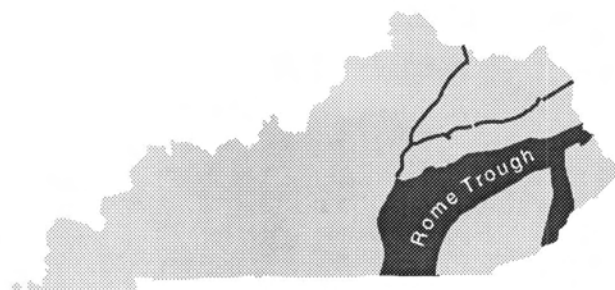


Kentucky Geological Survey
Donald C. Haney, State Geologist and Director
UNIVERSITY OF KENTUCKY

Cambrian Hydrocarbon Potential Indicated in Kentucky's *Rome Trough*



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and
James A. Drahovzal

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CAMBRIAN HYDROCARBON POTENTIAL INDICATED IN KENTUCKY'S ROME TROUGH

**David C. Harris
and
James A. Drahovzal**

ABSTRACT

A recent gas discovery in the Rome Trough has resulted in a new phase of deep exploration in eastern Kentucky. This activity is located in Elliott County, near the northern boundary fault of the Cambrian Rome Trough graben. The Carson Associates No. 1 Kazee well was drilled in 1994, and blew out with a reported uncontrolled flow of 11 million cubic feet of gas per day. Although completed at a much lower rate, this well renewed interest in the deep gas potential of the Rome Trough, which has seen sporadic drilling activity since the 1940's. Gas production in the Rome Trough is from marine sandstones and fractured shales assigned to the Cambrian Rome Formation or Conasauga Group. These units are significantly thicker in the fault-bounded extensional graben that trends west-southwest to northeast in eastern Kentucky and continues through West Virginia and Pennsylvania into New York. Recent mapping of the Precambrian basement surface has refined the structure of eastern Kentucky and the Rome Trough. Reservoir facies include fine- to very fine-grained, micaceous, and glauconitic sandstones and fractured shales. Coarser sandstones may occur near border faults, in fan-delta deposits. Traps are primarily structural, and faulting was contemporaneous with deposition. Stratigraphic traps may also exist in the trough, but have not been proven by drilling to date. Stratigraphic traps may include sandstones deposited in turbidite fans in deeper parts of the graben. Potential hydrocarbon source rocks have not been identified. Limited geochemical analyses of well and outcrop samples from the Rome and Conasauga intervals show poor hydrocarbon source potential. Composition of gas produced from the Rome Trough varies significantly in eastern Kentucky. Several occurrences of gas high in nitrogen and helium content were found in the western part of the trough, and may be related to proximity to the Grenville Front. Gas of commercial quality is typical in the eastern part of the trough, where several wells are producing gas with Btu values over 1,000. Significant hydrocarbon potential remains in the Rome Trough, but this play is characterized by complex faulting that influenced the deposition and distribution of potential reservoir rocks. Interpretation of high-quality seismic data will be a key factor to future success in this play.

INTRODUCTION

A recent gas discovery in the Rome Trough has Appalachian Basin operators re-evaluating the deep Cambrian potential of eastern Kentucky. The Rome Trough has seen sporadic exploration since the late 1940's, with very limited commercial success. A new phase of exploration activity began in mid-1994 with the completion of the Carson Associates No. 1 Kazee well in Elliott County, Ky. (Fig. 1). This well blew out during drilling and initially flowed 11 million cubic feet of gas per day (MMcfd) from a zone in the upper Conasauga Group/Rome Formation from 6,258 to 6,270 feet. Some formation damage is reported to have occurred after the well was brought under control, although the well was producing approximately 500 thousand cubic feet of gas per day (Mcfd) in

mid-1995. Carson Associates has recently drilled an off-set well to the 1994 Kazee discovery well. The No. 33 Lawson Heirs well was permitted to 7,500 feet in the Rome Formation, but results have not been announced yet.

Encouraged by Carson's Kazee well, Blue Ridge Group completed a second Elliott County Rome test in August 1995. The No. 1 Greene was drilled on a separate structure, and results have not yet been announced. The completion report and logs from this well are scheduled to be released on February 3, 1997.

These two wells are characteristic of a frustrating exploration history in the Rome Trough, which is marked by numerous gas and oil shows, but rare commercial production. Hydrocarbon shows in the trough date back to 1947, when gas and oil shows were reported from the

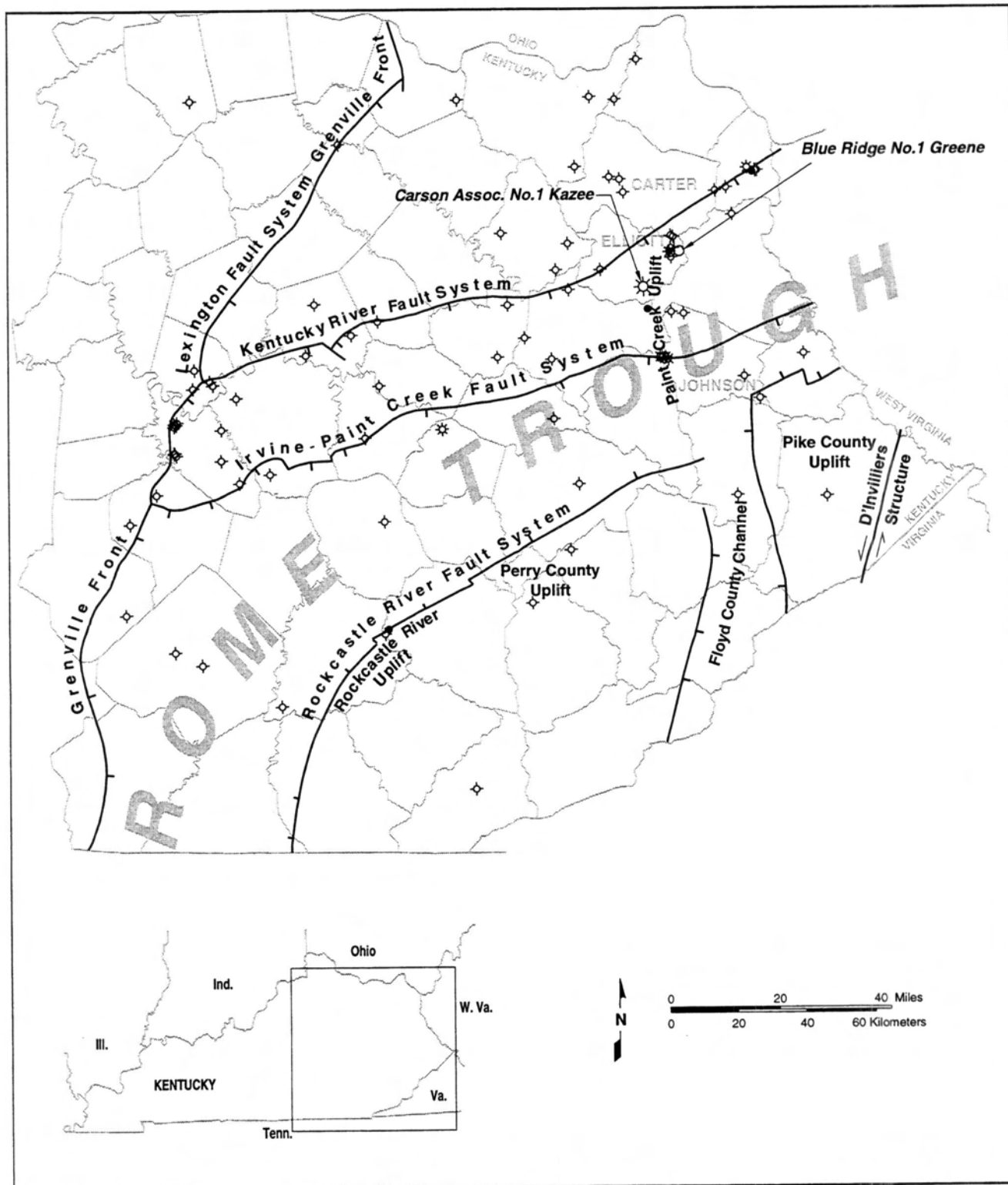


Figure-1. Location of the Rome Trough, pre-Knox wells, and major faults and structural features. Recent pre-Knox wells are indicated by arrows.

Rome Formation in the South Central No. 1 Hall well in Powell County, Ky. (McGuire and Howell, 1963; Weaver and McGuire, 1977). A well in Boyd County, Ky., the Inland No. 529 White, was completed as a Rome oil well in 1967, and produced about 30,000 barrels of oil. This well also produced about 90 Mcfcpd from the same zone. In 1980 the Lancaster No. 1 Lee well in Garrard County reportedly flowed 750 Mcfcpd of low-Btu gas from Rome Formation sandstones, but was never commercially produced. Numerous other wells have reported shows of oil or gas.

The first pre-Knox gas well in the Rome Trough was the Exxon No. 1 McCoy in Jackson County, W.Va. An initial open flow of 9.2 MMcfcpd and sustained production of 5.6 MMcfcpd was reported from a sandstone in the Conasauga Group from 14,350 to 14,360 feet. This well produced dry gas for about 6 months and had a total cumulative production of 427 MMcf before increasing water production forced the well to be plugged. The McCoy well holds the record for deepest production in the Appalachian Basin. In 1986, a second commercial gas well was reported from the Rome Trough. The Ashland No. 1 Williams well, in Johnson County, Ky., was completed in the Conasauga Group (Rome Formation of Kentucky). Initial open flow was 1.055 MMcfcpd from 6,250 to 6,350 feet in a fractured shale interval. A slight show of condensate was also mentioned in the completion report. This well was still producing in 1995, but production data are not available. Neither the McCoy nor the Williams well was offset, and both remain single-well pools.

No drilling to pre-Knox objectives occurred in the trough for the next 8 years. In 1994, Carson Associates successfully completed their No. 1 Kazee well as a Conasauga/Rome producer in Elliott County, Ky. This well tested a structure interpreted from recently reprocessed seismic data originally acquired by Exxon during the 1970's. Future exploration will rely heavily on interpretation of complex structures in the graben using enhanced seismic data.

sist of (in descending order) the Conasauga Formation, the Rome Formation, and the Mt. Simon Sandstone (Fig. 2). These units together are 300 to 600 feet thick in northernmost Kentucky, but they abruptly thicken across a series of extensional growth faults (the Kentucky River Fault System) into the northeast-southwest-trending Rome Trough rift basin (Woodward, 1961; Silberman, 1972, 1981; Webb, 1980; Sutton, 1981). In the trough, the pre-Knox section includes older and dramatically thickened units, with as much as 10,000 feet of pre-Knox sediments in some areas (Ryder and others, 1992) (Fig. 3). Rocks as old as Early Cambrian are in the trough, and have no equivalents to the north on the shelf. The Upper Cambrian Mt. Simon Sandstone is not present south of the northern boundary fault, and is probably equivalent

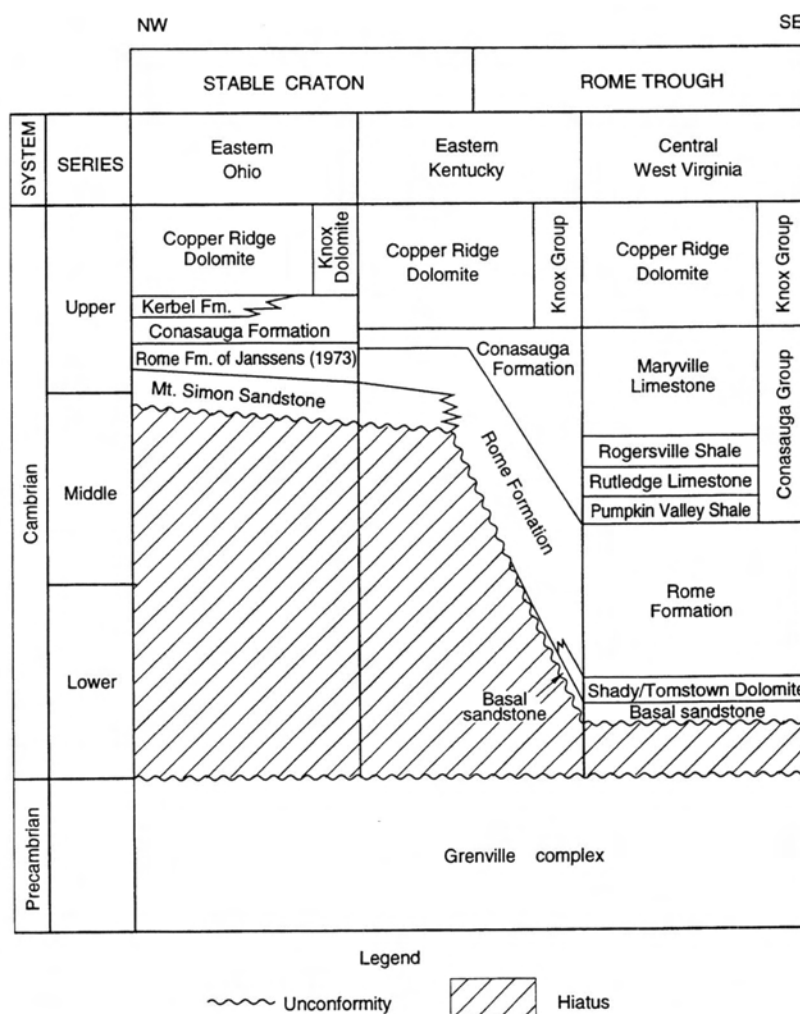


Figure 2. Cambrian stratigraphy of eastern Kentucky, Ohio, and central West Virginia.

STRATIGRAPHY

Stratigraphic units below the Cambrian-Ordovician Knox Group on the stable shelf in northeastern Kentucky con-

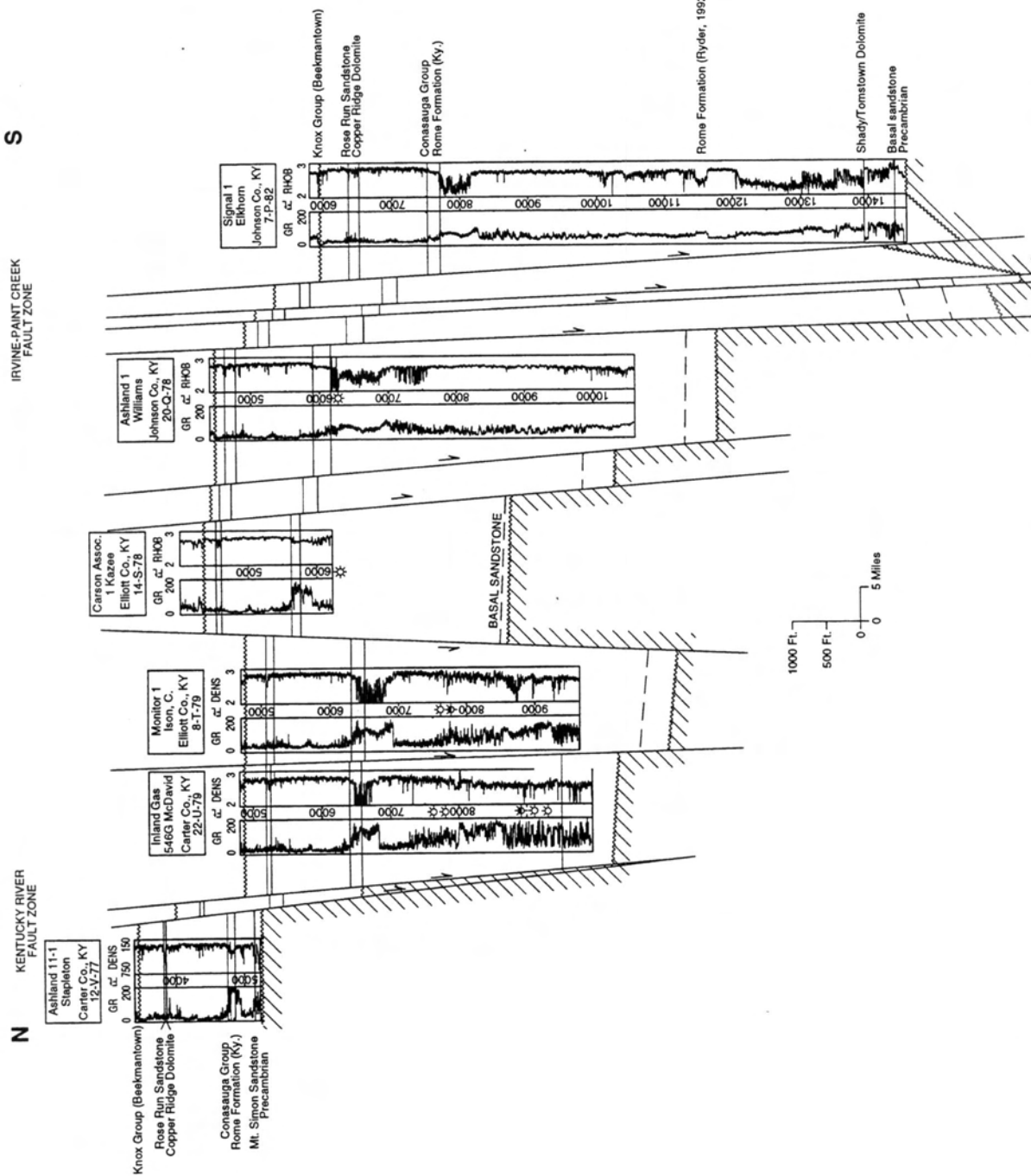


Figure 3. North-south cross section, eastern Kentucky. Location of section is shown in Figure 6. Precambrian basement is striped. Basement configuration is based on Drahovzal and Noger (1995).

to part of the upper Rome/Conasauga sequence. The expanded Cambrian section in the Rome Trough is largely conformable, and predominantly marine in origin (Ryder, 1992). A type log for the Rome Trough sequence is shown in Figure 4.

The pre-Knox sequence in the Rome Trough in Kentucky consists of the Conasauga Group, Rome Formation, Shady/Tomstown Dolomite, and a basal sandstone zone (Fig. 2). The Conasauga Group comprises a 2,400- to 5,500-foot-thick sequence of shale, limestone, dolomite, and siltstone, which conformably overlies the Rome Formation in the Rome Trough. The Rome Formation is a 1,000- to 2,900-foot-thick sequence of sandstone, siltstone, shale, limestone, and dolomite that overlies the Shady/Tomstown Dolomite. Depositional environments of the Conasauga Group and Rome Formation were interpreted by Donaldson and others (1988), who studied cores from two West Virginia wells. They described carbonate and clastic facies deposited in tidal flat, tidal channel, and shallow subtidal marine environments. Turbidite sandstones and potential for fan delta and basin-floor fan deposits in Kentucky were interpreted by Webb (1980) and Drahovzal (1994a-b).

Confined to the Rome Trough and the deeper Appalachian Basin to the southeast is a carbonate unit, the Shady/Tomstown Dolomite, which underlies the Rome Formation and overlies a basal sandstone (McGuire and Howell, 1963; Ryder, 1992). The Shady/Tomstown Dolomite interval consists of limestone in some areas, and is considered to be Early Cambrian in age.

The oldest sedimentary unit in the trough is a sandstone, informally named the Basal sandstone, which unconformably overlies middle Proterozoic crystalline basement rocks of the Grenville Province (McGuire and Howell, 1963; Webb, 1980; Sutton, 1981). This unit ranges from 20 to 650 feet thick and is commonly arkosic. Previously, the Basal sandstone in the Rome Trough was correlated with the Mt. Simon Sandstone on the craton. The Mt. Simon appears to be a much younger unit, and probably correlates with the uppermost part of the Rome Formation in the trough (Ryder, 1992).

STRUCTURE

The Rome Trough is the most significant structure affecting pre-Knox rocks in the Appalachian Basin. The trough is part of a larger Cambrian extensional feature, extending northeastward

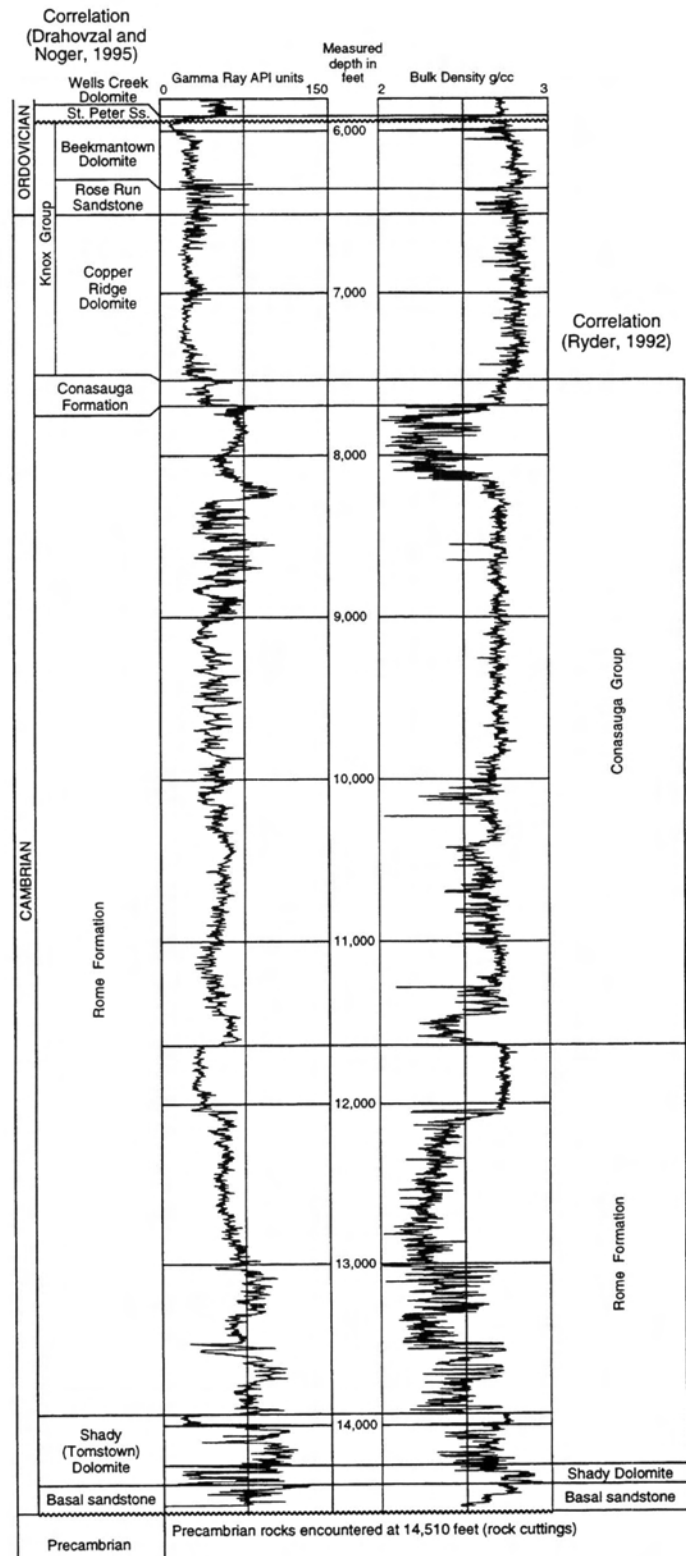


Figure 4. Type geophysical log, Rome Trough, Kentucky. Well is the Signal No. 1 Elkhorn, Carter coordinate section 7-P-82, Johnson County.

across West Virginia and Pennsylvania into southern New York, and associated with the similar-age Rough Creek Graben and Reelfoot Rift farther to the west in western Kentucky and Tennessee, eastern Missouri, Arkansas, and northwestern Mississippi (Wagner, 1976; Beardsley and Cable, 1983; Harper, 1989; Thomas, 1991; Potter and Drahovzal, 1994) (Fig. 5). The trough, first recognized by Woodward (1961), is bounded in Kentucky by the Kentucky River Fault

System and the Irvine-Point Creek Fault System on the north, and the Rockcastle Fault System on the south (McGuire and Howell, 1963; Webb, 1980; Silberman, 1981; Cable and Beardsley, 1984) (Fig. 1). The southern bounding fault system is more discontinuous than the northern bounding fault system. The Rome Trough has been interpreted as a failed Cambrian continental rift basin, which developed approximately 250 miles cratonward of the central area of Iapetan rifting. Maximum

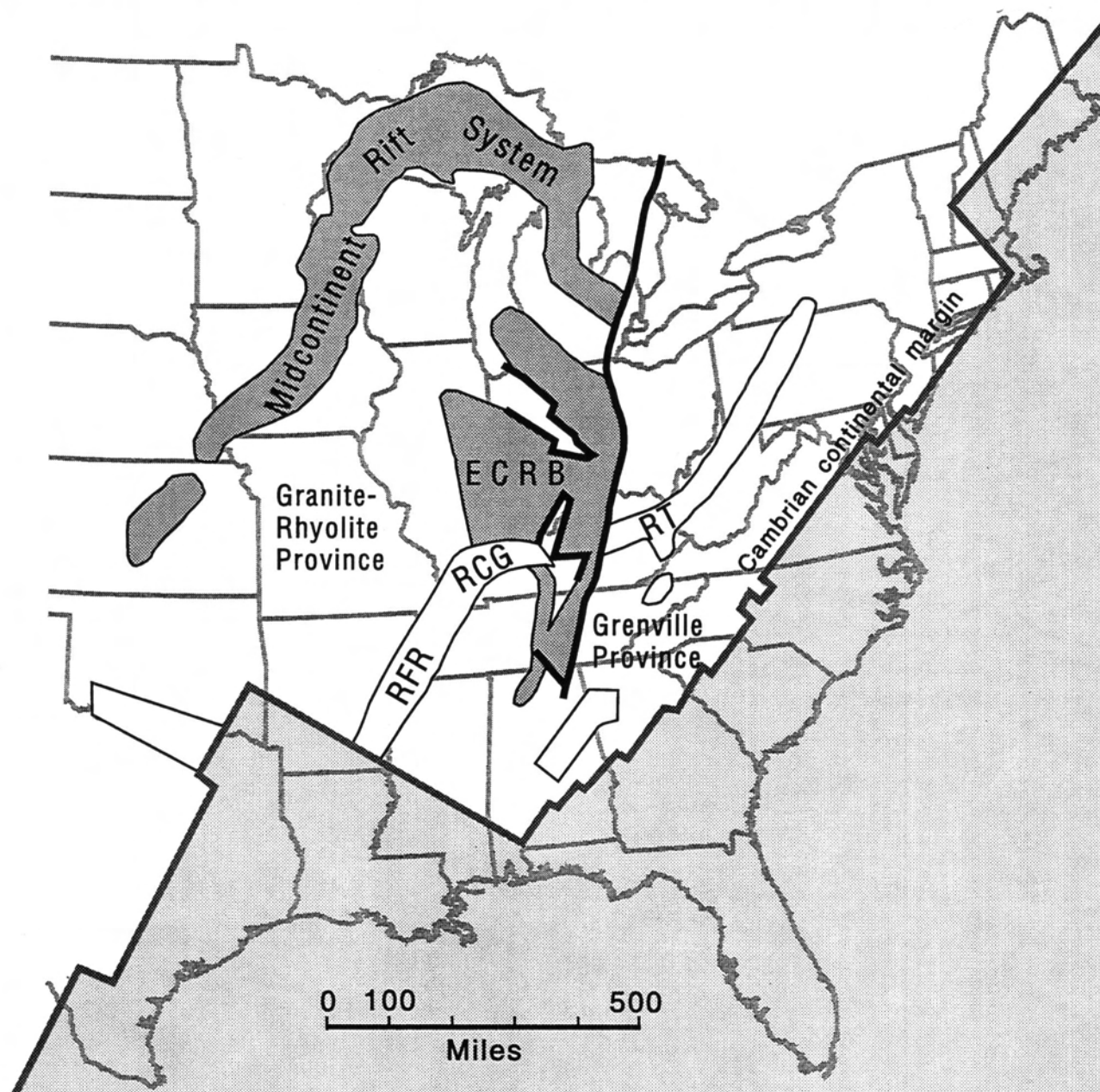


Figure 5. Precambrian (dark gray) and Cambrian (unshaded) basins, showing the Reelfoot (RFR)-Rough Creek (RCG)-Rome (RT) rift system and its relation to Precambrian provinces. ECRB is the East Continent Rift Basin.

subsidence within the trough occurred during the Middle Cambrian, based on paleontological data and the thickness of the Rome Formation. Cambrian depocenters are located along the northern rift margin in Kentucky and the southern margin in West Virginia, indicating that the rift is characterized by half-graben structures of alternate polarity.

A recently published structural map of the Precambrian basement surface in eastern Kentucky (Drahovzal and Noger, 1995) illustrates the regional configuration for the trough in Kentucky (Fig. 6). In eastern Kentucky, structural relief on the top of the Precambrian Grenville basement rocks is greater than 13,000 feet from the northern boundary to the deepest part of the Rome Trough. Relief along the southern boundary is generally only about 7,000 to 8,000 feet, and locally much less. Farther south, basement deepens into the Appalachian Basin. The resulting geometry is therefore a flat-bottomed graben bounded by a high northern shoulder that steps down across a series of down-to-the-south normal faults and a lower south-bounding shoulder that deepens into the graben across a few down-to-the-north faults. The graben generally deepens to the east, ranging from about -5,000 to -8,000 feet along the Grenville Front to more than -17,000 feet at the Kentucky-West Virginia border.

The dominant normal faults are oriented east-northeast (Fig. 1). Two north-south-oriented faults bound the Floyd County Channel in southeastern Kentucky, separating the Pike County Uplift from the Perry County Uplift. The latter uplift, together with the Rockcastle River Uplift, lies south of the Rockcastle River Fault System. North of the Floyd County Channel is a north-south surface structure, the Paint Creek Uplift. It is along this uplift and its flanks that the two recent wells were drilled. Current publicly available data neither confirm nor deny an uplift in the basement rocks along this axis. Reverse faulting in the basal part of the pre-Knox section is interpreted to represent a Cambrian wrench component that resulted in local transpressional structures (Drahovzal and Noger, 1995).

RESERVOIR CHARACTERISTICS

Potential reservoir facies in the Rome Trough consist of sandstones, carbonates, and fractured shales. Sandstones and fractured shales have been responsible for most of the production to date, but the dolostone intervals of the Conasauga Group and Shady/Tomstown Dolomite may have reservoir potential. Rome Formation sandstones have quite variable reservoir characteristics, and are difficult to predict. These sandstones are typically fine to very

fine grained, micaceous, and glauconitic. Coarser grained facies may occur in proximity to major border faults, where fan-delta deposits are likely (Webb, 1980). Limited seismic data may indicate such deposits, as well as basin-floor fans (Sutton, 1981; Drahovzal, 1994a-b) (Fig. 7a-b). Porosity data for the three commercial pre-Knox wells in the Rome Trough are limited. The Ashland No. 1 Williams well produces from a fractured shale, but the borehole is washed out over this interval, invalidating the porosity logs. The Exxon No. 1 McCoy produced from a 10-foot-thick sandstone that averaged 11 percent porosity. The producing zone in the Carson Associates No. 1 Kazee well was not logged.

TRAPPING MECHANISMS

Structural traps are the primary target in and around the Rome Trough, where basement-controlled normal faults influenced deposition and created potential structural traps during initial rifting and later reactivation. The three commercial gas wells that have been reported all appear to be structurally influenced. The Ashland No. 1 Williams well in Johnson County, Ky., produces from a fractured shale interval in the Conasauga Group (Rome Formation of Kentucky). This well is near the Irvine-Paint Creek Fault Zone in the Rome Trough, and fracturing is thought to be related to proximity to this fault. The Exxon No. 1 McCoy well in Jackson County, W.Va., produced for about 6 months from the Belgrove Field, a probable fault-related four-way closed structure in the Rome Trough. Data are limited for the recent Carson Associates No. 1 Kazee well in Elliott County, Ky., but it appears to be a fault-block trap.

Stratigraphic traps, although much higher risk, also represent potential reservoirs. Stratigraphic trapping could exist in both sandstones (including turbidite fans) and carbonates in the Conasauga, Rome, and Shady/Tomstown intervals due to depositional pinch-out, erosional truncation, and diagenetic variability. Potentially sand-rich fan deposits may exist in both the shallower block south of the Kentucky River Fault System (Fig. 7a-b) and the deep block south of the Irvine-Paint Creek Fault Zone (Drahovzal, 1994a-b) (Fig. 1). These inferred fans represent potential reservoirs that in some areas may be discontinuous in their distribution. Careful analysis of existing and new seismic data will be required to map these potential reservoir facies. Such facies, especially where combined with structure, could result in significant hydrocarbon traps.

SOURCE ROCKS

Potential source rocks for pre-Knox hydrocarbons in the Rome Trough are not well constrained. Stratigraphic separation of the pre-Knox interval from the Knox uncon-

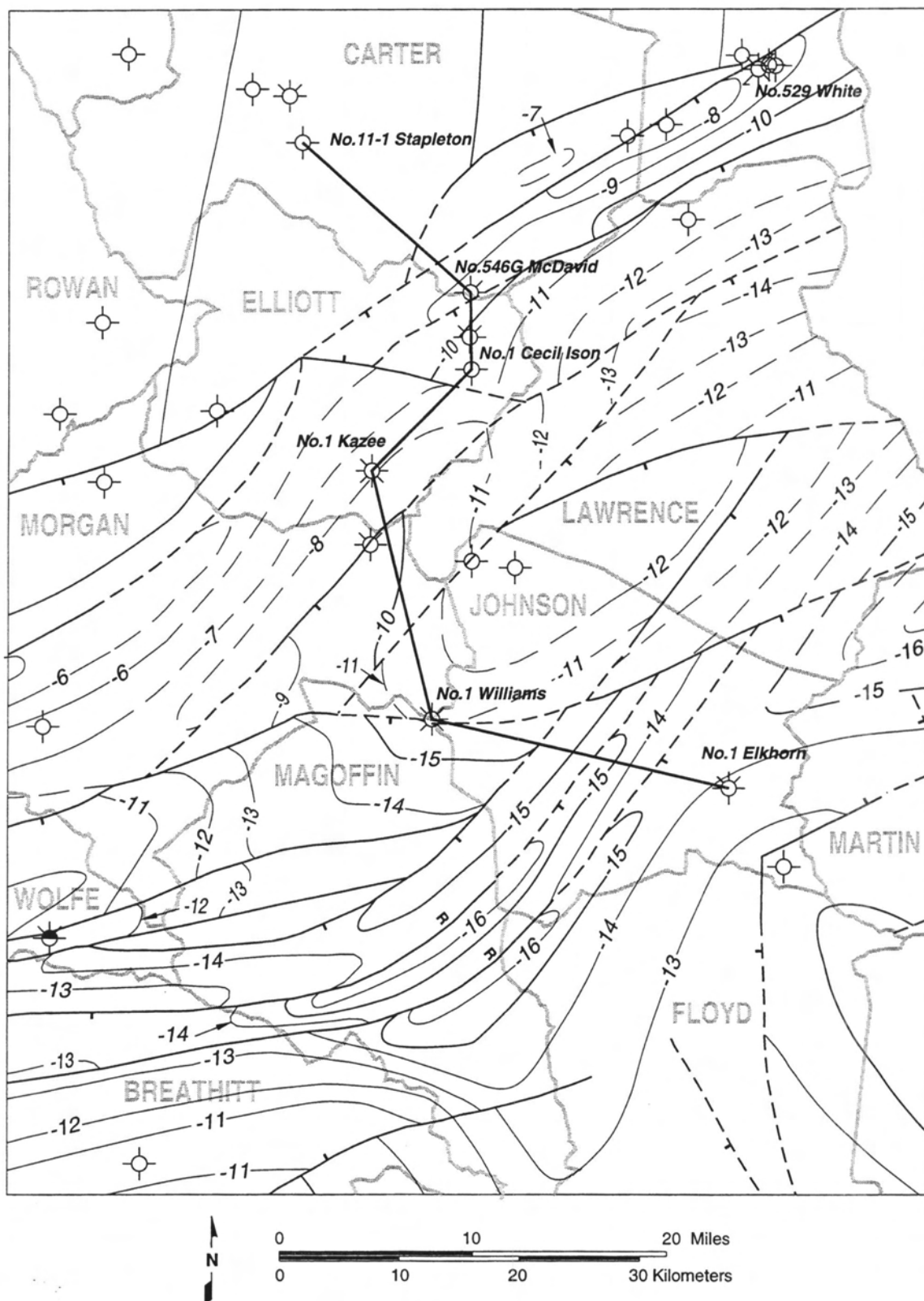


Figure 6. Structure of the Precambrian unconformity surface in Elliott-Johnson-Lawrence-Magoffin Counties, Ky. Line of cross section shown in Figure 3 is indicated by heavy line. Values are times 1,000 in feet below sea level. Modified from Drahovzal and Noger (1995).

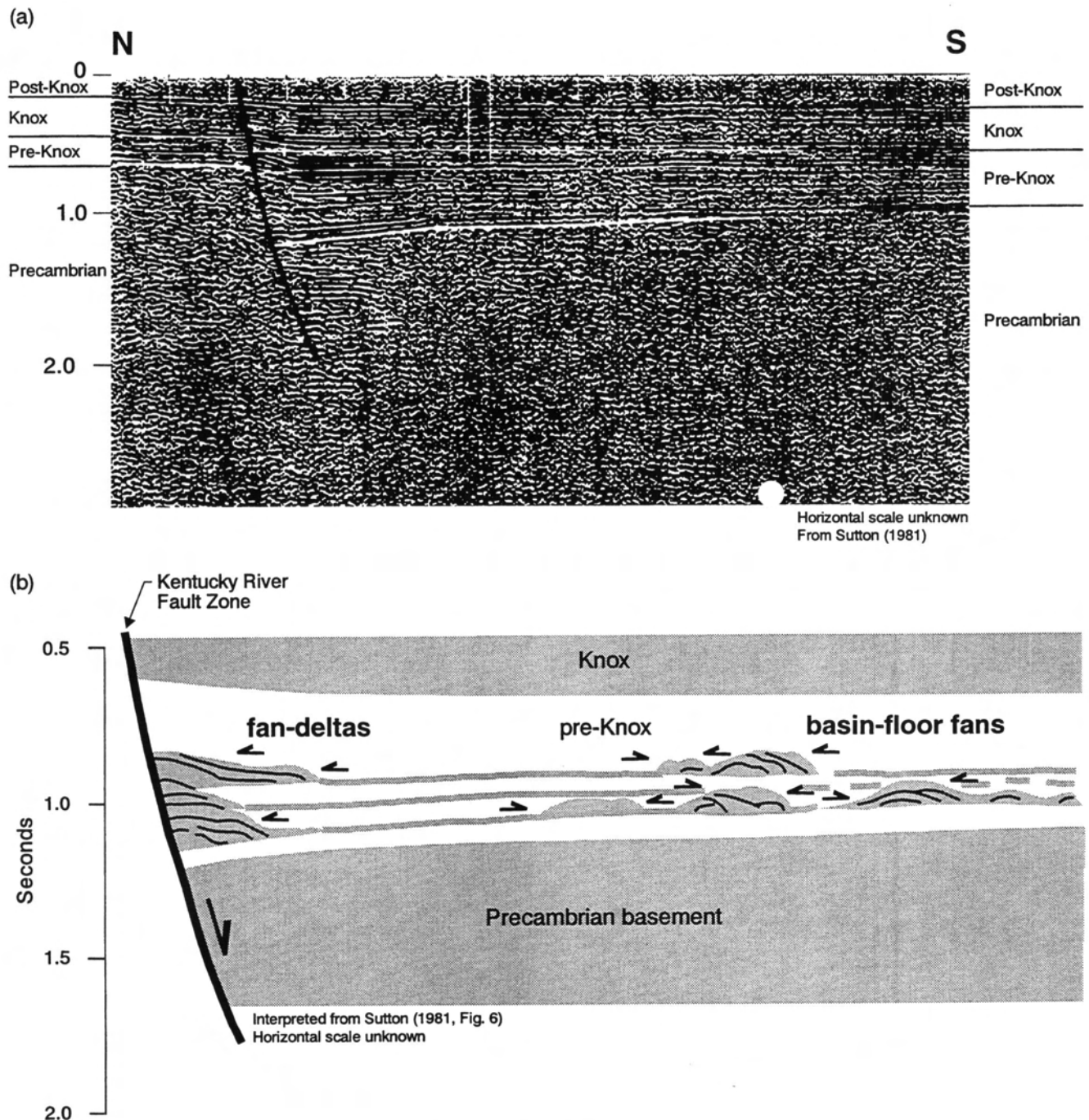


Figure 7. (a) Seismic section published by Sutton (1981). (b). Interpretation of Sutton's (1981) section, showing inferred fan deltas and turbidite fans. Pre-Knox interval is indicated, and arrows indicate onlapping reflectors.

formity make Upper Ordovician shales an unlikely source in these areas. Oil produced from the Rome-Conasauga interval in eastern Kentucky is distinguished by high gravity (41 to 54° API), unlike mostly lower gravity oils derived from post-Knox source

rocks. This suggests that both oil and gas in pre-Knox reservoirs were generated from pre-Knox source rocks at higher thermal maturities. Ryder and others (1991) analyzed 22 shale samples from the Rome and Conasauga interval in three wells in the Rome Trough of West Vir-

ginia and an outcrop section in Tennessee. Total organic carbon (TOC) values of these samples range from 0.05 to 0.59 percent, and they are considered to have low to marginal source potential. Ryder and others (1991) also calculated production indices (PI) for samples with TOC greater than 0.5 percent, using pyrolytic yields (S_1 and S_2). Average PI values for the pre-Knox samples range from 0.4 to 0.6, indicating that the interval sampled is in the gas generation window. Richer Cambrian source rocks may occur elsewhere in the basin and may have reached relatively high thermal maturity, generating the characteristic gas, condensate, and high-gravity oil found in pre-Knox reservoirs.

GAS COMPOSITION

Gas composition varies significantly within the trough. Gas from the Exxon No. 1 McCoy well had an almost pure methane composition, while gas from the Ashland No. 1 Williams gas has heavier components, consistent with reports of some produced condensate. Both wells had Btu values of over 1,000. At least two wells in the western part of the Rome Trough in Kentucky have encountered significant shows of low-Btu, non-combustible gas. The wells are located in Garrard County and yielded Rome gas with an average methane content of 15 percent and an average nitrogen content of 78 percent. These wells were of interest as a possible source of helium, which averaged an unusually high content of 1.6 percent. The origin of these high-nitrogen gases is not known, but Garrard County is located near the Grenville Front, a major tectonic suture between the Precambrian Grenville Province and the Keweenaw(?) East Continent Rift Basin (Drahovzal and others, 1992). A deep basement origin for some of this low-Btu gas is possible. The risk of low-Btu gas appears confined to the western Rome Trough, since gas produced farther east (Johnson and Elliott Counties, Ky., and Jackson County, W.Va.) is of commercial quality.

SUMMARY

Additional details of the Cambrian pre-Knox play in the Appalachian Basin can be found in Harris and Baranoski (in press). Recent activity in the Rome Trough has proven the presence of commercial accumulations of gas in Cambrian pre-Knox reservoirs. We feel additional discoveries will be made, but success in the trough will require acquisition and interpretation of high-quality seismic data to delineate complex structures and reservoir facies. In addition, detailed stratigraphic and diagenetic studies will be required to allow prediction of reservoir zones. The

Rome Trough remains largely a geologic puzzle. Integration of regional stratigraphy with the structural history will provide the key to successful exploration in this play. The Kentucky Geological Survey is currently involved in some aspects of this work, and welcomes industry involvement in this effort.

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MISSION STATEMENT

The Kentucky Geological Survey at the University of Kentucky is a State-mandated organization whose mission is the collection, preservation, and dissemination of information about mineral and water resources and the geology of the Commonwealth. KGS has conducted research on the geology and mineral resources of Kentucky for more than 150 years, and has developed extensive public databases for oil and gas, coal, water, and industrial minerals that are used by thousands of citizens each year. The Survey's efforts have resulted in topographic and geologic map coverage for Kentucky that has not been matched by any other state in the Nation.

One of the major goals of the Kentucky Geological Survey is to make the results of basic and applied research easily accessible to the public. This is accomplished through the publication of both technical and nontechnical reports and maps, as well as providing information through open-file reports and public databases.