REGIONAL SEISMIC LINES IN WEST VIRGINIA – *A PRELIMINARY LOOK AT THE ROME TROUGH AND ITS IMPLICATIONS FOR ENERGY RESOURCES*

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U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

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ACKNOWLEDGEMENTS

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ABSTRACT

The United States Geological Survey (USGS) acquired the license to 30 regional single-fold seismic lines in western and central West Virginia in support of ongoing structural and stratigraphic framework studies and energy assessments in the central Appalachians. This report illustrates single-fold seismic reflection data and associated support information. The locations of these regional lines form an irregular grid, generally mimicking drainage topography, which cover portions of western and central West Virginia.

This seismic data set was received digitally in SEG-Y format. The data were loaded into a workstation and initial interpretations were made using computer-assisted seismic interpretation software. Construction of digital synthetic seismograms for 16 wells having sonic logs located in the study area were completed in order to tie the seismic data, recorded in time, with actual formations penetrated by exploration boreholes, recorded in depth. The resultant comparisons confirmed the identification of a number of regional reflectors, such as the Trenton Limestone, a gas-producer in the region. Regional structure, such as faults, unconformities, and flexures associated with the opening of the Rome Trough, were also examined to judge the value of integration of this dataset for use in future studies of the structure of western West Virginia.

The CD-ROM contains digital files of the following: 1) This written report; 2) a small-scale graphic image of each seismic line in Adobe Acrobat® PDF format; 3) a map showing the location of the data; 4) a synthetic seismogram from each if the 15 wells in the data set in QuickSyn™ format.

patterns and rugged topography. In addition, sonic logs from fifteen wells were digitized and used to create synthetic seismograms.

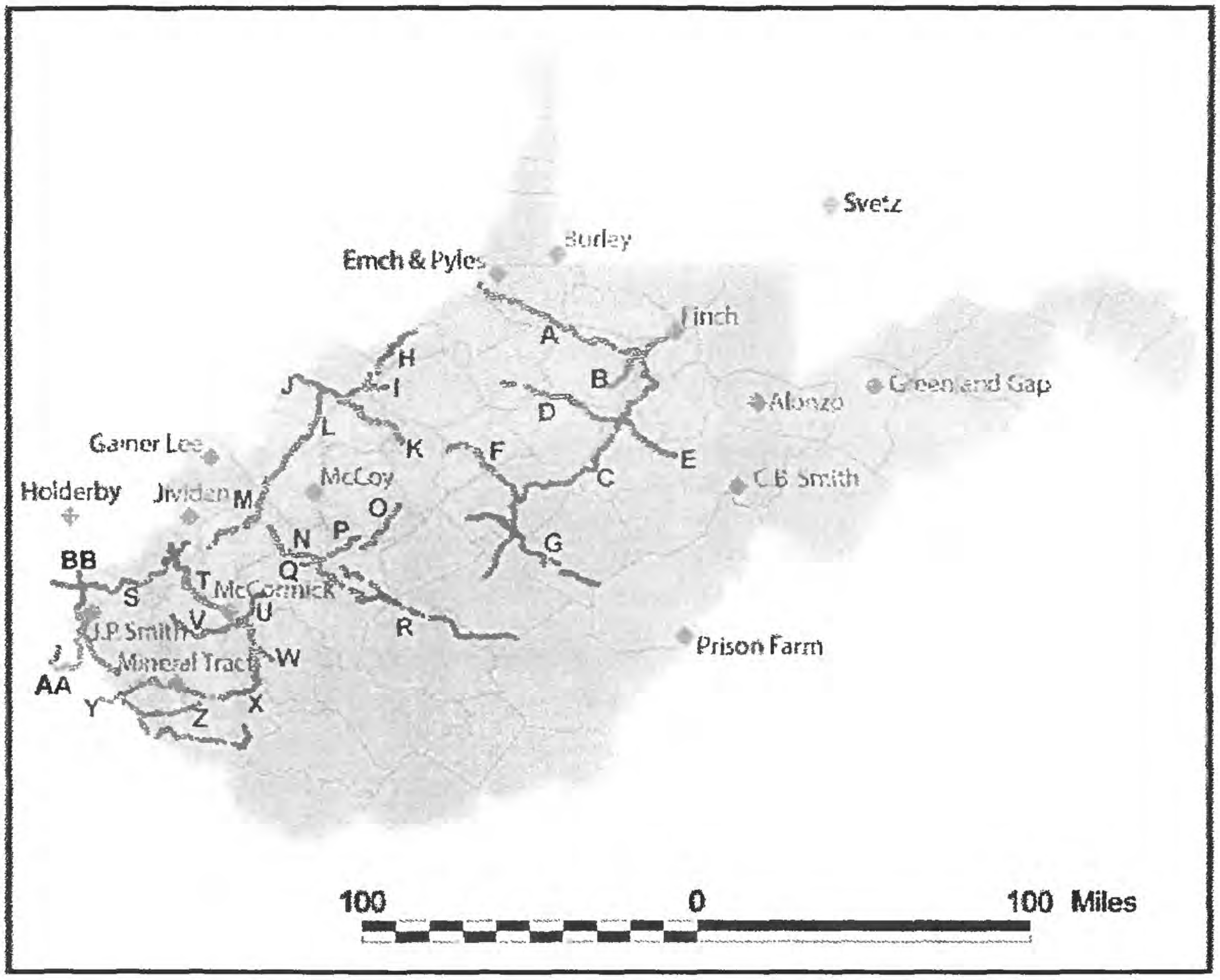

Figure 2 – Map of study area. Locations of wells are shown in orange. Location of seismic data shown in blue. Outline of Rome Trough shown by shaded region. Seismic lines labeled with letters.

The objective of the report is to analyze all 28 seismic lines, image the Rome Trough, identify the stratigraphic positions of major reflectors, and comment on relevance of the data to appraisal of energy resources. Selected line segments are interpreted and displayed in the report to show 1) overall data quality, 2) tops of prominent formations that correlate across most of the region, and 3) interesting geologic features that require more detailed analysis. Once synthesis and analysis of the data was

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ACQUISITION AND PROCESSING SPECIFICS

The seismic reflection data acquired for this study is located primarily in western and northern West Virginia, within a longitudinal window of approximately 79° to 84° W and within a latitudinal window of 37° to 39.5° N. These single-fold lines were shot from 1954-56. The coverage is very erratic, with wide areas within the study boundary entirely devoid of data and others, particularly in corridors roughly parallel to the Ohio and Big Sandy rivers, well covered.

This dataset was transcribed, digitally converted, and reprocessed through the following processing sequences:

1) resampling (as required)
2) datum correction
3) trace equalization
4) predictive deconvolution
5) constant velocity analysis
6) migration
7) normal moveout corrections (NMO)
8) hand statics
9) residual statics (as required)
10) time variant band pass filter
11) signal enhancement

The seismic data were acquired in lines of varying lengths. The longer lines typically reach 50 miles or more in length, whereas shorter lines can be limited to about 10 miles in length. Due to the rough topography, rivers, and cultural features, the data is often marked by gaps that limit resolution, particularly of shallower features.

INTRODUCTION

This study investigates the feasibility of using the single-fold seismic data to image Central Appalachian stratigraphy and structure through the identification of specific formations and sequences on the seismic data. Of particular importance is the nature of basement structure in the Rome Trough, a northeast-trending graben system of Middle Cambrian age, and its controls on syn-rift and post-rift depositional and structural trends. In turn, these trends may have influenced the distribution and quality of oil, gas, and coal in the region. For example, West Virginia is the largest coal producer in the eastern United States, and the distribution and thickness of Pennsylvanian strata containing the thickest coal beds in West Virginia may be a result of the geometry and development of the Rome Trough. Furthermore, growing interest in coal quality has yielded interest in the source of contaminants such as arsenic and sulfur, which may indirectly be influenced by fluid flow that, in turn, is governed by deep structures and faults which can only be imaged with seismic data.

Interest in natural gas has increased in recent years. The Trenton and Black River formations have been targeted for natural gas exploration and development in western West Virginia. Several minor discoveries have been made in the Trenton and Black River formations, primarily in Roane and Calhoun counties, and the number of drilling permits continues to rise (Avery, 2000).

To analyze the basement structure of the Central Appalachians, the USGS licensed 28 reprocessed 2-D regional seismic reflection transects across portions of western and central West Virginia (Fig. 1). These lines are single-fold data brokered by GeoFile, Inc. The data was gathered along roadsides in a region with dendritic stream

The input frequencies range from to 20 –90 Hz, the most common range of frequencies for explosive charges in this vintage of data. The higher frequencies associated with dynamite in exploration-grade reflection surveys on land typically attenuate quickly. It is likely that by a depth of 15,000-20,000 feet, or roughly equal to basement on the flanks of the Rome Trough and the Beekmantown in the trough, the dominate frequency range is reduced to 30-40 Hz. The thinnest layers resolvable with a 40 Hz wavelet are, at best, 150-200 feet. Thinner beds are typically impossible to image successfully, but still can interfere with the signal response of thicker beds.

As mentioned before, the lines have a complex acquisition geometry. Given the tortuous route of the lines, some minor undulations observed in the data are unrelated to the local geology. The seismic lines were set out along roads that followed the irregular topography of West Virginia. Thus, while the overall sinuosity of the dataset is low, locally the data meanders. Given unfolded strata, this winding of lines will usually not produce counterfeit structures on the seismic section. Where dipping strata are encountered, however, sharp changes in the line's shooting direction can cause disjointed changes in the reflector geometry. These bends in the line often give rise to false images that look like structures, generally small folds, but are actually the beds dipping in a single direction. Furthermore, complex line acquisition geometry does not truly represent the location of the line on the map, as the navigational files of the line are simplified by the interpretation package so that the line consists of shot points connected by straight lines, when in fact the receivers are not in a straight line between the shot points. This effect, however, is thought not to affect the navigation of the survey noticeably.

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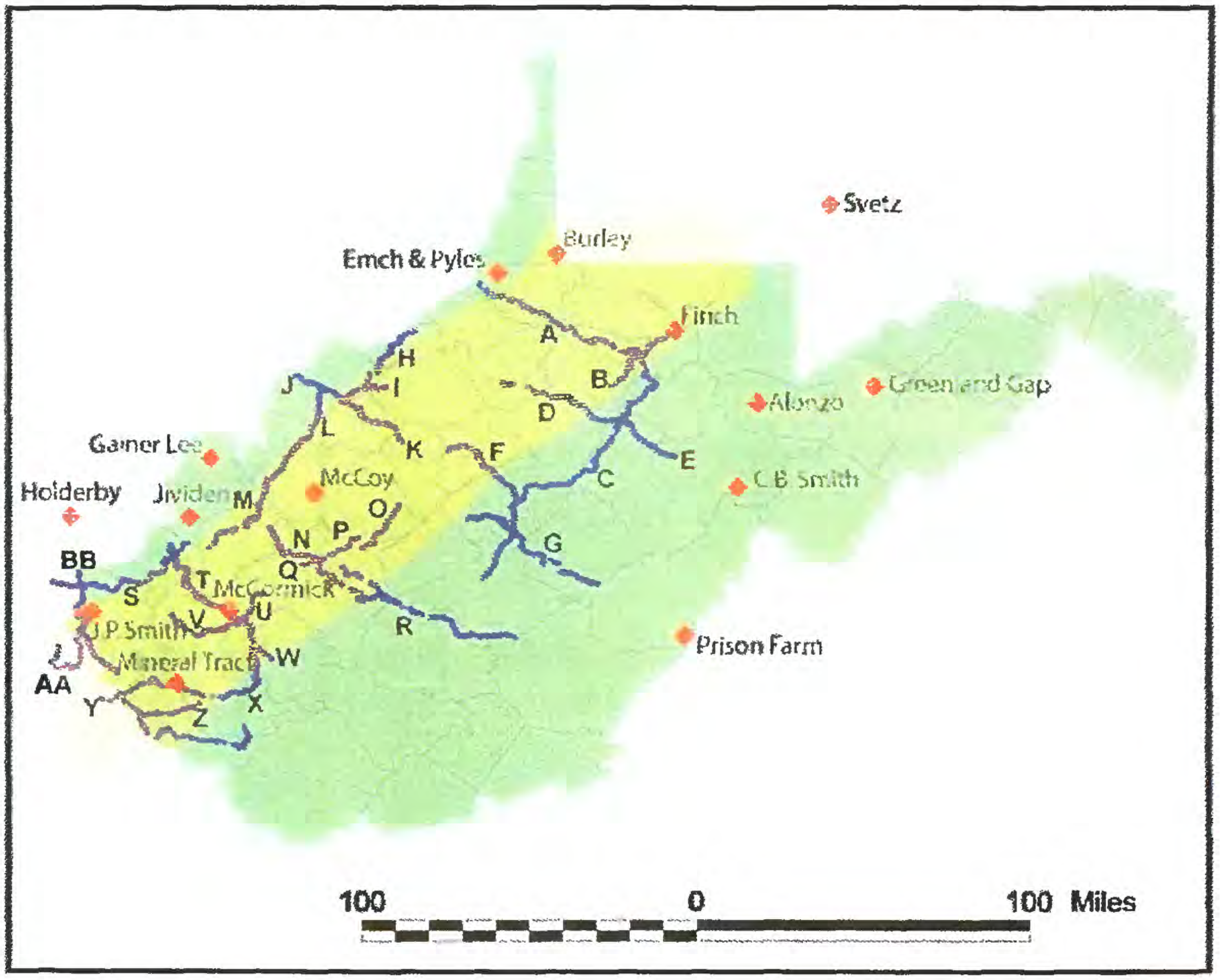

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Fig. 2) all meet these criteria. The Greenbrier Limestone, although a strong regional reflector, is too high in the stratigraphic section for it to appear on the single-fold seismic data. It is discontinuous on the seismic data and many of the sonic logs do not begin at such a shallow depth. Similarly, few wells penetrate basement so correlation between synthetic seismograms having a basement reflection and surface seismic data are sparse.

complete, the basic geometry of the Rome Trough was imaged and the tops of some of the prominent formations were correlated across most of the study area.

Although rifting had ended, differential subsidence continued in the syn-rift the trough between Late Cambrian and Early Ordovician time, forming a thickened zone of post-rift strata of the Knox group. By about the end of the Early Ordovician time, differential subsidence ceased providing accommodation space and the thickness of the Trenton Limestone (a prominent reflector) and younger post-rift strata remained relatively constant over the Rome trough.

Despite the data limitations, the basic outline of the Rome Trough is clearly visible on the longer lines and certain portions are resolvable on many of the shorter lines. Below the basement unconformity, few internal reflections and little structure is resolvable in the Middle Proterozoic metamorphic and igneous rocks. Outside the east and west flanks of the Rome Trough, the coherency of the signal below the Trenton Limestone decreases significantly, particularly that of the top of basement. This lack of coherent reflectors is caused by the absence of the many sandstones which overlie basement in the center of the trough. On the flanks, dolomite of the Copper Ridge Formation (eastern side) and the Knox Group (western side) lie directly on the basement (Ryder and others, 1996). Therefore the density and velocity contrast between the basement and the syn- and post-rift strata is diminished when compared to the interior of the trough. Within the flanking normal faults, sandstone associated with the Rome Formation and a number of other, unnamed shale and sandstone layers, lie on the basement. Here the amplitude at the top of basement is generally stronger than in the flanks, despite the significantly deeper depths.

The Rome trough dominates the geometry of the syn-rift sediments. Ryder (1992) and Shumaker and Wilson (1996) cited well log and seismic reflection data, respectively, that clearly illustrate a thick series of synrift strata. The margin of the Rome trough are

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REGIONAL STRUCTURAL FRAMEWORK

The Rome trough is a Cambrian extensional feature that lies primarily in the northwestern half of West Virginia. The trough runs parallel to regional structural strike and roughly parallel to the northwestern border of West Virginia (Fig 1). It is a portion of a larger system of grabens that continue north and south along the central Appalachian foreland (Thomas, 1991; Shumaker and Wilson, 1996). The Rome trough is thought to have formed during the latest stages of the Early Paleozoic extension opening of the Iapetus Ocean.

Previous interpretations of the Rome trough by Shumaker and Wilson (1996), on seismic data located very close to the lines in this dataset, show a series of major normal faults bounding the flanks of the Rome trough. The normal faults that bound the Rome Trough are visible in this data set as high angle offsets that step into the basin though the Cambrian- and Ordovician-aged strata (from the basement up to somewhere in the thick Beekmantown group depending on the line). Basin-bounding faults are easily visible on many of the NW-SE sections, and their uppermost extents mark the boundary between syn- and post-rift sediments. Wilson (2000) noted the eastern side of the Rome trough is controlled by one large 'East-Margin' fault with displacement increasing northward from 1 km near the McCormick well to a maximum of 1.7 km before shrinking back to 1 km near the Pennsylvania-West Virginia state line. While exact measurements like these are difficult on this dataset due to lack of proximal well data, the presence of up to *three* primary faults marking the southeastern boundary of the Rome trough is strongly suggested (Fig. 3). On the northwestern side of the Rome Trough, the lines are too sparse

SEISMIC IMAGING

The single-fold nature of the data renders everything younger than the Greenbrier Limestone (Table 1), including coal seams, nearly uninterpretable. Coal resources in the regions are primarily located in Pennsylvanian strata, with the thickest being the Pittsburgh coal-bed in the Conemaugh Group. In the study area, Pennsylvanian and younger strata are nearly impossible to image, primarily because the data is the single-fold. The end-to-end placements of the processed seismic records leave gaps in the data which show up as triangle-shaped muted zones which start at 0.3 seconds and widen until almost no signal is recorded at 0.1 seconds or less. In areas where a record or two could not be acquired because of topographical or cultural reasons, the gaps in the data are even larger. The only discernible and consistent horizon in the muted time segment is the Mississippian Greenbrier Limestone, which is present between 0.2 to 0.4 seconds on the seismic data and corresponds to an approximate depth of about 500-1300 feet. This problem is aggravated by irregular topography, erratic line geometry, and gaps in the lines. Similarly, structures affecting strata younger than Mississippian are nearly impossible to image. The most prominent reflectors are generally found at the interface between shale and an underlying limestone or dolomite layer, such as the Onondaga and Conasauga groups. Here, the reflection coefficients are the highest. Therefore, the tops that are commonly the easiest to see are the Greenbrier Limestone, Onondaga Limestone, Trenton Limestone, and the Beekmantown Group (Table 1). The Grenvillian basement is also intermittently bright, as alternating Phanerozoic strata of differing acoustic impedances overly the denser Precambrian crust.

reactivated basement faults and subsequent compression (Rodgers, 1963), is visible on one line that is located in the northwestern portion of the study area (Fig 1).

The Burning Springs anticline is a positive flower structure that indicates compressive oblique movement preceded by normal fault movement. The anticline marks the location of a regional east-dipping syndepositional growth fault that dates from approximately Ordovician times. A small amount of syndepositional growth across the fault can be seen, slightly below the Trenton Limestone, but resolution problems prevent imaging of growth across the fault below the Trenton Limestone.

Subsequent reactivation of the fault zone by oblique compression led to the formation of a positive flower structure that is rooted in Lower Cambrian or older strata. The Paleozoic rocks are lifted into what looks like a tent-shaped box fold where the snap bends in the strata are marked by faults. Although only one seismic line crosses the anticline, the symmetrical geometry of the anticline strongly suggests the line is perpendicular to the strike of the fault, indicating the Burning Springs anticline is nearly north-south in strike.

The Burning Springs anticline displays a remarkable resemblance to the Cambridge fault zone (Root, 1996). However, unlike the Cambridge fault zone, no salt can be seen in proximity to the Burning Spring anticline. Furthermore, the relief across the Burning Springs anticline appears significantly greater, reaching approximately 250 ft or more. Dating the reverse movement of the faults is difficult, but offsetting relationships would suggest an age of the Alleghenian orogeny, concurring with tectonic histories that indicate regional compression during that time (Shumaker and Wilson, 1996).

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Interest in coal quality, such as sulfur and arsenic content, has focused attention on fault-controlled fluid flow in regions below coal production. High concentration of sulfur, arsenic, and other elements in these fluids are thought to influence coal geochemistry with these contaminants. Faults that may serve as conduits for fluids which later contaminate coal seams can also be interpreted on a few of the northwest-southeast sections that cross the edges of the Rome trough.

Natural Gas

Much of the future natural gas potential in the Appalachian Basin lies in deeper, relatively unexplored Lower Paleozoic strata. These strata are present within the Rome trough, which already has semi-economic fields throughout its length. For example, the Trenton Limestone, an emerging gas producer in the Central Appalachians, is clearly visible as a strong positive amplitude event throughout the area of seismic coverage (Fig. 3), and minor structures along the tops of the Trenton and other formations can be seem of the seismic data.

Gas recovery is enhanced by high permeability. Fracture zones are one way of enhancing permeability, and strata throughout West Virginia exhibit systematic fracturing (Kulander and Dean 1993). These fracture patterns, however, are not visible on this seismic data. The data does not contain the higher frequencies that permit analysis of regional fracture trends.

Hydrocarbons have been shown to affect amplitudes on seismic sections. Oil and gas slow the propagation of P-waves and thus often yield negative amplitudes at the interface above a hydrocarbon reservoir. Of particular interest are bright spots, smallish high amplitude zones, which in places like the Gulf of Mexico indicate concentrations of

Correlating reflectors on the seismic data to actual formation tops is greatly facilitated by the synthetic seismograms that were generated from sonic logs in the region (Fig. 2). Although the wells are almost never directly coincident with the seismic lines, their proximity, combined with the relatively straightforward regional structural framework, make it possible to convincingly correlate major reflectors to actual tops.

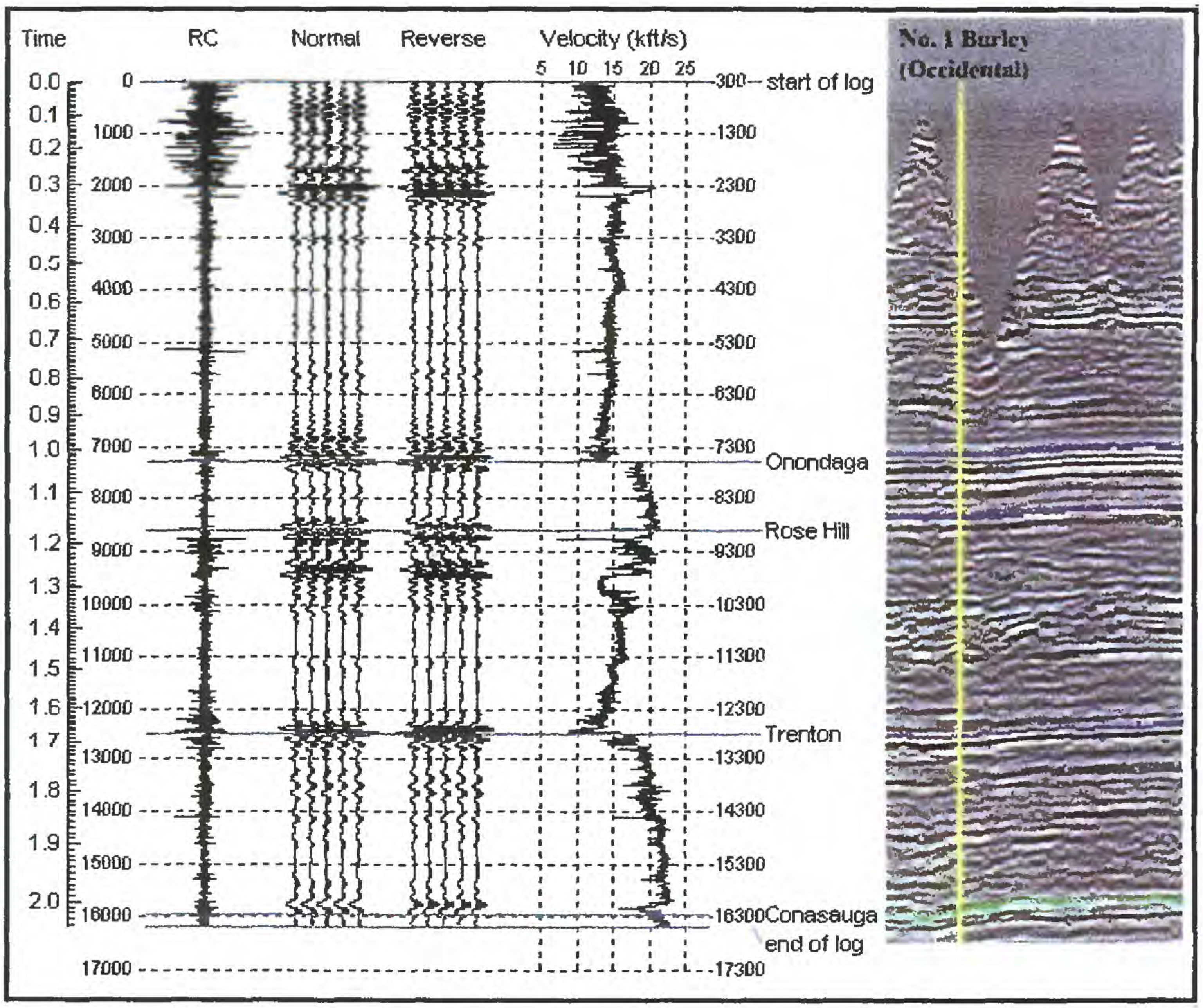

Figure 2 – Correlation of the synthetic seismogram from Occidental Petroleum's No. 1 Burley well to seismic line A (location shown in Fig. 1). Even over a gap of more than 15 miles, several regional reflectors can be correlated to the synthetic.

The best formations to use for synthetic seismogram to seismic section correlation are units with both high reflection coefficients and a regional continuity. The Onondaga Limestone, Rose Hill Formation, Trenton Limestone, and the Conasauga Group (Table 1;

CONCLUSIONS

This dataset is useful for general regional structural studies over the Rome trough. The wide grid of data provides reasonable imaging of the syn- and post-rift sedimentary sequences as well as the geometry of the top of basement. The well data allows the correlation of some of the formations to individual reflectors. Large structures such as trough-bounding faults are also visible, although interpreting individual faults from line to line is often impossible. The most widely interpretable strata are rocks with high seismic velocities, typically limestone, that are overlain by shale. These typically have formation tops with striking positive amplitudes and include the Conasauga Limestone, the Greenbrier Limestone, and the gas-bearing Trenton Limestone. In addition, thicker units of strata may have internal members that show up on seismic, such as the Beekmantown member of the Knox Group.

The limitations of this dataset are numerous. Upper Mississippian and younger strata are too thin and shallow to be accurately imaged, preventing interpretation of individual coal seams or thin coal-bearing strata. Intra-formational features such as facies sequences or small channels are also below the resolution of these data.

Thickness changes of the sediments in the Rome trough convey a general history of the basin. The pre-rift basement dates from the Grenvillian. The earliest syn-rift sediment, the Mount Simon Formation, dates from the Middle Cambrian. The opening of the basin occurred asymmetrically, with the southeastern side of the basin subsiding more than northwestern side. Within the stratigraphic interval showing the greatest thickening over the basin-boundary faults lies the Rutledge Formation and the Beekmantown

Fig. 2) all meet these criteria. The Greenbrier Limestone, although a strong regional reflector, is too high in the stratigraphic section for it to appear on the single-fold seismic data. It is discontinuous on the seismic data and many of the sonic logs do not begin at such a shallow depth. Similarly, few wells penetrate basement so correlation between synthetic seismograms having a basement reflection and surface seismic data are sparse.

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REGIONAL STRATIGRAPHY

The regional stratigraphy is well constrained by well data and surface mapping and can be divided into three sequences based on the opening of the Rome trough. All rocks below the unconformity at the top of the Grenvillian basement represent the pre-Rome trough record. The section from the Mount Simon Formation to the Conasauga Formation represents the syn-rift record; these strata having been deposited while the normal faults and flexure on either side of the Trough were active (Table 1).

Pennsylvanian	Monongahela Group Conemaugh Group Allegheny Group Pottsville Group
Mississippian	Mauch Chunk Group *Greenbrier Limestone* MacCrady Formation Pocono Group
Devonian	Ohio Shale West Falls Group (shale) *Onondaga Limestone* Oriskany Sandstone Helderberg Limestone
Silurian	Salina Group Lockport Dolomite Rose Hill Formation Tuscarora Sandstone
Ordovician	Juniata Formation Martinsburg Formation *Trenton Limestone* Black River Group Wells Creek formation Knox Group: a) Beekmantown Formation
Cambrian	b) Rose Run Sandstone c) Copper Ridge Formation *Conasauga Formation* Rome Formation Mount Simon Formation
	Basement unconformity
Precambrian	Grenvillian Basement

Table 1 – General stratigraphic column in western West Virginia. Prominent reflectors in italics. (Modified from Shumaker and Wilson, 1996; Root, 1996; and Ryder and others, 1996)

APPENDIX B:

DESCRIPTION OF THE FILES ON THIS CD-ROM

Digital Images of Seismic Displays: Small-scale displays of each line have been generated on a GEOGRAPHIX/SEISVISION® work station at a horizontal scale of 1:250,000 for distance and 1.5 inches/second for two-way travel time ("PRN" files). Although the vertical exaggeration of these displays is approximately 6:1 (assuming an average velocity of 10,000 ft/sec), the longest line (R-15) is about 78 inches long. The PRN files from SEISVISION were converted to compressed Adobe Acrobat® PDF files using the "Distiller" function in Adobe Illustrator®. The,.PDF files can be opened, viewed, and printed using the free downloadable version of Adobe Acrobat® Reader 4.0. There are two sets of numbers at the top of each display, one labeled 'Shot' indicating Shotpoint number, the other CMP which is an acronym for Common Mid Point and is equivalent to the term CDP used elsewhere in this document. On the displays, these numbers are the same because as described above, we made the Shotpoint number equal to the CDP number in order to have a unique index number for each.

Base Map: The base map was constructed using Arc-Info software with further enhancements made in Adobe Illustrator®.

Synthetic Seismogram: Sonic logs for 16 wells in the region were digitized from paper logs by Center Line Data of Denver and used to create synthetic seismograms. The resultant digitized sonic logs were converted to synthetic seismograms by using the QuickSyn ™ program, version 3.0, by GeoTools. These synthetics, annotated with formation tops from drilling records and information from previous literature, were then inserted into the seismic sections to correlate reflectors to specific formations.

Although rifting had ended, differential subsidence continued in the syn-rift the trough between Late Cambrian and Early Ordovician time, forming a thickened zone of post-rift strata of the Knox group. By about the end of the Early Ordovician time, differential subsidence ceased providing accommodation space and the thickness of the Trenton Limestone (a prominent reflector) and younger post-rift strata remained relatively constant over the Rome trough.

Despite the data limitations, the basic outline of the Rome Trough is clearly visible on the longer lines and certain portions are resolvable on many of the shorter lines. Below the basement unconformity, few internal reflections and little structure is resolvable in the Middle Proterozoic metamorphic and igneous rocks. Outside the east and west flanks of the Rome Trough, the coherency of the signal below the Trenton Limestone decreases significantly, particularly that of the top of basement. This lack of coherent reflectors is caused by the absence of the many sandstones which overlie basement in the center of the trough. On the flanks, dolomite of the Copper Ridge Formation (eastern side) and the Knox Group (western side) lie directly on the basement (Ryder and others, 1996). Therefore the density and velocity contrast between the basement and the syn- and post-rift strata is diminished when compared to the interior of the trough. Within the flanking normal faults, sandstone associated with the Rome Formation and a number of other, unnamed shale and sandstone layers, lie on the basement. Here the amplitude at the top of basement is generally stronger than in the flanks, despite the significantly deeper depths.

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APPENDIX D:
SYSTEM REQUIREMENTS

This disc will operate properly on any PC hardware platform capable of reading the ISO 9660 standard. The display programs and other software packages can access the data files directly from the CD-ROM. Technical information is contained in files in MS-WORD format and Internet format. Graphics files are contained in Adobe Acrobat® PDF format. Minimum hardware/software requirements are as follows:

All Platforms: CD-ROM drive with ISO 9660 software driver, software capable of reading ASCII text files and PDF-format graphics files. Technical information can also be accessed by software capable of reading MS-WORD97 format or Internet format files.

IBM-compatible P/C: To use the display software: 640K main memory, hard (fixed) disk, monochrome monitor, EGA/VGA/SVGA graphics, MS or PC-DOS 3.1 or higher. See Appendix A for details of the IBM P/C-compatible seismic display software provided on this CD-ROM.

defined by abrupt increases in thickness within the stratigraphic section from the Mt. Simon Formation through the Beekmantown Formation. This increase in thickness over the boundary faults and flexures decreases gradually upward in the section, indicating a gradual change in the rate of fault movement and post-rift differential subsidence, roughly concurring with Wilson's (2000) Rome trough reconstructions, particularly along the western boundary of the Rome trough. The Trenton Limestone is the youngest formation affected by post-rift differential subsidence, and that is observed only in the deeper parts of the Rome trough along the West Virginia and Pennsylvania border. The upper contact of the Trenton Limestone is unaffected by post-rift differential subsidence throughout the study area.

Post-rift strata are generally well imaged throughout the survey. The strongest reflectors in the post-rift sequence are typically the Greenbrier Limestone, the Onondaga Limestone, and the Rose Hill Formation (Fig. 3).

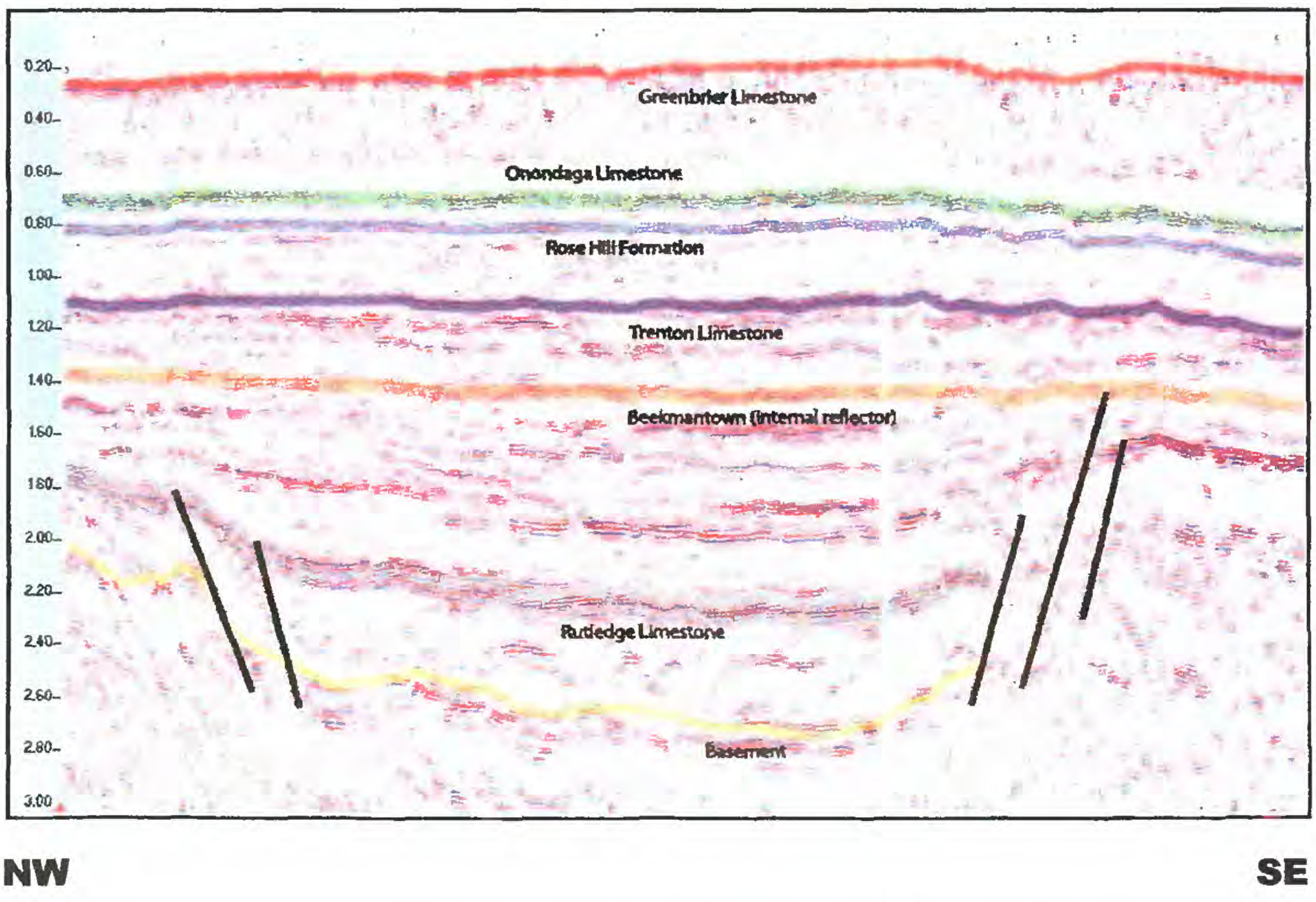

Figure 3 – Northwest-southeast seismic section N (location shown in fig. 1), showing the Rome Trough and some prominent reflectors. Boundary faults are visible on the flanks of the basin.

REGIONAL STRUCTURAL FRAMEWORK

The Rome trough is a Cambrian extensional feature that lies primarily in the northwestern half of West Virginia. The trough runs parallel to regional structural strike and roughly parallel to the northwestern border of West Virginia (Fig 1). It is a portion of a larger system of grabens that continue north and south along the central Appalachian foreland (Thomas, 1991; Shumaker and Wilson, 1996). The Rome trough is thought to have formed during the latest stages of the Early Paleozoic extension opening of the Iapetus Ocean.

Previous interpretations of the Rome trough by Shumaker and Wilson (1996), on seismic data located very close to the lines in this dataset, show a series of major normal faults bounding the flanks of the Rome trough. The normal faults that bound the Rome Trough are visible in this data set as high angle offsets that step into the basin though the Cambrian- and Ordovician-aged strata (from the basement up to somewhere in the thick Beekmantown group depending on the line). Basin-bounding faults are easily visible on many of the NW-SE sections, and their uppermost extents mark the boundary between syn- and post-rift sediments. Wilson (2000) noted the eastern side of the Rome trough is controlled by one large 'East-Margin' fault with displacement increasing northward from 1 km near the McCormick well to a maximum of 1.7 km before shrinking back to 1 km near the Pennsylvania-West Virginia state line. While exact measurements like these are difficult on this dataset due to lack of proximal well data, the presence of up to *three* primary faults marking the southeastern boundary of the Rome trough is strongly suggested (Fig. 3). On the northwestern side of the Rome Trough, the lines are too sparse to correlate trough-boundary faults from one section to another, but the presence of a series of smaller normal faults that step-up to the northwest is strongly evident.

Evidence of thin-skinned tectonics, common to the Valley and Ridge structural province to the east, is not visible in this dataset. The south- and easternmost portions of this dataset end before reaching the more structurally complex Allegheny Plateau and related fold and thrust belts of the Valley and Ridge province to the east. Extensive diffractions and sporadically dipping reflectors suggest structures below basement and may also indicate that the basement unconformity is likely angular in nature.

The Burning Springs anticline (Fig. 4), a basement-related fold caused by

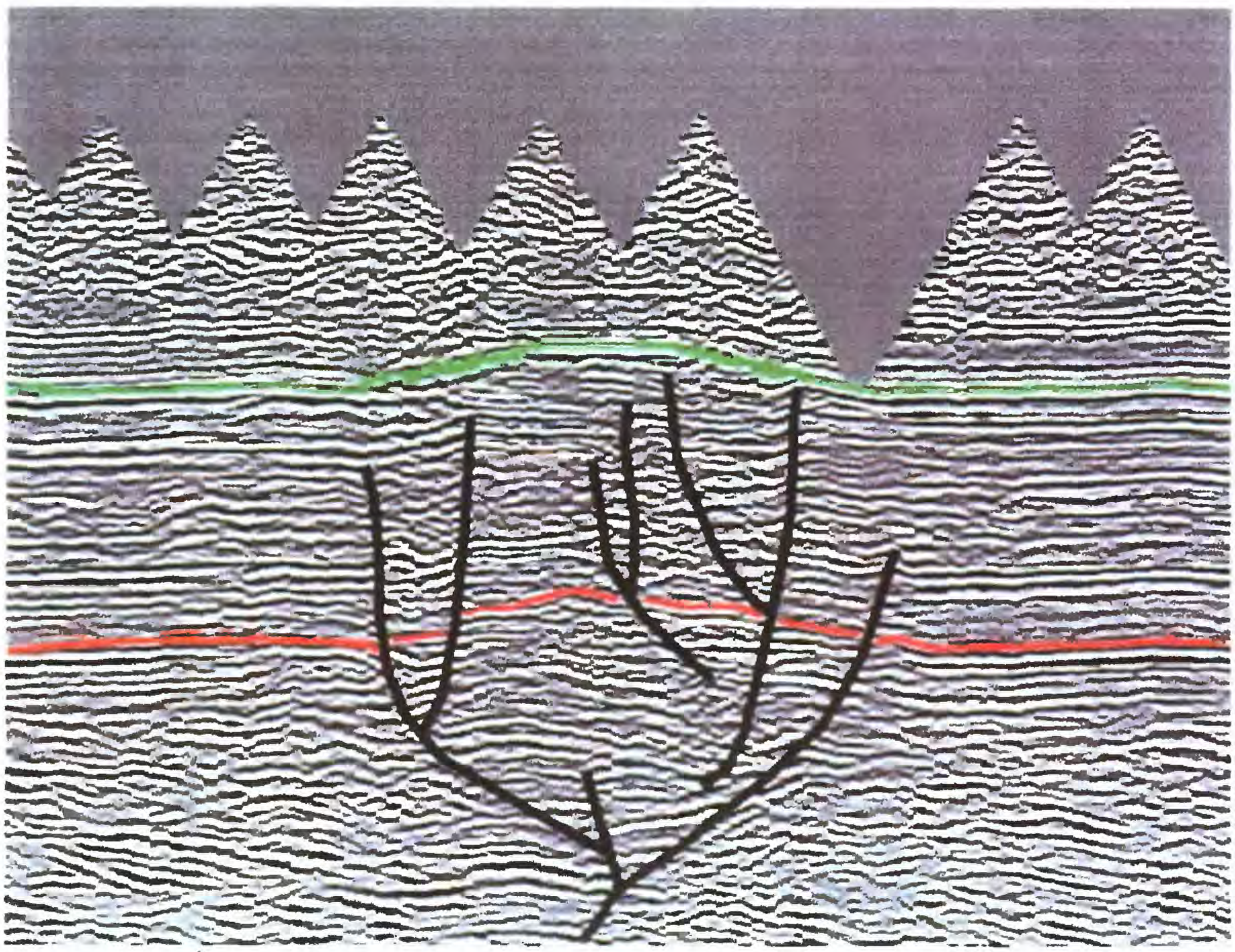

Figure 4 - East-west seismic line (line H, shown in Fig. 1) over Burning Springs anticline. The Onondaga Limestone is shown in green. The Trenton Limestone is shown in red. Faults are shown in black.

reactivated basement faults and subsequent compression (Rodgers, 1963), is visible on one line that is located in the northwestern portion of the study area (Fig 1).

The Burning Springs anticline is a positive flower structure that indicates compressive oblique movement preceded by normal fault movement. The anticline marks the location of a regional east-dipping syndepositional growth fault that dates from approximately Ordovician times. A small amount of syndepositional growth across the fault can be seen, slightly below the Trenton Limestone, but resolution problems prevent imaging of growth across the fault below the Trenton Limestone.

Subsequent reactivation of the fault zone by oblique compression led to the formation of a positive flower structure that is rooted in Lower Cambrian or older strata. The Paleozoic rocks are lifted into what looks like a tent-shaped box fold where the snap bends in the strata are marked by faults. Although only one seismic line crosses the anticline, the symmetrical geometry of the anticline strongly suggests the line is perpendicular to the strike of the fault, indicating the Burning Springs anticline is nearly north-south in strike.

The Burning Springs anticline displays a remarkable resemblance to the Cambridge fault zone (Root, 1996). However, unlike the Cambridge fault zone, no salt can be seen in proximity to the Burning Spring anticline. Furthermore, the relief across the Burning Springs anticline appears significantly greater, reaching approximately 250 ft or more. Dating the reverse movement of the faults is difficult, but offsetting relationships would suggest an age of the Alleghenian orogeny, concurring with tectonic histories that indicate regional compression during that time (Shumaker and Wilson, 1996).

IMPLICATIONS FOR ENERGY RESOURCES

This set of seismic and well data is located in proximity to important coal and natural gas reserves and resources. While the sparse density of data prohibits detailed analysis of these resources themselves, such as coal maps or amplitude extraction ("bright spot") analysis in gas reservoirs, interpretation of regional petroleum migration and structural framework studies will benefit from inclusion of this dataset.

Coal and Coal-bed Methane

The irregular topography of West Virginia makes static corrections necessary and difficult. The variations in elevation, combined with the age and quality of the data conspire against imaging the Pennsylvanian at a level sufficient for interpretation. In addition, the thin and sporadic coal beds within the Pennsylvanian are below the resolution of this older seismic data. Indirect interpretation of the coal through thicker and less ephemeral formations is a possibility in areas where the younger strata are visible on the data.

Whereas coal resources are not directly visible on this seismic data, this dataset does contain pertinent information about deeper structures and stratigraphy that may affect coal location, quantity, geochemistry and fracture zones for coal-bed production. Location of gross coal reserves is a direct result of the tectonic framework of the Appalachians. Accurately defining the geometry of the Rome trough and neighboring provinces contributes to a more accurate the coal assessments in the region. Even if the actual coal seams are not resolvable on seismic, simply understanding the location and geometry of nearby marker beds will help locate the nearby coal seam, provided the coal can be assumed to be relatively continuous.

Interest in coal quality, such as sulfur and arsenic content, has focused attention on fault-controlled fluid flow in regions below coal production. High concentration of sulfur, arsenic, and other elements in these fluids are thought to influence coal geochemistry with these contaminants. Faults that may serve as conduits for fluids which later contaminate coal seams can also be interpreted on a few of the northwest-southeast sections that cross the edges of the Rome trough.

Natural Gas

Much of the future natural gas potential in the Appalachian Basin lies in deeper, relatively unexplored Lower Paleozoic strata. These strata are present within the Rome trough, which already has semi-economic fields throughout its length. For example, the Trenton Limestone, an emerging gas producer in the Central Appalachians, is clearly visible as a strong positive amplitude event throughout the area of seismic coverage (Fig. 3), and minor structures along the tops of the Trenton and other formations can be seem of the seismic data.

Gas recovery is enhanced by high permeability. Fracture zones are one way of enhancing permeability, and strata throughout West Virginia exhibit systematic fracturing (Kulander and Dean 1993). These fracture patterns, however, are not visible on this seismic data. The data does not contain the higher frequencies that permit analysis of regional fracture trends.

Hydrocarbons have been shown to affect amplitudes on seismic sections. Oil and gas slow the propagation of P-waves and thus often yield negative amplitudes at the interface above a hydrocarbon reservoir. Of particular interest are bright spots, smallish high amplitude zones, which in places like the Gulf of Mexico indicate concentrations of gas. The top of the Trenton Limestone is a strong reflector throughout most of the survey area, but distinguishing individual bright spots is largely below the resolution of this dataset, largely defeating modern amplitude extraction techniques used for reservoir fluid analysis. In other words, reservoir and trap assessment studies are not likely to benefit from this data.

In summary, the dataset will benefit structural framework and tectonic development studies in the Rome Trough. This, in turn, will assist in answering migration and source rock questions related to exploration. For example, speculation as to the role of basement faulting in hydrocarbon migration and maturity in West Virginia has fueled previous studies of the framework and development of the Rome Trough, primarily in central and southern West Virginia.

CONCLUSIONS

This dataset is useful for general regional structural studies over the Rome trough. The wide grid of data provides reasonable imaging of the syn- and post-rift sedimentary sequences as well as the geometry of the top of basement. The well data allows the correlation of some of the formations to individual reflectors. Large structures such as trough-bounding faults are also visible, although interpreting individual faults from line to line is often impossible. The most widely interpretable strata are rocks with high seismic velocities, typically limestone, that are overlain by shale. These typically have formation tops with striking positive amplitudes and include the Conasauga Limestone, the Greenbrier Limestone, and the gas-bearing Trenton Limestone. In addition, thicker units of strata may have internal members that show up on seismic, such as the Beekmantown member of the Knox Group.

The limitations of this dataset are numerous. Upper Mississippian and younger strata are too thin and shallow to be accurately imaged, preventing interpretation of individual coal seams or thin coal-bearing strata. Intra-formational features such as facies sequences or small channels are also below the resolution of these data.

Thickness changes of the sediments in the Rome trough convey a general history of the basin. The pre-rift basement dates from the Grenvillian. The earliest syn-rift sediment, the Mount Simon Formation, dates from the Middle Cambrian. The opening of the basin occurred asymmetrically, with the southeastern side of the basin subsiding more than northwestern side. Within the stratigraphic interval showing the greatest thickening over the basin-boundary faults lies the Rutledge Formation and the Beekmantown member the Knox Group, indicating basin subsidence reached a peak sometime during the late Cambrian to the Early Ordovician. After that, subsidence appears to have waned until the Middle Ordovician, when the basin-bounding faults ceased movement and thickening over the Rome trough no longer occurred.

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APPENDIX A:
OWNERSHIP SPECIFICATION

SEISCO, Inc., as the agent responsible for enforcing the GeoFile seismic data license agreements issued by GTS Corporation during its bankruptcy liquidation, has granted permission to the USGS to publish the report entitled "Regional Seismic Lines in West Virginia-*A Preliminary Look at the Rome Trough and its Implications for Energy Resources*", authored by Christopher S. Kulander. In order to protect the proprietary ownership rights to the seismic data evaluated in the report, SEISCO requires that the seismic lines carry arbitrary line names and not their official line names.

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APPENDIX B:

DESCRIPTION OF THE FILES ON THIS CD-ROM

Digital Images of Seismic Displays: Small-scale displays of each line have been generated on a GEOGRAPHIX/SEISVISION® work station at a horizontal scale of 1:250,000 for distance and 1.5 inches/second for two-way travel time ("PRN" files). Although the vertical exaggeration of these displays is approximately 6:1 (assuming an average velocity of 10,000 ft/sec), the longest line (R-15) is about 78 inches long. The PRN files from SEISVISION were converted to compressed Adobe Acrobat® PDF files using the "Distiller" function in Adobe Illustrator®. The .PDF files can be opened, viewed, and printed using the free downloadable version of Adobe Acrobat® Reader 4.0. There are two sets of numbers at the top of each display, one labeled 'Shot' indicating Shotpoint number, the other CMP which is an acronym for Common Mid Point and is equivalent to the term CDP used elsewhere in this document. On the displays, these numbers are the same because as described above, we made the Shotpoint number equal to the CDP number in order to have a unique index number for each.

Base Map: The base map was constructed using Arc-Info software with further enhancements made in Adobe Illustrator®.

Synthetic Seismogram: Sonic logs for 16 wells in the region were digitized from paper logs by Center Line Data of Denver and used to create synthetic seismograms. The resultant digitized sonic logs were converted to synthetic seismograms by using the QuickSyn ™ program, version 3.0, by GeoTools. These synthetics, annotated with formation tops from drilling records and information from previous literature, were then inserted into the seismic sections to correlate reflectors to specific formations.

APPENDIX C:
DISCLAIMER

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APPENDIX D:
SYSTEM REQUIREMENTS

This disc will operate properly on any PC hardware platform capable of reading the ISO 9660 standard. The display programs and other software packages can access the data files directly from the CD-ROM. Technical information is contained in files in MS-WORD format and Internet format. Graphics files are contained in Adobe Acrobat® PDF format. Minimum hardware/software requirements are as follows:

All Platforms: CD-ROM drive with ISO 9660 software driver, software capable of reading ASCII text files and PDF-format graphics files. Technical information can also be accessed by software capable of reading MS-WORD97 format or Internet format files.

IBM-compatible P/C: To use the display software: 640K main memory, hard (fixed) disk, monochrome monitor, EGA/VGA/SVGA graphics, MS or PC-DOS 3.1 or higher. See Appendix A for details of the IBM P/C-compatible seismic display software provided on this CD-ROM.