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-