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

Shale to the south. This change, together with draping of the Utica over the underlying competent Trenton, traps petroleum along the southwestern extension of the Lima-Indiana trend. (4) Fracture systems related to regional fracturing of the early Paleozoic rocks. Apparently these systems have provided fracture-enhanced reservoirs. Similar configurations are well known in the Scipio-Albion trend in southern Michigan. Secondary dolomitization and sulfide mineralization are common in association with these fractured features. (5) Possible porosity-permeability traps, probably on structure, where dolomite is replaced laterally by dense limestone. (6) Small anticlinal terraces off the main arch system, related to minor production. These terraces appear as down-to-the-basin noses on structural maps.

Considered together, the Lima-Indiana fields are a "giant" field extending 120 mi (193 km) in Ohio and another 50 mi (80 km) in Indiana. Before 1900, thousands of wells were drilled, as shallow as 1,100 ft (334 m), producing over 220 million bbl of oil at initial rock pressures between 100 and 450 psi (690 and 3,100 kPa). Exploration continues at a modest pace.

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Berea Sandstone Gas Reservoir in Portage County, Ohio

The Mississippian Berea Sandstone is a reservoir for shallow gas in Randolph and Suffield townships of Portage County, Ohio. The Berea Sandstone is well known in Ohio from its outcrops at the outskirts of Cleveland. It is among the more productive formations in Ohio where it yields gas, oil, or gas and oil at moderate to very shallow depths. The great differences in reservoir quality, sandstone distribution, and producibility in Berea oil and gas fields are partly related to the use of the term "Berea" for several sandstone bodies that produce from different structural and stratigraphic settings.

In Portage County, the Berea Sandstone is up to 60 ft (18 m) thick and has a porosity in the 15-25% range. The sand is white, medium to fine-grained quartz, poorly cemented, and without substantial shale interbeds. The reservoir lies below the "Cap Berea," a gray, cemented thin bed at the base of the Sunbury Shale (driller's Coffee shale). The sequence is similar to the outcrop found on the eastern side of Cleveland, but not like western outcrops of Berea Sandstone. In Portage County, the sand is currently interpreted as fluvial or deltaic. Within the field, thickness of the reservoir and hydrocarbon saturated zone varies little.

Natural gas is produced from the top 30 ft (9 m) of the reservoir. The reservoir energy is water drive. The gas fields lie just updip from a steep structural terrace interpreted as a fault zone. The trap for the fields is anticlinal and the Sunbury Shale is the seal. New wells drilled into the reservoir at 400-500 ft (122-152 m) in depth produce gas without water. Initial open flow tested up to 1.0 MMCFGD at an initial reservoir pressure of about 80 psig (552 kPa). This producing configuration of a nearly uniform sandstone reservoir on structure differs markedly from that found in Medina and Ashland Counties, Ohio, where the Berea Sandstone is also a producing reservoir.

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Cave Levels of Trenton–Black River in South-Central Michigan

Four generalized cave levels of the Trenton–Black River in south-central Michigan are most notable because of lost circulation zones in productive field areas. The levels are herein referred to as uppermost, upper middle, lower middle, and lowermost.

The uppermost cave level extends about 250 ft (76 m) into the Trenton. It is best developed in the widest, most productive areas of Albion-Scipio, where the drill bit dropped as much as 62 ft (19 m). About 59 productive wells in Albion-Scipio lost circulation at this level.

The upper middle level includes the lower, slightly argillaceous Trenton, and the uppermost Black River formation. This level is developed to some extent in all fields, and is a common zone of solution-collapse brecciation. Because this level is collapsed, lost circulation is less common.

The lower middle level below the "Black River shale" is not penetrated by many wells in Albion-Scipio. Where penetrated, it is developed in all fields, and is the main producer in most smaller fields. About 26 wells in Albion-Scipio lost circulation at this level, with the drill bit dropping as much as 80 ft (24 m).

The lowermost cave level extends into the Glenwood Shale. It is the most widely developed level, but is intersected by few productive holes. Only seven wells lost circulation at this level in Albion-Scipio, but the drill bit has dropped as much as 8 ft (2.4 m) in the Glenwood. This cave level effectively drained some oil from reservoirs where the oil-water contact intersects the Glenwood.

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Silurian and Lower Devonian of Southwestern Virginia

Thermal maturity of the Silurian and Lower Devonian rocks in Virginia west of New River decreases southwestward. Oil and gas shows are reported.

The total thickness of Lower Devonian plus Silurian strata ranges from 52 to 1,000 ft (16 to 305 m), with a maximum in Buchanan County. Sandstones were derived from sources southeast of the central Appalachian basin, some from lands southeast of the outcrop belt, and some formed by reworking of sandstones within the outcrop area. Sandstones change northwestward to shales in the Clinch and Rose Hill Formations. In the Middle Silurian and Helderberg Group, sandstones grade northwestward to limestones. Limestones in the Hancock Formation change westward to dolomite. The Onesquethaw Stage is represented by sandstone, chert, and limestone assigned to the Wildcat Valley and Huntersville Formations.

In the Middle Silurian (Keefer or "Big Six" sandstone) and Early Devonian (Wildcat Valley Sandstone), longshore currents carried sand across the southwest end of the basin toward Kentucky.

Several regional unconformities are present. These unconformities are mostly related to sea level changes, but some are probably tectonic in origin. Five unconformities are significant: (1) at base of Silurian, (2) at base of upper Helderberg over much of the area, (3) at base of Oriskany Sandstone, (4) at base of Huntersville Formation, and (5) at base of Upper Devonian black shales in extreme western Virginia, where Chattanooga Shale overlies Middle Devonian to Middle Silurian strata.

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Basement and Structural Control of Ordovician Trenton Dolomite in Extreme Southeastern Michigan, with Emphasis on Hydrocarbon Accumulations in Relationship to Dolomitization

Recent exploration activities along the northerly extension of the Bowling Green fault have sparked renewed interest on the flanks of one of North America's first giant oil fields (Lima-Findlay field). Extreme southeastern Michigan lies on the northwest flank of the Cincinnati arch and the southeastern flank of the Michigan basin. Within the study area, basement and structural control dictate the occurrence of dolomite within the predominantly limestone Trenton Formation. Commercially productive hydrocarbon accumulation within this study area has been associated with dolomitization within the top 150 ft (46 m) of the Trenton Formation.

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Upper Devonian Catskill Delta of West Virginia

Oil and gas reservoir rocks of the Upper Devonian of West Virginia were deposited as shoreline sands along a coastal plain characterized by marine-dominant deltas (Catskill delta complex). These sandstones exhibit facies relationships between red beds and interbedded sandstones and shales that shift westward and eastward with offlap and onlap. Outcrop equivalents at Elkins, West Virginia, are correlated with the interval of Balltown to Fourth sands. Subsurface correlation indicates that maximum westward progradation occurred during deposition of the Gordon and Gordon Stray sands, and that transgression mainly characterized the younger Devonian sands of the Thirty-foot, Fifty-foot and Gantz.