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.

SCHMIDT, RICHARD A., NORMAN R. WARPINSKI, and DAVID A. NORTHROP, Sandia Laboratories, Albuquerque, N.M.

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.

SCHULTZ, D. M., R. E. MILLER, D. LIGON, H. LERCH, C. GARY, and D. OWINGS, U.S. Geol. Survey, Reston, Va.

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.

SEABAUGH, P. W., R. R. ZIELINSKI, Mound Facility, Miamisburg, Ohio, and C. A. KOMAR, Morgantown Energy Technology, Morgantown, W. Va.

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

establish an accurate geochemical cross section of the basin if the development of the Devonian shale is to be optimized.

SHUMAKER, ROBERT C., West Virginia Univ., Morgantown, W.Va.

Paleozoic Disruptive Deformation in North American Continent and Its Relation to Formation and Development of Interior Basins and Deformation Within Orogenic Core

The two major disruptive tectonic events during the Paleozoic which affected the North American craton seem to be associated with Appalachian-Ouachita orogenic events. The first Paleozoic cratonic disruption was tensional rifting, which occurred during the Avalonian intrusive-metamorphic event (±560 m.y.). Evidence continues to mount that these Cambrian rifts of the Appalachian-Ouachita foreland, such as the Rome trough of Kentucky and West Virginia, are not Cambrian aulacogens. By time and position, the rifts seem to be incipient basins along a developing back-arc trough. However, this disruptive deformation was not restricted to the developing arc trough, but extended far into the craton where it commonly involved reactivation of older rift zones. These zones formed the axial portion of the subsequently developed Paleozoic basins. The Paleozoic basins developed by epeirogenic movement after a period of relative quiescence during Late Cambrian through Early Ordovician (pre-Taconic) time.

The second Paleozoic continental disruption created large upthrust blocks in the craton during the Pennsylvanian and early Permian, probably by compressional deformation. This event ties, both by time and position, to deformation within the Ouachita part of the orogenic core. Upthrust crustal blocks in the craton may be bounded by reactivated faults of precursor rifts. When they formed, the upthrusts often developed near the axial part on the middle Paleozoic basins to form the late Paleozoic yoked basins. The occurrence of axial rifts within interior and foreland basins, and of axial upthrusts in the craton-margin basins, suggests an interrelation among rifts, basin formation, and the late-forming yoked basins. The developing foreland trough (the Appalachian-Ouachita geosyncline) has a tectonic history similar to that of the cratonic basins but, along its trend, tensional bending of the basement predominated.

SITES, ROY S., Amoco Production Co., New Orleans, La.

Tectonics of Petersburg Region, West Virginia

Detailed surface mapping, combined with investigations of two deep wells, nearby seismic profiles, and other studies enabled construction of detailed cross sections to basement across the Nittany anticlinorium of West Virginia.

Mapping shows the local large anticlines to be thrust faulted, to plunge into synclines, and to divide near terminations into several smaller plunging anticlines. Bed-extension structures occur in ductile rocks between noses of anticlines that plunge past each other in opposite directions, and there appears to be an increase in the density of longitudinal jointing in plunging anticlinal noses. Field sections show that much pre-folding shortening occurred by intraformational wedging and solution cleavage.

The northeast-trending Wills Mountain anticline, adjacent to the Appalachian structural front, is a northwestward thrust along the ramping Sponaugle thrust with decreased stratigraphic displacement and throw northeastward. However, northeastward along trend, northwestward forward motion is transferred to a higher level by growth of the Kittlelick thrust and consequently the Hopeville anticline, thus maintaining a consistent surface expression of the Willis Mountain anticline northeastward. The deep structures of the anticlinorium in the Petersburg region consist of several imbricated structural blocks involving Cambrian-Ordovician carbonate rocks, with small net slips on southeast-dipping reverse faults located east of the larger Wills Mountain structural block.

Shortening estimated from the cross sections reveals relative age relations of major structures, ramping thrusts, and decollements within the Nittany anticlinorium and also allows predictions of amounts of shortening and deformation outside the anticlinorium. Most structures in the Petersburg region developed by a west-northwest-directed gravity-spreading mechanism in which decollements allowed the ductile units to shorten nearly twice as much as the more rigid units.

The study provides insight for exploration for potential hydrocarbon resources within numerous subsurface, perhaps complex, structural traps and areas of increased fracturing in which effective permeability has probably been increased, particularly in the Devonian shale.

SPRINGER, THOMAS E., and ERNEST B. NUCKOLS, Los Alamos Sci. Lab., Los Alamos, N.M.

Cottageville Gas Field Correlation Analyses for Reservoir Modeling

At the Los Alamos Scientific Laboratory we are currently developing a model for the fractured Devonian gas shale reservoir in Cottageville, West Virginia. This involves integrating all the available geologic, geophysical, and gas-production data into a self-consistent model that will account for the observed flows and pressures. The purpose is to further the understanding of possible production mechanisms in a highly fractured reservoir and to develop tools and methodology to apply to other reservoirs.

We are using a single-phase Darcy-flow simulator and a data base management code that provides capabilities for selecting, ranking, rotating, mapping, meshing, and plotting various attributes of wells in the field.

We have been determining how to use the known data in the model by various correlation processes. Subsea depths of stratigraphic zones near the producing horizon, obtained from 99 wells in the field, have been interpolated onto a 250-m-interval grid pattern from which isopachs and structure (including their first and second derivatives in the two horizontal directions) have been calculated. Individual well-flow data, as represented by initial or final open flow, integrated produc-