rithmic series equation, d = (s-1)/1nN where S is the number of species showing significant associations and N is the number of individuals. A species diversity map constructed by contouring the computed indices of diversity reveals that at least three fossil communities existed in the Helderbergian sea throughout the study area. The boundaries of these communities are undulatory and subparallel with the axis of the Appalachian basin. Areas with lower species diversity are interpreted as deeper water environments.

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Petrologic Evaluation of Significance of Natural Fractures in Low-Porosity Shale Gas Reservoirs—Results of Investigation in Upper Devonian of Virginia and West Virginia

Economic production of gas from the Devonian shales of the Appalachian basin is dependent on the presence of natural or induced fracturing. Investigation of natural fractures in five cored wells of varying productivity, located in areas of regional fracturing and not crestally located on folds, indicates that fracture frequency alone is not the sole control of well productivity. A one-to-one relation between natural fractures seen in the core and gas shows indicated by temperature and sibilation logs is not present. This is attributed to degrees of permeability enhancement by different fracture types and the presence of favorable shale lithotypes for recharging the fracture system. No system of abundant microfractures was documented after petrographic study of nearly 400 shale samples by radiography, thin section, and SEM. Thus, only macroscopic fractures are of importance.

Horizontal to subvertical slickensided fractures, even with frequencies of 2 to 3 per ft, are not associated with gas shows in organic-rich, laminated shales. Examination of their surfaces by SEM at 30,000× shows complete obliteration of grain-to-grain boundaries and a uniform, glassy surface of low permeability. Stimulation by hydraulic fracturing of a well dominated by slickensided fractures resulted in production equal to that of a well (same formation thickness and porosity) that possessed only one fracture (slickensided). Presence of slickensided fractures does not greatly influence open flow or final flow after fracturing of a shale reservoir.

High-angle vertical fractures, associated with higher gas productivity, retain some openness and permeability in the subsurface due to mineralization and slight movement between fracture surfaces characterized by coarse twist hackles. Mineral-filled fractures, commonly 1 to 2 mm in width, were seen in thin section to be tightly mineralized by dolomite with little intercrystalline porosity. SEM observation reveals that many seemingly unmineralized fracture surfaces have minor mineralization. Tightly and partially mineralized vertical fractures in nonproductive portions of the shale sequence were associated with organic-poor, nonlaminated shales which have less potential for recharging the meager fracture porosity present.

The most productive well, final open flow of 1,007 MCFGD, possessed high-angle vertical fractures in its pay zone of organic-rich, laminated shale. These fractures have coarse twist hackles which show evidence of later vertical movement. Slight offsetting along these hackles opened widths up to 28 mm. This well is not located near photolineaments. Vertical fractures with no mineralization or indication of offsetting along hackles are interpreted as being closed at depth and do not contribute to shale productivity.

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Upper Niagaran and Lower Cayugan Stratigraphy and Depositional Environments of Central Appalachian Basin

Data from geophysical logs and sample descriptions of 677 wells were used to prepare nine cross sections and 38 maps that illustrate upper Niagaran and lower Cayugan stratigraphic relations and environmental constructions within the central Appalachian basin of New York, Pennsylvania, West Virginia, Ohio, Maryland, and Ontario. Ten basin-wide stratigraphic intervals (genetic sequences of strata) were correlated and mapped on the basis of interpreted time-stratigraphic markers. Fourteen lithofacies, which are repeated in several of these intervals, were recognized in the subsurface on the basis of characteristic radioactivity-log patterns supplemented with sample descriptions. Four of the lithofacies occur in dolomite, either with or without sulfates, three in limestones and shales, and two each in halite and sandstone.

Stratigraphic and lithofacies analysis reveals that the Lockport Formation in the northern and western parts of the basin is a rock-stratigraphic unit consisting of reefal, shallow-water, and carbonate tidal-flat facies that undergoes a complete gradation eastward into transitional marine and continental clastics within the first five intervals of the study. The remaining intervals were dominated by restricted evaporite basins, carbonate mud flats, and carbonate-sulfate mud flats (sabkhas) over the northern and western parts of the basin, whereas less restricted shallow-marine to intertidal environments were present in the southeast.

Detailed correlations indicate several inconsistencies in past correlations of Upper Silurian strata, most notably the miscorrelation of the Williamsport and Newburg sandstones that has resulted in considerable confusion in nomenclature and correlation in the Silurian of West Virginia.

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Recovery of Energy from Michigan Antrim Shale by In-Situ Process

A 12-member team at Dow Chemical Co. has completed 3 years of a 4-year, $14 million contract with DOE to assess the feasibility of recovering energy from Antrim oil shale. The contract has four specifically identified tasks: (1) shale characterization; (2) in-situ fracturing and assessment; (3) in-situ extraction trials; and (4) environmental, public policy, and legal assess-

ment.

At the experimental site in Sanilac County, Michigan, the Antrim Formation is about 200 ft (60 m) thick at 1,200 to 1,400 ft (365 to 425 m) below the surface. Under Task 2, several wells have been drilled into the Antrim layer in three 10-acre plots. Each plot has been subjected to a different fracturing procedure: (a) hydraulic fracturing followed by explosive fracturing; (b) explosive underreaming followed by explosive fracturing; (c) chemical underreaming followed by explosive fracturing.

The plot which appeared, on the basis of permeability studies, well-to-well communications, and various downhole logging studies, to offer the best chance of success in Task 3 was chosen for an in-situ extraction trial. This trial was scheduled to begin in August 1979.

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Cross-Strike Structural Discontinuities—Exploration Rationale for Eastern Plateau Province

Cross-strike structural discontinuities (CSDs) are zones of structural disruption several kilometers wide in the Appalachian and other overthrust belts. CSDs are not faults or fault zones. They typically contain about 1,000 cu km of unusually fractured rock. For example, in eastern West Virginia, one CSD (Parsons lineament) trends west-northwest at least from the Appalachian front to the Intraplateau structural front, with no evidence of basement involvement. The Parsons lineament has double to triple the normal joint intensity in exposed Upper Devonian siltstones. Another CSD (Petersburg lineament) trends west-southwest from the western Valley and Ridge province, and crosses the Appalachian structural front. The Petersburg lineament aligns with Arkle's hinge line, a probable basement flexure under the western and central Plateau province, and has twice-normal joint intensity in exposed Lower Pennsylvanian sandstones. The two CSDs appear to intersect in southern Tucker and northern Randolph Counties, West Virginia.

CSDs and their intersections, particularly beneath intersections of short air-photo lineaments, may comprise highly permeable fractured reservoirs. If the seal is preserved, CSDs can provide a tool for extending exploration into the little-tested eastern Plateau province of West Virginia and adjacent states, where organic-rich Devonian shales are thick and thermally mature.

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Structural Control of Onondaga Reefs (Devonian) in South-Central New York State

The lower Middle Devonian Onondaga Formation is a restricted marine limestone that extends throughout southern New York State. Thicknesses locally range from 15 to about 260 ft (5 to 78 m) with the thicker parts generally attributed to organic reefal buildups. The reefs may be algal and mudbank as well as wave-resistant structures, however, they contain porous sections that form natural-gas reservoirs if coincident with structural closure. Early interpretations considered the reefs and tectonic structures independent; however, recent investigations suggest that incipient folding was the main control on reefal formation.

Structure and isopach maps constructed from tops picked on about 1,400 wells drilled in New York State in the area bounded by 75°30′ and 78°30′ indicate that anticlinal folds are coincident with isopach thicks that indicate reefal buildups. Organic accumulations thus are interpreted as related directly to Appalachian folding. Breaks in trends accompanied by changes in thickness are related to contemporaneous organic reaction to tectonic relief. This relation not only dates the inception of folding but also simplifies exploration for natural-gas reservoirs. Because the reefs are confined to the anticlines, there is no need for stratigraphic tests off structure.

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Revision of U.S. Geological Survey and U.S. Bureau of Mines Coal Resources Classification System

In 1976, the U.S. Geological Survey and U.S. Bureau of Mines published a system of coal-resources classification that incorporated definitions and criteria to be used by the two agencies. This system was adopted by many state geological surveys. However, because of criticism and ambiguities, the two agencies decided to revise, enlarge, and make more precise the definitions and criteria and to include advice, suggestions, and recommendations aimed at guiding those engaged in resource estimation. In addition, a decision was made to include conversion data for the English and metric systems of measurement. Finally, a report was to be written that would be a compendium on the methodologies and criteria for the classification of coal resources and reserves.

Advice from the state geologists of the principal coal-bearing states was solicited. Similarly, the existing 1976 classification system was discussed with representatives of the nations cooperating in the International Energy Agency's (IEA) World Coal Reserves and Resources Data Bank Service. Their comments were considered and incorporated in the revision that is nearing completion.

In 1977, the U.S. Department of Energy took over most of the coal-related functions and personnel of the U.S. Bureau of Mines. The revision is under the auspices of the Department of Energy and the U.S. Geological Survey.

Throughout the revision, every effort has been made not to negate the hundreds to thousands of coal-resource estimates already published or being prepared by geologists and engineers in the United States. Also, foreign resource specialists have indicated that the revision should have international comparisons as an objective. This objective has been accomplished.

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Projection of Favorable Gas-Producing Areas from Paleoenvironmental Data