During a transgression of the McKenzie sea, areas of thicker Keefer sand stood as submerged topographic highs. The local relief provided optimum sites for the patch reefs to develop and offered better protection to the fauna from being overwhelmed by incoming terrestrial clays. Conversely, the shaly interreef deposits of the McKenzie are present in areas of thinner Keefer Sandstone; they were laid down in turbid, relatively deep water between highs. A minor regression followed as represented by middle McKenzie intertidal sediments, and growth of the patch reefs ceased when the area emerged above the level of low tide.

Two southwest-northeast tracts of thicker McKenzie Formation and Keefer Sandstone mark the trends of Keefer topographic highs and associated McKenzie patch reefs. These trends now offer the best potential gas in the Middle Silurian of western West Virginia.

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Mauch Chunk Alluvial Plain and Mud-Flat Sediments in Northern West Virginia

Regional subsurface analysis of red beds of the Mauch Chunk Group (Upper Mississippian) in northern West Virginia, using oil and gas well logs and cuttings, suggests that deposition was in alluvial-plain environments grading basinward into mud flats.

Thickest net sandstone in the Mauch Chunk Group is in Barbour, Tucker, and Preston Counties in a belt 10 to 15 mi (16 to 20 km) wide striking north-northeast parallel with and just west of major fold axes of the Appalachian Plateau. This belt comprises numerous dip-oriented (west to northwest), vertically stacked, anastomosing subbelts and dendroids. Belt position reflects a gradient change from what were higher elevations on the east onto more level and tectonically stable areas of northwestern West Virginia. Lithofacies interpreted for the area include (1) channel fill–levee deposits as gray-green sandstone, siltstone, or non-red shale, and (2) flood-basin (overbank-levee) sediments as red and green shale. Streams carried a large suspended load and very fine to fine-grained sand. To the northwest, sandstone percentage decreases, and alluvial-plain facies interfinger with mud flats. Distal mud facies include laterally persistent limestone beds, and tidal-channel units with massive sandstone fill.

The overall genetic aspect of Mauch Chunk stratigraphy is a general regressive facies shift to the northwest. The boundary between Mauch Chunk red beds and coarse clastic alluvial sediments of the overlying Pottsville Group reflects changes in gradient, supply, and source area relief.

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Dilation Brecciation—Proposed Mechanism of Fracturing, Petroleum Expulsion, and Dolomitization in Monterey Formation, California

The Monterey Formation has been selectively replaced by dolomite and subsequently fractured, brecciated, and relithified with several generations of dolomite cement. The two dolomite types are distinctive in morphology, color, stoichiometry, δC^{13}, δO^{18}, and insoluble and trace-element content.

Dilation breccias evidently originate in embrittled rocks through a distinctive sequence of steps induced by tectonism: dilatancy, fluid expulsion, natural hydraulic fracturing, brecciation, hydroplastic flow, injection, and dolomite precipitation. Development is most abundant in, but not restricted to, areas of strike-slip faulting.

Initially, breccia clasts are angular, large, and closely fitted. In advanced development, smaller clasts appear unsupported and volumetrically subordinate to fracture-filling dolomites. Complex examples contain a very wide range of unsorted clasts and cement, similar to a slurry. They appear to be injected under pressure into swollen bedding planes and terminal fractures.

Tectonic stresses cause an initial compression and subsequent dilation (elastic) of rock microcracks and imperfections. With continued stress, the cracks are propagated inelastically and develop into major fracture networks. Fracturing associated with excess pore-fluid pressures triggers an instantaneous flow of connate fluids across several hundred feet of newly fractured strata. The resulting sharp drop in fluid pressure and temperature causes rapid precipitation of fracture-healing dolomite. The relithified rock is then subject to renewed dilatancy and rupture.

The dilatancy is pervasive and sufficient in magnitude to cause the expulsion of indigenous petroleum held initially in the organic matrices of the relatively impervious Monterey Shale. Several periods of petroleum migration are recorded in breccia paragenesis.

Dilation breccia is a distinct form of nondepositional breccia. It probably occurs in many tectonic provinces.

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Constraints and Problems in Producing Gas from Eastern Shales

The enormous gas resources locked in the various Mississippian and Devonian shale layers of the major eastern geologic basins naturally attracts the interest of energy policy makers and commercial entrepreneurs who are motivated to see and participate in the exploitation of that fraction which can be easily recovered. To succeed in this endeavor, however, certain constraints have to be faced, and other nagging problems have to be resolved. This paper classifies the constraints and the problems so that they can be dealt with systematically, and so that the expectations will not overtake the prospects and the realities.

The fact that the shale gas resource is widespread, and indeed reasonably evenly spaced, must be weighed against the observation that so far very few ways have been found to achieve high levels of prolonged production even from the historic reservoir locations. The obstacle that most appears to limit recovery is the fact that the shale matrix which holds much of the gas has the character of a molecular sieve. This means that somehow transport paths must be induced (especially when they do not naturally preexist) so that gas can easily move toward the wellbore sinks. Completing shale wells with stimulations that induce fractures and other types

of rubble, and which otherwise break down the formation to increase the effective wellbore radius, frequently will be indicated.

Another major obstacle is the necessity of minimizing skin damage resulting from the drilling, completion, and stimulation processes. A third obstacle has to do with economics which is dependent on the cost-effectiveness of the exploration and exploitation procedures that are followed in particular cases. Although it would be convenient to have evidence that a high selling price (e.g., due to market demand) would circumvent the major constraints and avoid the attending problems, the evidence points on the contrary to the need for achieving a technologic breakthrough before the full impact of economics will be felt.

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In-Situ Testing of Well-Shooting Concepts

The creation of multiple fractures from a wellbore has been demonstrated for a high-energy gas fracturing concept. In this concept, the gas pressure pulse due to the deflagration of a propellant is designed to give (1) pressure-loading rates sufficient to initiate multiple fractures, (2) peak pressures below the flow stress of the formation to avoid rock compaction, and (3) a duration of burn sufficient to allow gas penetration and extension of the fractures. Three experiments were conducted adjacent to a mine drift and the results were observed directly by mineback through the experimental areas. Tests with three different propellants to give different burning rates and, hence, different pressure loadings and pulses resulted in phenomenologically different behavior. Mineback of the intermediate test (pressure loading rate of 20 psi (138 kPa) /msec, peak pressures of 13,800 psi (95,151 kPa), and burn time of 9.0 msec) indicated 12 separate fractures from 0.5 to 8.0 ft (0.15 to 2.4 m) long for the 20-lb (9 kg) propellant charge. Tests with a faster and slower burning propellant yielded only single fractures less than 5 ft (1.5 m) long and features normally associated with explosive and hydraulic fracturing, respectively.

Multiple fracturing alleviates many of the postulated limitations of explosive and hydraulic fracturing techniques for the effective stimulation of Devonian shales. An expected test series is being conducted as part of the Eastern Gas Shales Program to examine several techniques for multiple fracturing based on this controlled-pressure-loading concept. Test results will be evaluated with respect to the application of such techniques for formation evaluation and stimulation of that resource.

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Implications of Gaseous Hydrocarbon Geochemistry of Shallow Core Sediments from Florida-Hatteras Slope

Light-hydrocarbon (C_1 to C_4) concentrations and compositions were determined in sediments from 23 piston cores on the Florida-Hatteras slope and innermost Blake Plateau. On the basis of seismic profiles, cores were taken from slump masses, an accretionary wedge, channel cuts, fault zones, and over a diapir.

Maximum total C_1 to C_4 hydrocarbon concentrations in the sediments analyzed were less than 38 ppm. Light-hydrocarbon concentrations of less than 10 ppm were found in most samples, and methane, ethane, and ethylene were generally the major components. At two sample sites, however, concentrations were greater than 10 ppm. Samples from a channel cut contained hydrocarbons through butane with total C_1 to C_4 concentrations of nearly 25 ppm. Samples from the diapir site contained mainly methane although ethane and propane were present; the total C_1 to C_4 concentrations were under 38 ppm.

Geochemical surveys that measure light hydrocarbons in surficial sediments have been used as a prospecting tool in offshore petroleum and natural gas exploration. In the shelf and slope areas being considered, background distributions must be established to distinguish anomalous hydrocarbon concentrations that result from natural seeps. Extremely low concentrations of light hydrocarbons and the presence of biologically formed ethylene in the sediments from this study area imply that background levels are possibly due to microbial production of gas from near-surface organic matter rather than by diffusion from underlying petrolific sources. The ubiquitous occurrence of low concentrations, in the ppb range, of the hydrocarbons through butane in slope sediments may arise from microbial production either directly as metabolic by-products or indirectly as degradation products. The possibility that microbes may be related to the occurrence of low concentrations of light hydrocarbons through butane in surface sediments must therefore be considered when evaluating petroleum potential from near-surface data.

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Interpretation and Statistical Analysis of Kentucky and West Virginia Open-Flow Data, Incorporating Geochemical Information

Cluster and regression analyses have been used to screen for predictive models and to test whether open-flow data can provide insight to aid in the assessment of near-optimum design for gas production from Devonian shale. The analysis shows that data from a Kentucky–West Virginia frac study should be partitioned. The vertical stress variable (X_6) was found to be the key variable; it is directly related to depth. Maximum flow occurs when $3{,}400 < X_6 < 4{,}100$ and minimum flow occurs when either $X_6 < 3{,}000$ or $X_6 > 4{,}100$. This zonation characteristic of the high flow values implies that the location of the prolific reservoir is the key to successful well production. This reservoir effect is consistent with our recent geochemical data and an extension of the geochemical cross section can be made. The optimization aspect was addressed using nonlinear (quadratic) models. Usable, optimal parameters valid on a regional basis can be generated. The study serves to illustrate that priority should be given to the effort to