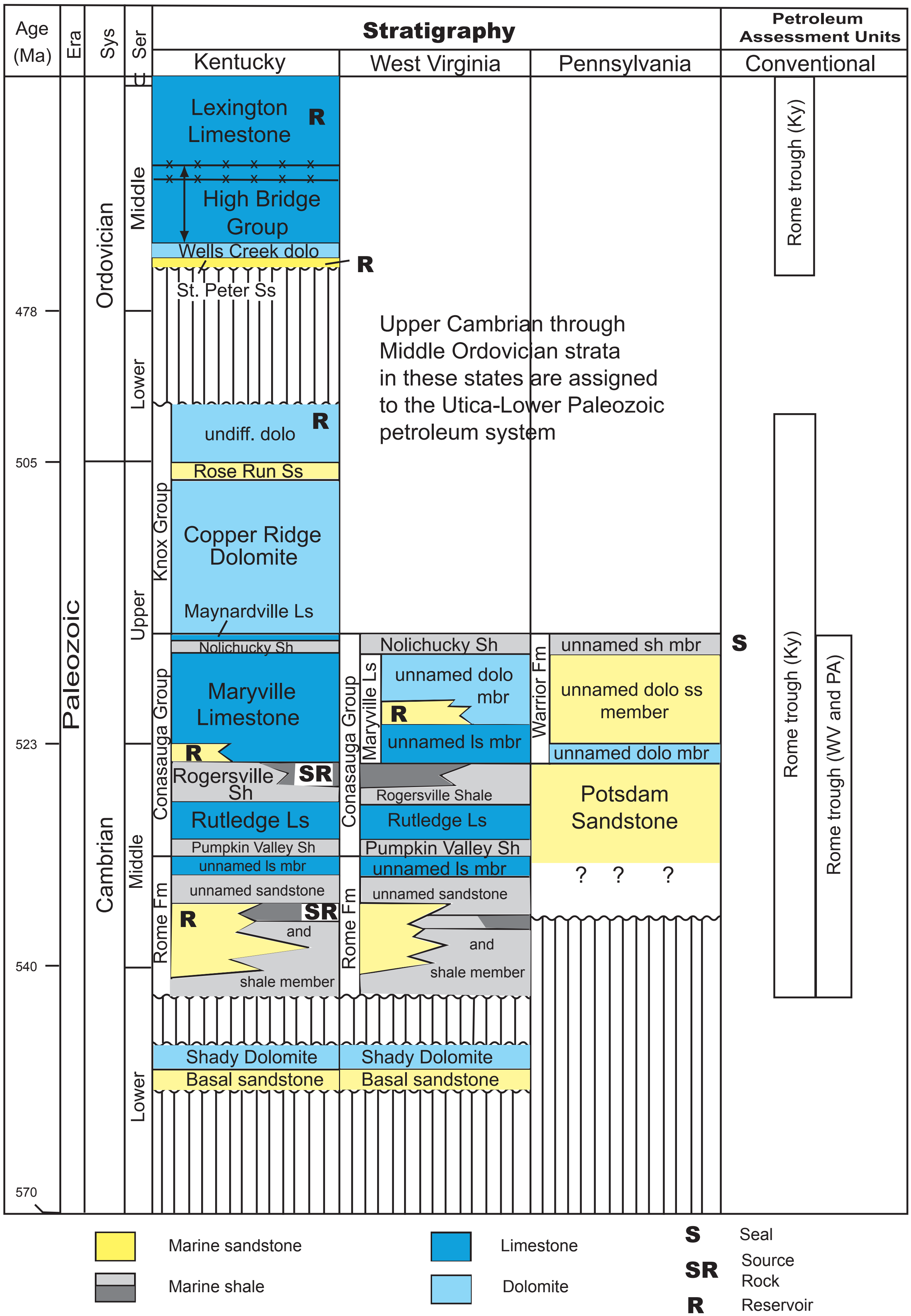
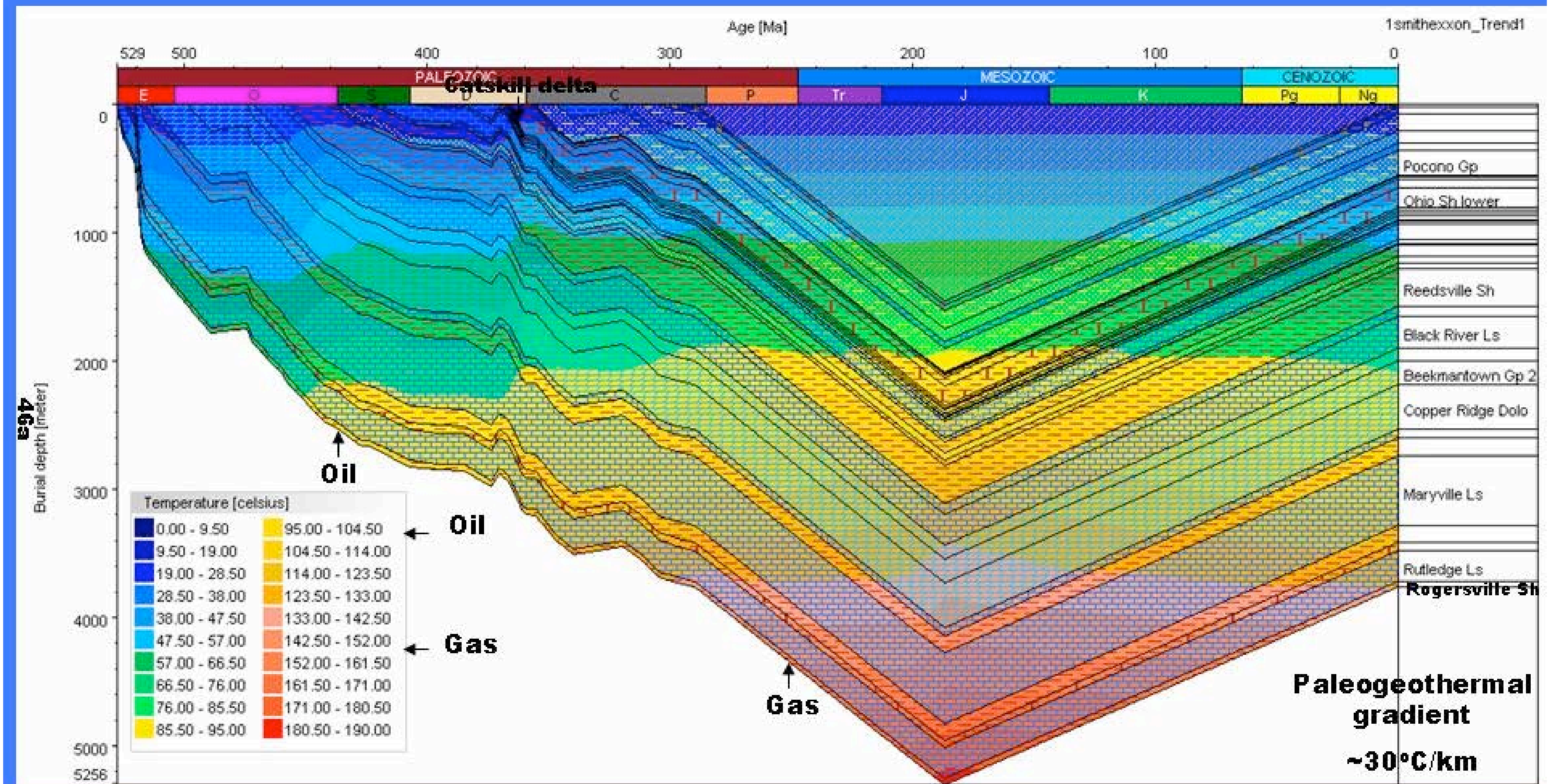


Figure 26. Correlation chart showing the stratigraphic units of the Conasauga-Rome/Conasauga Petroleum System and reservoirs, seal, and source rock. Abbreviations: dolo, dolomite; (Ls)ls, limestone; Sh(sh); shale; (Ss)ss, sandstone; fm, formation; Gp, Group; Mbr(mbr), member; undiff., undifferentiated.



Conasauga-Rome/Conasauga Total Petroleum System

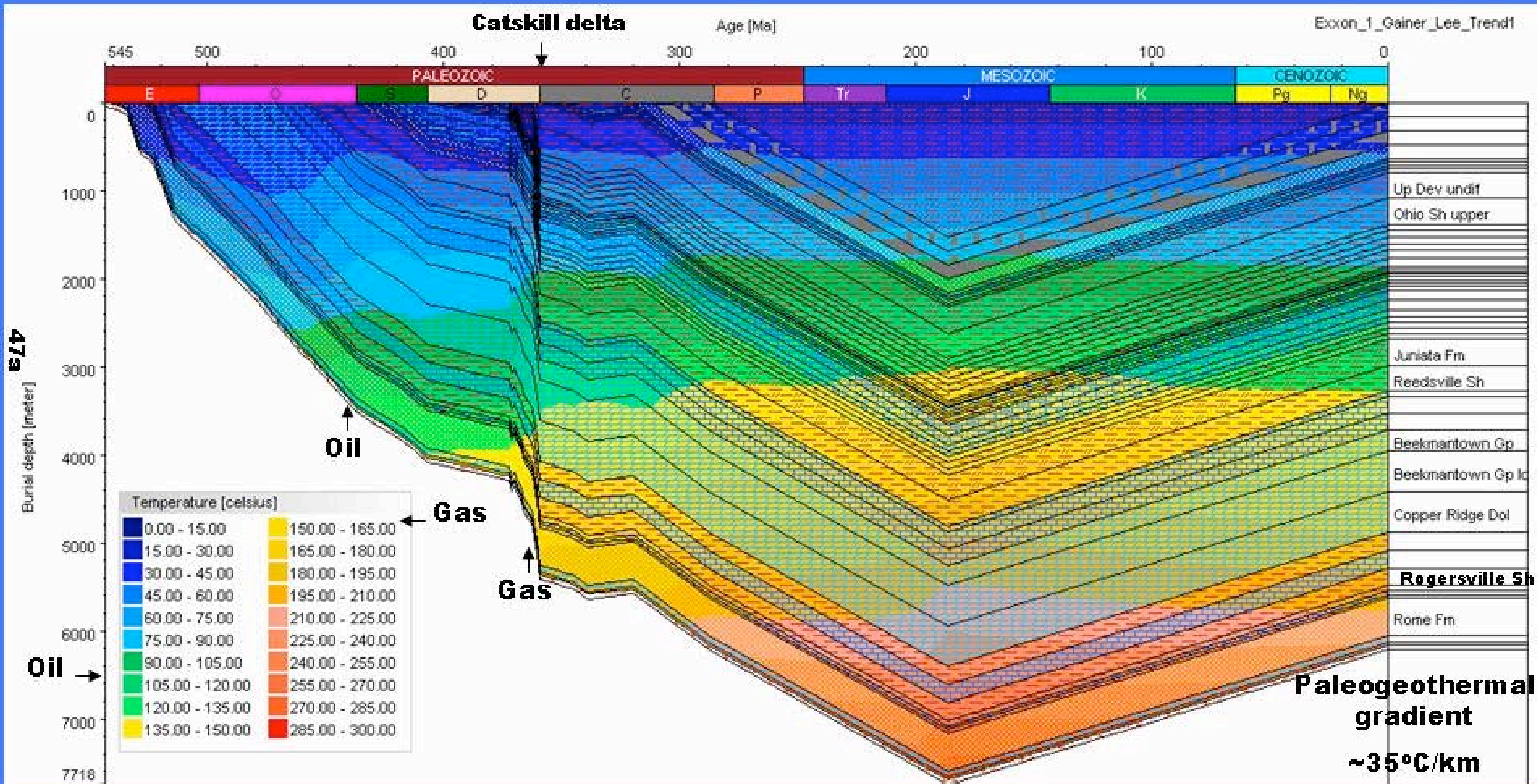
Figure 27. Burial and temperature history model for the Exxon No.1 Smith well, Wayne County, West Virginia. See figure 4 for the location of the well.



46a

Burial and temperature history model for the Exxon No.1 Smith well

Figure 28. Burial and temperature history model for the Exxon No.1 Gainer-Lee well, Calhoun County, West Virginia. See figure 4 for the location of the well.



Burial and temperature history model for the Exxon No. 1 Gainer-Lee well

Figure 29. Events chart for the Conasauga-Rome/Conasauga Petroleum System.

Events Chart for Conasauga – Rome/Conasauga Petroleum System

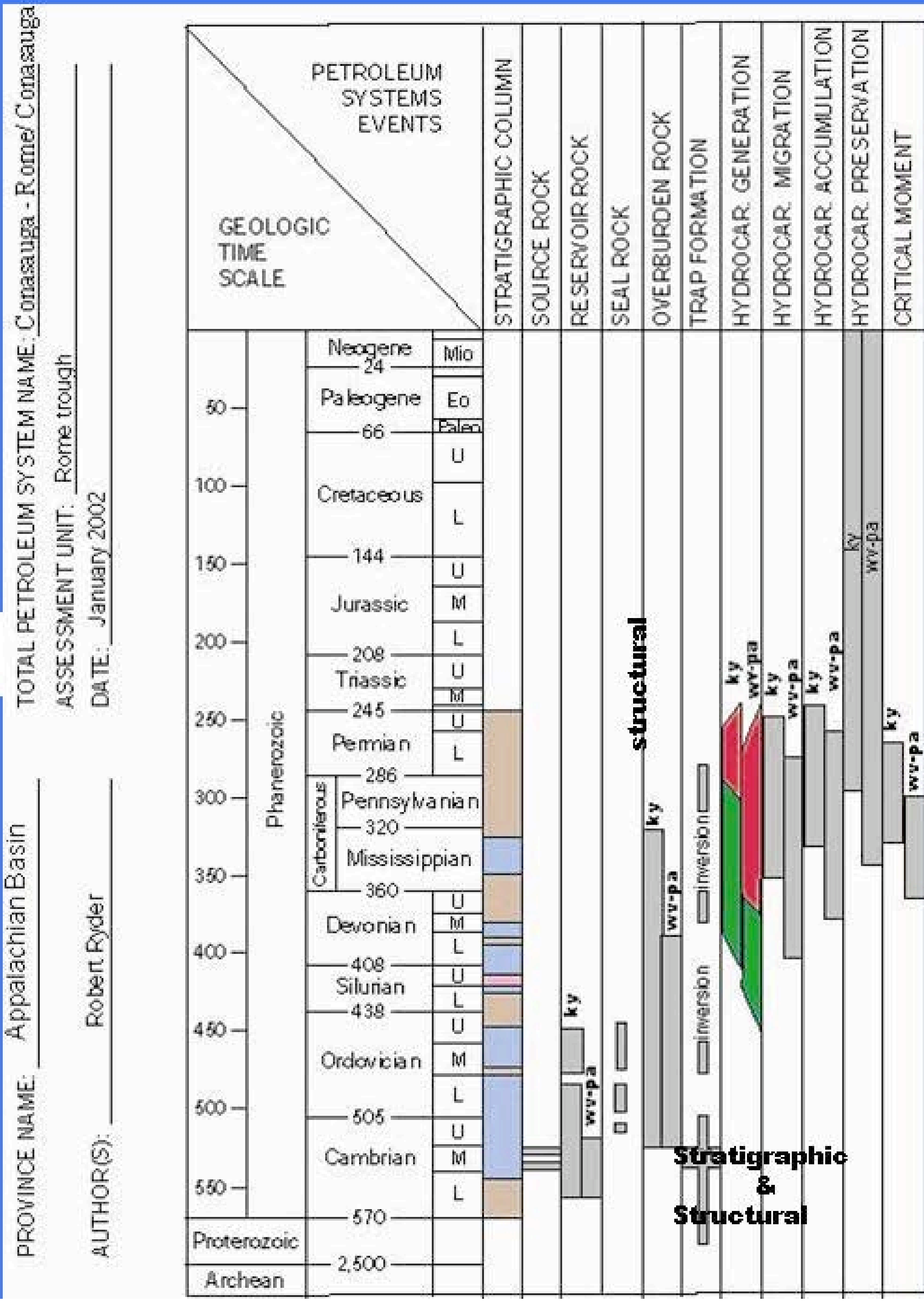


Table 1. Data for wells, sample depths, total organic carbon content (weight percent), and RockEval analyses

Well name	Latitude Longitude	API number	Age & unit sampled	Sample depth (ft)	Total organic carbon (wt.%)	T_{max} (°C)	HI (mgHC/g orgC)	OI ($mgCO_2$/g orgC)	S_1 (mgHC/g orgC)	S_2 (mgHC/g orgC)	S_3 ($mgCO_2$/g orgC)	PI
Texaco No.1 Kirby, Garrard Co., KY	37°43'03"N 84°37'56"W	1607921048	Cambrian Rome Formation	4,628	3.26	444	417	11	0.55	13.61	0.35	0.04
				4,628.8	0.70	446	356	16	0.30	2.49	0.11	0.11
Columbia Gas Transmission 9674T Mineral Tract 10, Mingo Co., WV	37°54'16"N 82°10'10"W	4705900805	Cambrian Rome Formation	16,233.5	0.15	–	33	180	0.04	0.05	0.27	0.50
				16,235.5	0.51	–	15	54	0.12	0.08	0.28	0.60
				16,239.5	0.58	–	15	46	0.15	0.09	0.27	0.62
Exxon No.1 McCoy, Jackson Co., WV	38°43'50"N 81°34'12"W	4703501366	Cambrian Maryville Limestone of the Conasauga Group	14,364.5	0.19	–	26	200	0.02	0.05	0.38	0.33
				14,380.5	0.59	–	18	54	0.13	0.11	0.32	0.54
				14,386.5	0.25	–	40	112	0.09	0.10	0.28	0.50
				14,400.5	0.51	–	29	86	0.12	0.15	0.44	0.46
			Cambrian Rome Formation	16,310	0.84	428	49	–	0.23	0.41	–	0.36
				16,461	0.09	–	88	177	0.05	0.08	0.16	0.42
				16,493	0.11	–	63	190	0.05	0.07	0.21	0.42
Exxon No.1 Smith, Wayne Co., WV	38°13'09"N 82°32'05"W	4709901572	Cambrian Rogersville Shale of the Conasauga Group	11,150.5	2.83	460	61	13	1.79	1.72	0.36	0.51
				11,161.5	4.40	469	59	6	2.71	2.58	0.27	0.51
				11,161.5 (extracted)	3.16	477	40	10	0.08	1.26	0.32	0.06
				11,180.5	1.20	414	63	23	0.81	0.75	0.27	0.52
				11,195.5	2.08	465	55	12	1.60	1.15	0.25	0.58
			Cambrian Rome Formation	12,440.3	0.15	475	13	100	0.03	0.02	0.15	0.60
				12,478.5	0.22	361	32	50	0.03	0.07	0.11	0.30
				12,497	0.14	299	7	50	0.03	0.01	0.07	0.75
				13,710.5	0.13	319	38	85	0.03	0.05	0.11	0.38
				13,734.5	0.21	299	43	48	0.04	0.09	0.10	0.31