lineament zones clearly cut across several stratigraphic levels, indicating Mesozoic and Cenozoic reactivation of favorably oriented preexisting basement faults. The depositional control of sedimentary units, fracture propagation due to basement-block tectonics, and apparent reversals of fault movement observed at the surface are also suggested in a conceptual model.

WARD, L. W., U.S. Geol. Survey, Reston, VA

Late Tertiary Evolution of Salisbury Embayment

Upper Tertiary beds of the Chesapeake Group deposited in the Salisbury embayment preserve a detailed record of periodic sedimentation that is punctuated by unconformities and diastems. Correlation of these Miocene and Pliocene units is possible by the use of various microfossil and macrofossil groups. The unconformities that separate the beds are easily recognized and regionally traceable. Detailed analysis of the beds indicates that most formations are the product of one or more marine transgressions.

One transgression is represented by the Old Church Formation (upper Oligocene/lower Miocene), six by the Calvert Formation (lower and lower middle Miocene), two by the Choptank Formation (middle middle Miocene), three by the St. Marys Formation (upper middle Miocene), two by the Eastover Formation (upper Miocene), three by the Yorktown Formation (middle and upper Pliocene), and one by the Chowan River Formation (upper Pliocene).

In this sequence, on the basis of mollusk data, a temperature chart can be constructed that reflects oscillation within the cool-temperate to subtropical range. The relative stability of the temperatures and the continuing submergence of the Salisbury embayment allowed a richly fossiliferous, diverse, essentially temperate molluscan assemblage to form. This nearly endemic, perched fauna was decimated during the period of low sea level after the Yorktown transgression and before the Chowan River transgression. The result was a large-scale extinction at the generic as well as specific level because of low temperatures and the loss of habitat due to the low sea level stand.

Thus, the beds of the Chesapeake Group record a detailed history of regional and local tectonism, and global and local sea level fluctuations.

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Development and Geology of Harlem Gas Field, Delaware County, Ohio: An Ordovician Carbonate Exploration Model

Gas in commercial quantities was first discovered in 1964 in Harlem Township, Delaware County, by Federal Oil and Gas Company in their 1 Fronk well. This well had an initial production of 4,435 MCFGD after treatment, from the Black River Limestone (Ordovician). Following this discovery, several unsuccessful attempts were made through the 1970s to locate additional reserves in this area.

After an extensive geophysical investigation of the area, Industrial Natural Gas Corporation drilled the 1 Jackson well in 1982. This well had an initial production rate of 225 MCFGD and proved there were additional reserves in the field. Since then, numerous wells have been drilled defining this field, and more than 300 mmcf of gas has been produced.

The geology of the field is more complex than that associated with most oil and gas deposits within the state. The reservoir is located along a northwest-trending fault and fracture system. This fracture zone cuts a northeast-trending anticlinal nose. The reservoir rock is dolomitized Trenton and Black River Limestone. Trapping is accomplished by porous dolomite sections being surrounded by relatively impermeable limestone and dolomite.

This field provides a modern model to which future exploration for hydrocarbons in the Ordovician carbonates of Ohio may be keyed.

WILSON, THOMAS H., and ROBERT C. SHUMAKER, West Virginia Univ., Morgantown, WV

Three-Dimensional Structural Interrelationships Within Cambrian-Ordovician Lithotectonic Unit of Central Appalachians

A block diagram of the Cambrian-Ordovician lithotectonic unit illustrates three-dimensional structural interrelationships within that sequence along the length of the central Appalachian Valley and Ridge and Plateau provinces. Examination of the block diagram and the sections used to construct it illustrates that the Valley and Ridge portion of the central Appalachians can be divided into three sections based on shortening differences within the Cambrian-Ordovician lithotectonic unit. These differences are measured between the Allegheny structural front and the northwestern edge of the Great Valley. In the southern part of the central Appalachians, the shortening across this segment is approximately 23% of a 61-km undeformed length. To the north, shortening increases to 43% of a 119-km undeformed length across Shenandoah County, Virginia, and Hardy and Grant Counties, West Virginia. In this central section, shortening increases from that in the southern section and ranges from 39% of a 120-km undeformed length across the Broadtop coal basin to 44% of a 195-km length across the Nittany arch. This central section can be further subdivided on the basis of internal shortening differences. To the north of the Nittany arch, the Lackawanna syncline and the structures bounding it assume a more northerly trend, and the shortening across this northernmost section is only 8% of an 88-km undeformed length. Our discussion is focused on Cambrian-Ordovician fault systems within the the southern part of the middle section, and on their relationship to higher level structure, northwest in the plateau.

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Seismic Detection of Fractured Reservoirs: A Case Study of a Devonian Shale Gas Field in West Virginia

Interpretation of seismic data over the Cottageville gas field in West Virginia reveals the presence of numerous changes in the amplitude and shape of reflections within the lower and middle Huron Shale. Production from the lower Huron is fracture controlled, and some of the more pronounced changes in amplitude and shape occur in the more productive areas of the field. These changes are related to the development of low-impedance intervals that extend into the middle Huron Shale. Gamma-ray logs and a velocity log from the field indicate that the basal part of the middle Huron is homogeneous in character. Changes in reflection character from this interval arise from changes in the bulk properties of the rock over an area the size of a Fresnel zone. The Fresnel zone radius at the lower Huron depth is approximately 400 ft, so changes in bulk properties of the rock over this scale may not be observable in the well bore. Reduction of the shear and bulk moduli caused by increased fracture intensity and the dependance of P-wave velocity on these properties could produce the observed changes in impedance. The organic portions of the lower Huron have been intensely fractured; however, these fractures are often closed or are partially mineral filled, so fracture related changes in P-wave velocity are less likely.

Our research indicates that the fractured Devonian shale reservoir is detectable on conventional seismic data.

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Lower and Middle Cambrian Shady Dolomite Above the St. Clair Thrust Fault, Tazewell County, Virginia

Previous studies in southwestern Virginia indicate a major decollement at or near the base of the Rome Formation. Recent geologic mapping in the structurally complex southeastern corner of the Amonate quadrangle, southwestern Virginia, identified as much as 800 ft of Shady Dolomite and 600 ft of Rome Formation above the St. Clair thrust fault. The Shady Dolomite, which contains several chert and shale beds up to 1 ft thick, is light gray to white, finely to coarsely crystalline, and thick bedded to massive. The upper part of the unit contains interbeds of grayish-red and reddish-brown shale and siltstone and is in normal stratigraphic sequence with the overlying Rome Formation. "Sunbursts" of barite crystals and pyritized fractures occur approximately 300 ft below the top contact. Above the St. Clair thrust fault, the Shady Dolomite is highly deformed and brecciated, and it contains nappe structures. The dolomite is thrust over Devonian shale, which is overturned and dips 35° to the southeast. The shale is in sequence with strata as young as Late Mississippian. The dolomite dips 55° to the southeast and is truncated by the thrust approximately 1 mi southwest and 0.5 mi northeast of "The Jumps" on State Route 637 at Rourkes Gap, Virginia. This occurrence of Lower and Middle Cambrian strata indicates that the decollement extends locally below the base of the Rome Formation. Fractured zones associated with ramp and splay faults and probable truncated stratigraphic and structural traps may be favorable for the accumulation of hydrocarbons beneath the decollement.

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Transition from Clastic to Peat Sedimentation in Appalachian Basin Pennsylvanian Swamps in West Virginia and Pennsylvania

Paleobotanic, sedimentologic, and lithologic analyses of 34 core samples of underclay from the New River and Kanawha Formations of the proposed Pennsylvanian System stratotype, West Virginia, and 14 samples from strip mines in the Llewellyn Formation from the anthracite fields, Pennsylvania, indicate that more than half of the coal beds studied began forming in response to changing sedimentation and edaphic conditions that were facies independent. Peak formation was a consequence of factors that favored increased organic accumulation in swamps previously dominated by clastic deposition (clastic swamps). The underclay beds grade upward from gray mudstone that is intensely rooted, but otherwise free of plant fossils, to fissile, vitrain-rich, rooted, black shale containing abundant plant fossils, to coal. The black shale flora consists of lycopod, pteridosperm, and calamite branches and large trunks. Foliage is absent because it was destroyed by rooting and decay. The trunks are lying in situ. They are unidirectionally oriented in places, and usually associated with *Stigmaria* rooted hummocks. Trunk accumulations are never associated with flood-transported or lacustrine sediments. Trunks were preserved when a rising water table led to a reduced oxidation potential in the underlying mud. The change from clastic sedimentation to peat formation was rapid in most swamps, as evidenced by a transition zone only a few millimeters thick. However, evidence of longer transition stages is present for some swamps where as much as 0.5 m of black shale was deposited. Occasionally, several cycles of underclay-black shale formation were repeated before peat accumulation began. The transitional process could have been arrested at any time before ideal peat-forming conditions were attained. The gradual transitions from clastic to organic sedimentation suggest that swamp types form a continuum between clastic and peat swamp end members.

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Thick-Skinned, Thin-Skinned, and Balanced Sections of Southern Appalachians

The conflict between thick-skinned and thin-skinned thrust belt hypotheses in the southern Appalachians has been conclusively decided in favor of the thin-skinned interpretation by seismic surveys and drilling results. Balanced cross sections are a logical development stemming from the thin-skinned thrusting hypothesis. Three detailed balanced sections across the region (northern Alabama, Knoxville area, and Blacksburg area) are compared with the early thin-skinned and thick-skinned models of Rodgers, Cooper, and Chamberlin. In Virginia, Cooper's hypothesis about the order of thrusting and synchronous evolution of structures associated with basement fault motion have been disproved by modern mapping, fabric, and paleontologic work. In northeast Tennessee, the no-basement hypothesis has been relatively well established since the work of Rich. In the Alabama-Georgia segment, discussion continues about the origin of some major structures. Balanced section concepts require that the sections be restored to their pre-deformational configurations.

In retrospect, the geologic reasoning based on surface stratigraphic thicknesses and structural styles should have convinced us of the thin-skinned nature of thrusts without the seismic data that seemed essential at the time. The COCORP seismic results should have been no surprise had the geologic reasoning of balanced sections been believed.

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Newark Rift System: A Potentially Prolific Hydrocarbon Province

Many oil tests in the Newark rift system have been encouraging. The data from these tests combined with data collected previously indicate that the geologic and geochemical criteria required to produce significant quantities of hydrocarbons have been met in several of the basins.

Most of the wells drilled heretofore were not positioned using specific geologic or geophysical data. In fact, the industry only recently recognized the play as viable and has applied geophysical techniques to the search for potential hydrocarbon-bearing structural or stratigraphic traps. This activity has partially revealed the geologic processes involved in the development of the basins. The Sanford basin of North Carolina, for example, is a simple half graben, whereas the Richmond basin of Virginia seems to be more complex structurally and may have been affected more by wrench tectonics, producing structures similar to those found in the lake basins of the East Africa rift system.

Each basin's hydrocarbon migration history, however, cannot be fully documented at this embryonic stage of exploration. It is, therefore, necessary to continue to build the geophysical, geological, and geochemical data bases until a well-substantiated model of the migration history can be established. The migration history together with the tectonic evolution of the basin enhances the chances of finding where hydrocarbons are presently trapped. Currently, prospects are being evaluated in several basins. There is a reasonable chance that reserves will be found. At the very least, the wells will aid the exploration effort and refine the exploration theories.