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

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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.

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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.

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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 production, and decline curves each characterized by fitting to a sum of up to three exponential decay curves (adjusting for those wells in which a later cleanup occurred), are also interpolated onto the grid.

We are then using contingency tables to study the degree of correlation between different geologic and flow parameters. For example, final open flows show a much higher correlation with structure or with its curvature along the major fracture trend than they do with the slope of the structure normal to the fracture trend.

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Petrology and Depositional Environments of Boyle Dolomite (Middle Devonian) in East-Central Kentucky

The Middle Devonian Boyle Dolomite is a sequence of dolomite, dolomitic limestone, limestone, chert, and shale which has been deposited on a regional unconformity that truncates successively older units toward the axis of the Cincinnati arch. The Boyle varies in thickness (0 to 11 m) and crops out in a 40-km-wide, northeast-trending, arcuate belt on the eastern margin of the Blue Grass region.

The Boyle Dolomite is divided into the following four lithofacies: Kiddville, Winston (Boyle limestone), Casey, and Duffin. The basal Kiddville is a quartzose dolomicstone with abundant fish remains and represents the slow accumulation of a lag deposit in a platform environment. The Winston (Boyle limestone) is a crinoidal grainstone-packstone and indicates a full marine transgression with high-energy winnowing action on the shelf. The Casey is a cherty dolomicstone with a sparse fauna and represents continued transgression of carbonate mud environments. The Duffin is an interbedded dolomicstone and shale with an abundant and diverse trace-fossil assemblage and marks the transition between carbonate and clastic deposition in Middle to Late Devonian time.

An upward decrease in fossil abundance, diversity, and detrital clastics corresponds to an increase in the percentage of dolomite. Iron substitution in the dolomite crystal lattice increases upward and suggests an influence of reducing diagenetic environments. Trace-fossil analysis reveals a shelf to slope assemblage in the Boyle.

The Boyle Dolomite represents the marine transgression in the western margin of the basin during Middle Devonian time. The transition between open-marine carbonate and anoxic black shale is a shelf to slope carbonate mud with a predominant infaunal assemblage.

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Hydrothermal and Uplift Histories of Northern Appalachian Basin

Geochemical and structural analysis techniques were integrated in an investigation of epigenetic mineralization on fault zones to develop an evolutionary model for the post-Paleozoic history of the northern Appalachian basin. Analysis of faults in outcrop, excavations, and oriented drill cores revealed the occurrence of strike-slip and dip-slip faults which are representative of a fabric which is persistent in style, orientation, and magnitude across New York State. The elements of this fabric do not decrease in frequency with distance from the Allegheny structural front nor do they fan around the centers of deformation as do the Allegheny structures. Indeed the west-northwest trends of the normal faults and the acute bisectrix of the conjugate strike-slip faults are parallel with the short axis of the Appalachian basin. Their formation is attributed to the stresses produced during the asymmetric uplift of the basin in post-Paleozoic time.

Mississippi Valley-type epigenetic mineralization was deposited along these fault zones where they served as the dominant channels for circulating fluids within the well-cemented sandstones. Homogenization of fluid inclusions in vein minerals revealed an intermittent range of depositional temperatures from that typical of the peak of diagenesis in deep sediments, 170°C, to as low as 70°C. The higher temperatures may reflect waning of an elevated heat-flow regime produced by dehydration during diagenesis. The temperatures between 112 and 70°C are attributed to cooling during uplift.

Strike-slip faulting was initiated at temperatures near 170°C as indicated by syntectonic deposition of high-temperature calcite. Normal faulting did not occur until the hydrothermal brines had cooled to 112°C. Minor deformation and entrapment of secondary fluid inclusions continued to 70°C. The timing of tectonic events can be estimated by several techniques which generally indicate a late Paleozoic to early Mesozoic age for strike-slip faulting and a late Mesozoic to Cenozoic age for normal faulting.

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Patterns of Species Diversity in Helderberg Group of West Virginia and Virginia

Twenty-five outcrops of the Lower Devonian Helderberg Group in West Virginia and Virginia were analyzed for stratigraphic, petrographic, and paleontologic variations to interpret depositional environments. Fossil counts, by species, were made along 260 line-transects of standard sampling lengths in 14 of the 25 outcrops.

The stratigraphic study suggests that Helderberg sediments were deposited in the Virginias during an overall Early Devonian transgressive phase of deposition, and that formations comprising the Helderberg Group in the study area are rock-stratigraphic rather than time-stratigraphic units.

Thirty-three interspecific fossil associations involving 10 of 34 species of New Scotland invertebrate macrofossils were identified using a chi-square test for independence. Species showing significant associations were grouped into a primary recurrent group and a related secondary recurrent group by the Fager method. There is a direct relation between the number of interspecifically associated strophomenids in a sample and the percentage of fine-grained sediment.

An index of species diversity was calculated for each outcrop using the Fisher, Corbert, and Williams loga-