ation.

Other major fracture sets are well developed in isolated areas of Cuyahoga County. Superimposed on the major fracture sets is a random, fine-scale fracture network which constitutes 50.8% of all fractures.

The major fracture sets conceivably provide pathways for the migration of natural gas. In northeastern Ohio, the only commercial production of natural gas is in areas of apparently increased fracture intensity.

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Pyrolysis of Eastern Gas Shales—Effects of Temperature and Atmosphere

Shale samples from well cores from Christian County, Kentucky, and Effingham, Henderson, and Tazewell Counties, Illinois, were studied for the noncondensable (at room temperature) hydrocarbon gases produced during pyrolysis. The data show a direct correlation of the total hydrocarbon gas (C_1 to C_5) yield from the shale pyrolyzed at 600°C to the organic carbon content of the shale and relations of the gas released from specially "canned" core sections at room temperature to the organic carbon content and to the total porosity of the shale.

The composition of the noncondensable hydrocarbon gases was studied on selected black-shale samples with stepwise increases in temperature. The formation of alkanes is favored over alkenes at low temperature. Alkenes, C_1, and C_2 species from thermal cracking are positively identified when the shale has been heated to above 120°C, if other conditions remain constant.

The effect of the pyrolysis atmosphere on the yield of light hydrocarbons (C_1 to C_8), acetaldehyde, acetone, carbon monoxide, and carbon dioxide during thermal degradation of selected gram-sized black-shale samples was studied also. The effects of varying the amount of oxygen in the pyrolysis atmosphere have been monitored. The yield of an individual hydrocarbon generally increases until the oxygen content of the pyrolysis atmosphere reaches 10%. Above 10% oxygen there is a slight decrease in yield. The yield of carbon monoxide and carbon dioxide increases directly with the increase of oxygen content of the pyrolysis atmosphere.

Data derived from this study may improve our understanding of the potential for gas production and the prediction of gas production from the eastern black shale. It may also provide information useful for controlling the quality of the gas produced by shale pyrolysis.

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Regional Coalification Patterns in Eastern Kentucky, Virginia, West Virginia, Ohio, Maryland, and Southern Pennsylvania

An isoreflectance map, based on the average maximum reflectance of the vitrinite macerals, was compiled from 329 coal samples from Kentucky (75 samples), Virginia (14 samples), West Virginia (200 samples), Ohio (10 samples), Maryland (15 samples), and southern Pennsylvania (15 samples). This map shows that coalification increases toward the Allegheny Front (or in west-to-east and northwest-to-southeast directions) in the northern part of the Appalachian coal basin. The dry-ash-free fixed carbon contents of the coals show the same general trends.

The isoreflectance map shows that the rank increases to a maximum in two directions: (1) from Ohio eastward to the Allegheny Front in southern Pennsylvania, Maryland, and Mineral County, West Virginia; and (2) from Ohio and northeastern Kentucky to the central part of McDowell County, West Virginia. This increase in rank can be attributed to the eastward thickening of the strata, but the major factor in the coalification was probably the increase of thermal activity and temperatures coupled with the Appalachian orogeny.

An attempt to determine the temperatures of coalification by using the level of metamorphism of P. J. Hood showed that the temperatures during the effective times for coalification were approximately 85 to 90°C near the northwestern boundary of the coalfield and approximately 180°C in central McDowell County where the highest reflectance of 1.80% R_{max} occurred.

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Exploration Strategy for Unconventional Natural Gas Resource—Devonian Shales

Exploration rationales, exploration techniques, and prospects are the key elements of EGSP's ideal exploration strategy for the Devonian shales of the Appalachian, Illinois, and Michigan basins. An exploration rationale is a theory of how several known or suspected geologic circumstances may combine to create a favorable environment for the generation and accumulation of producible hydrocarbons. The unconventional nature of the Devonian shales as a natural gas resource demands shale-specific rationales. These are characterized by a hypothesized geologic mechanism for the creation of a natural fracture system, because fracture permeability is essential to shale production. Although fractures are a necessity, they alone are not sufficient. Hence, shale-specific rationales include supporting information on black shale thickness, kerogen content, thermal maturity, reported shows, production history, etc. Exploration rationales are area-specific, but generally not site-specific. Prospect development is the process by which site-specific prospects issue from area-specific rationales. Exploration techniques are the means employed, short of drilling, to evaluate rationales and optimize local geologic factors in site selection.

The development of seven exploration prospects associated with the Newman Ridge and Greendale synclines in eastern Tennessee and southwestern Virginia illustrates EGSP's exploration strategy.

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Middle and Upper Devonian Stratigraphy in North-

western West Virginia

Regional stratigraphic studies of the Middle and Upper Devonian clastic sequence of West Virginia have been based on gamma-ray-density logs, cores, and sample studies. In northwestern West Virginia, the Upper and Middle Devonian unit is characterized by interbedded gray and black shales, with the darker shales recognized on gamma-ray logs as zones of increased radioactivity. The overall thickness of the section decreases toward the west whereas the proportion of black shale increases toward the west. The proportional increase in black shale occurs in two ways; there is an increased number of black shale beds in the west, and the thickness of the interbedded gray shales decreases.

The study area extends across the western boundary of the Rome trough, with the presence of this tectonic feature manifested in two ways in the sediments accumulated over the trough. First, there is a pronounced thickening of the sediments into the trough, and second, the Rhinestreet Shale Member of the West Falls Formation and the Huron Member of the Ohio Shale undergo a facies change from black shale west of the trough to gray shale in the trough area. Further, cross sections and isopach maps provide additional evidence that the Rome trough controlled basin configuration in the region and thus influenced sedimentation during the deposition of the Upper and Middle Devonian clastic sequence in northwestern West Virginia.

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Past and Current Developments for Drilling New Albany Shale Gas in Western Kentucky

Gas from the New Albany Shale was produced in western Kentucky prior to 1890. Old fields have been abandoned with little record of production history. Current exploration for gas in the New Albany Shale began in 1976. Three fields have been discovered, and development has been progressing steadily spurred by the increase in gas price. Drilling and completion techniques have varied. Sale of natural gas has been limited to availability of local markets, and proximity to existing natural gas pipelines. Leasing of exploration acreage is continuing and plans for future drilling to develop the New Albany Shale as a reservoir and source for natural gas appear to be excellent in western Kentucky.

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Novel Formation-Evaluation Concepts for Shale Reservoirs and Black Shale Formations

Highly radioactive, black and organic-rich shales are present in the United States, in several geologic provinces, and elsewhere. Such organic-rich shales are not only potential source rocks but commonly owe their localized but significant production potential to natural fracture systems in an otherwise impermeable rock. These natural fracture systems are concentrated in the interbedded brittle, calcareous, cherty or silty zones.

Natural gamma-ray spectral information, such as that from the Spectralog, easily locates calcareous or silty zones, as both are characterized by low values of potassium and thorium, but excessively high values of uranium. These interpretive concepts have already assisted in many successful gas and oil well completion and recompletion attempts in the more permeable and/or fractured intervals of such shale formations.

The Spectralog allows a continuous monitoring of the source rock potential (SRP) of shales in open and cased boreholes. Hence, SRP variations can be studied both versus depth and on a lateral basis using appropriate mapping techniques. Gamma-ray spectral data also assist in detailed stratigraphic correlations, for; in addition to total gamma-ray counts, the Spectralog measures the individual gamma rays emitted by potassium (K^{40}), the uranium series nuclide bismuth (Bi^{214}), and the thorium series nuclide thallium (Tl^{208}).

Interpretive experiences with SRP, including SEM pore-system studies, in the Miocene Monterey Formation in California, the Cretaceous Niobrara and Pierre Shales of Colorado, the Lower Mississippian and Upper Devonian Woodford Shale of Oklahoma and West Texas, and the Eagle Ford Shale in the Cretaceous carbonate trend in south Texas indicate application potentials similar to those in the Devonian gas shales of the Appalachian basin.

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Characterization of Production Mechanism in Devonian Shale and Its Sensitivity to Change in Various Reservoir Parameters

The U.S. Department of Energy is supporting cooperative research for enhanced gas recovery in a major effort to help reverse our country's decline in natural gas reserves. A potential major source of natural gas is the Devonian shale of the Appalachian region, estimated to contain hundreds of trillion cubic feet of natural gas. As part of the DOE's Eastern Gas Shales Project, we undertook the task of making a comprehensive analysis of the production of natural gas from the Devonian shales. Two reservoir-stimulation models were validated and used in characterizing the production mechanism of the Devonian shale.

There are two widely held theories on the occurrence of natural gas in the Devonian shales. One theory, the single-porosity theory, is that the gas is present as free gas in a macrofracture system and is produced as Darcy law type flow through these fractures. The second, the dual porosity theory, assumes a macrofracture porosity of smaller magnitude and that, in addition to free gas in the fracture system, there exists a volume of gas present as an adsorbed phase within the shale matrix which diffuses into the fracture system and is produced as pressure drops. The likelihood of one system being present as opposed to the other was studied. Sensitivity analyses were conducted on various reservoir parameters. The validity of conventional transient-pressure-analysis techniques in the Devonian shale was also investigated.

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