mapped in the Salina and overlying groups, whereas the top of the underlying Lockport Group has been mapped as a relatively smooth homocline dipping south. An appropriate method was selected that is dependent on the simplicity of the structural configuration at depth rather than the complexity of near-surface reflectors. The interface between the Vernon Shale (basal Salina) and the underlying Lockport carbonates is an easily identified reflector on seismic sections. By using the map of the Lockport surface as a reference, reflectors immediately above and below can be mapped using the travel times between reflectors and velocity analyses to calculate isopach information between reflectors. Additional reflectors can be mapped by adding or subtracting isopach information in an upward or downward continuation manner.

This velocity correction involves digitizing the seismic reflectors and shotpoint map, making or obtaining subsurface regional maps of a reference horizon, and performing simple mathematical calculations on a microcomputer. Independent operators can use this inexpensive and straightforward method to rescue some analog seismic data that might otherwise be regarded as useless. Subtle zones of structural closure have been mapped where initial observations suggest the presence of chaotic deformation.

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Control of Lineament in Fluid Migration and Ore-Mineral Localization in Rifts and Rift-Faulted Basins

Many paleorifts and rift-faulted basins are characterized by high gravity, magnetic, and thermal anomalies, and high-density mantle cushions in the crust. Base metals are among the many important ore minerals and hydrocarbon accumulations occurring in the sedimentary formations and fracture zones of such rifts, and basins are commonly related to thermal processes and fluid migration through fractures, faults, and other micro or macro passages. Experimental and theoretical studies show that thermomechanical stresses owing to diapirism result in (1) development of fractures or faults and their patterns, (2) rejuvenation and opening of preexisting fractures, faults, or lineaments providing passages for migration of fluids or hydrothermal solutions, and (3) orientation of fracture pattern of preexisting anisotropy in rocks. Experiments show that changing property from brittle to brittle-ductile to ductile influences the volume percentage of dilation of the preexisting fractures and exerts control on the orientation, patterns, and opening of fractures in the overlying rocks. Rock mechanics experiments also show that extensive en echelon fractures or faults that develop under high fluid pressure by brittle to brittle-ductile extensional fracturing provide additional passage for the migration of fluid during active thermal uplift or rift formation, but they close during subsidence or basin formation. However, marginal fractures or thrust faults formed during doming and uplift open during subsidence and rift-basin formation, and facilitate fluid migration and late hydrothermal ore-mineral localization.

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Micro-Platform Carbonate Development and Facies in Mauch Chunk Formation (Chesterian) of Southwestern Pennsylvania

Through much of southwestern Pennsylvania, adjacent Maryland, and West Virginia, Upper Mississippian (Chesterian) strata are represented by intertonguing of red clastics of the Mauch Chunk Formation and carbonates of the Loyalhanna and Wymps Gap Limestones.

The lower clastic wedge of the Mauch Chunk represents an episodic shoreline progradational event that buried the underlying Loyalhanna carbonates. The sea level rise concurrent with the Wymps Gap transgression resulted in nearly continuous deposition of clastics in nearshore areas while carbonates were being deposited on more offshore areas. This resulted in the development of a lobe of clastics (forming a small platform) that created significant topography to be transgressed by the deepening Wymps Gap sea. Facies development of the Wymps Gap carbonates was markedly influenced by this inherited topography. In areas where clastics are thin, the Wymps Gap is represented by a medium-bedded, dark-gray, petroliferous, clay-rich carbonate mudstone to wackestone. These sediments are representative of open shelf deposition, in moderate water depths below storm wave base. Along the margin of the thick clastic lobe, the Wymps Gap is represented by a light-gray, locally cross-bedded carbonate grainstone to packstone. These accumulations appear to represent a slope-break platform-edge shoal environment. Over the top of the thick lobe of clastics, highly argillaceous, nodular-bedded, variegated, bioturbated carbonate mudstone to packstone formed. These facies represent platform deposition landward of the shoal environment in an open-circulation shallow lagoon.

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Undiscovered Recoverable Natural Gas in Pennsylvania—Estimates and Projections

The total of probable, possible, and speculative resources of undiscovered recoverable natural gas from conventional reservoirs in Pennsylvania is estimated to be approximately 8.5 tcf. The total undiscovered and potentially recoverable gas resource in unconventional reservoirs may be about 11.1 tcf.

Conventional natural gas resources were estimated in five general stratigraphic "packages," using differing approaches made necessary by the variable character and density of the data available, conditioned by time considerations. These packages and their total of probable, possible, and speculative resources are: Mississippian and Upper Devonian sands, 3.6 tcf; Onondaga/Oriskany and related reservoirs, 1.5 tcf; Lower Silurian Medina Sandstones, 1.8 tcf; Silurian Tuscarora and Cambrian-Ordovician formations, 0.7 tcf; Eastern Overthrust belt, 0.9 tcf.

Unconventional resources are: natural gas in coal beds, 2.7 tcf; Devonian shale gas, 8.4 tcf.

General subdivisions of the estimated conventional resources are 31% probable, 40% possible, and 29% speculative. In contrast, subdivisions of estimated unconventional resources are 11, 24, and 65%, respectively.

Short-term projections demonstrate that production of natural gas in Pennsylvania can be doubled without stress and maintained at that level for several years. Much beyond 10 yr, however, projections become speculations. One can say only that significant quantities of natural gas will be produced in Pennsylvania for many more decades. Whether gas production 50 yr hence will be in greater, equal, or lesser quantities than current production is beyond meaningful prediction.

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Hydrocarbon Production in Appalachian Basin: a Glance at the Forest

The Appalachian basin covers approximately 175,000 mi^2 (450,000 km^2) and contains about 0.5 million mi^3 (2 million km^3) of sediments. In the century and a quarter since Drake's first well, more than 500,000 wells have been drilled, producing 3.2 billion bbl of oil and 41 tcf of gas, mostly from shallow depths. Basin oil and gas production largely peaked by World War I. The stratigraphic nomenclature of the basin has arisen from that largely developed by early cable-tool drillers.

Hydrocarbon production has been established in all of the Appalachian's Paleozoic systems. Devonian rocks have been the most productive, and the Mississippian and Devonian combined account for more than three-fourths of all Appalachian oil and gas production. Stratigraphic traps are by far the dominant feature of Appalachian oil and gas fields.

Although the Appalachian basin is a generally mature oil and gas province from a developmental standpoint, this is only true above a depth of much less than 10,000 ft (3,000 m). New shallow discoveries will doubtless continue to be made. In addition, using the improved exploration technologies now available to the petroleum industry, it is reasonable to expect deeper discoveries, particularly in association with the deeper unconformities known to exist in the basin.

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Ohio Paleozoic Source-Reservoir Combinations: Source Rock Quality and Source-Oil Correlation Studies

Although relatively simple structurally, the Interior Lowland area underlying Ohio and adjacent states constitutes a rich and varied hydrocarbon habitat. Structural style included influences of three subsidence episodes, broadly encompassing the Appalachian orogeny to the east and the Michigan and Illinois basins to the northwest and southwest, respectively. A sedimentary sequence covering the whole Paleozoic succession is variously present and becomes generally younger toward the southeast. Hydrocarbons are produced from numerous reservoir intervals within this Paleozoic section. Prominent among these are the Cambrian-Ordovician Knox Group, Ordovician Trenton Limestone, Silurian Medina Group, Devonian Oriskany and Vanango Sandstones, Mississippian Berea Sandstone, and Pennsylvanian coal measure sands. A variety of petroleum types, implying an equal variation in source rock characteristics, has been recognized. Reservoirs have been charged variously from finely textured organic-rich source beds cosedimented within the same succession. Whether the simplistic case of source charging of syndepositional or directly adjacent reservoir beds is normal or whether more complex long distance lateral and/or vertical emplacement processes are involved has yet to be subject to definitive study. Some of the more prominent source candidate rocks include the Conasauga Shale (Cambrian), Reedville or Utica Shale (Ordovician), Ohio Shale (Devonian), and Bedford or Sunbury Shale (Mississippian), in addition to various Pennsylvanian intervals.

Using kerogen pyrolysis-carbon isotopic source-oil correlation technology, it is possible to match petroleums with their precursor sources.

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Environmental Aspects of Middle Ordovician Limestones in Central Appalachians

Black River and Trenton limestones of the outcrop belts in West Virginia and Maryland were deposited on a gentle carbonate ramp that sloped eastward into a deep-water shale basin. The overwhelming sediment type on the ramp was lime mud, deposited below wave base. Water turbidity and circulation fluctuated, which precluded many epifauna. Burrowing infauna, however, were common. The consistency of the mud varied from soft to firm, and hardgrounds developed locally. The more coherent muds were probably stabilized by early dewatering and cementation. Another common sediment type, fossiliferous lime mud, represents patches of organisms that inhabited the muddy substrate. These communities, dominated by echinoderms, trilobites, and brachiopods, had both low densities and diversities. Patches were initially established by large, flat brachiopod pioneers but did not greatly expand because of the high physiologic stress and the soft consistency of adjacent substrate. Occasionally, bioclastic sands were produced by storms reworking skeletal grains of the patches. These storm deposits cut into underlying sediments, and the bioclastic debris was clearly locally derived. Other skeletal sands, containing abundant calcareous algae and *Tetradium* corals as well as peloids and intraclasts, were deposited above wave base on shallower portions of the ramp. Rare cross-laminated peloid sands were confined to small lenses and channels at various depths, and intermittent bottom currents were probably responsible for their deposition. Into progressively deeper water on the ramp, skeletal sediments decreased in abundance; storm- and current-laid sediments also decreased; and shales increased. Carbonate sedimentation eventually ended when the ramp facies were overstepped by basinal shales.

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Lower Pennsylvania Depositional Environments Reinterpreted

In southeastern Tennessee, northwestern Georgia, and northeastern Alabama, the Cumberland Plateau (Walden Ridge and its southwestern extension, Sand Mountain) is underlain by a relatively small Pennsylvanian basin known as the Raccoon Mountain basin.

Stratigraphic units in this basin, of most interest to our discussion, are the uppermost Mississippian Pennington Formation and lowermost Pennsylvanian Gizzard Group (Signal Point, Warren Point, and Raccoon Mountain formations). The Mississippian-Pennsylvanian boundary (between Pennington and Raccoon Mountain) is transitional, and much of the upper part of the Pennington consists of siliciclastics.

Previous workers have suggested that Mississippian-Pennsylvanian rocks are regionally facies equivalent, with the Pennington Formation representing a shallow marine environment and the Warren Point-Raccoon Mountain formations representing marginal-marine, barrier, and back-barrier environments. This suggestion was based largely on inferences made on observed sedimentary structures, particularly the alleged occurrence of low-angle beach-face beds.

New insight, based on sedimentary structures exposed in roadcuts and stripmine highwalls throughout the Raccoon Mountain basin, has enabled reinterpretation of environments of deposition of Pennsylvanian sandstones and shales. It is suggested that most of these Lower Pennsylvanian rocks accumulated in fluvial and paludal environments.

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Shelf Sedimentation Above Storm Wave Base in Upper Ordovician Reedsville Formation in Central Pennsylvania

Interbedded fine-grained sandstone and shale in a generally coarsening-upward sequence characterize the Reedsville Formation. Data on sedimentary structures, lithology, bedding characteristics, and fossils for eight measured stratigraphic sections indicate that most beds were deposited by occasional storm-generated currents. Storm facies exhibit (1) abundant winnowed shell lags coupled with low-angle cross-stratified finer sediment, (2) abrupt lateral thickness variation in many beds, (3) sharp, erosive upper and lower bed contacts, and (4) well-preserved, unabraded outer sublittoral benthic fauna. Hummocky cross-stratified beds are common, and in many places are associated with wave-rippled sandstones.

A shallow open-shelf environment is inferred. Storms of variable intensity and duration periodically scoured and suspended bottom sediments and deposited individual fining-upward units under conditions of strong but waning bed shear. An overall increase in the sandstone/shale ratio from bottom to top in the progradational sequence suggests gradual shallowing and more frequent storm-wave influence. Uppermost beds contain intertidal fossil communities. Paleocurrent data indicate east- and northeast-directed sediment transport.

These interpretations are not consistent with the common assumption that the Reedsville is simply the deep-basin, distal equivalent of the adjacent Martinsburg Formation. The present data suggest that Reedsville sediments accumulated on a shelf west of a structural hinge line that comprised the western margin of the thicker, deeper water Martinsburg sequence. Differential subsidence across this shelf-edge hinge line may account for the significant differences in paleobathymetry of the two formations.

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Six Types of Trap or Reservoir-Producing Configurations in Trenton Limestone Reservoir, Northwestern Ohio

Six types of petroleum-producing configurations are recognizable in the oil and gas fields of the Lima-Indiana trend whose reservoirs are the Trenton Limestone of Ordovician age. The data that support recognition of these six structural, structural-stratigraphic, and possibly stratigraphic-permeability trapping configurations are mixed, but involve consideration of the pattern of 34 fields or pools on the main anticlinal trend of the Findlay arch as well as 12 smaller fields or pools to the northwest in the Michigan basin and 20 fields to the southeast at the updip edge of the Appalachian basin.

The reservoir is mainly dolomite and the producing portion of the reservoir generally occurs near the top of the Trenton Limestone. The more porous dolomite has been analyzed chemically for Ca/Mg ratios, Na, Sr, Fe, and other elements in cores to supplement petrographic studies off the main oil field trend in Wyandot County.

The six play configurations are the following. (1) An anticlinal trap along the crest of the Findlay arch. Here, as elsewhere, the seal and presumably the source are the overlying Utica Shale. (2) A faulted anticlinal trap on the western side of the Findlay arch. The fault, the Bowling Green fault, generally limits production to the upthrown eastern side. (3) An updip facies change from the Trenton Limestone into the overlying Utica