

indicates that the site of volcanic activity shifted during time. A growing orogenic source area shed terrigenous sediment into the basin and onto the Trenton ramp. Initially, these muddy influxes came from the north and from the south, but terrigenous mud eventually swamped the entire ramp and carbonate sedimentation then came to an end. Trenton Limestones have only minor intergranular porosity because of abundant mud matrix and cementation. The only significant contribution to porosity is in fractures. Thus, wells with Trenton shows are characterized by high initial potential that decreases rapidly.

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Early Days Along Oil Creek, Pennsylvania (1859-1865)

Beginning in late August 1859, with the success of the Drake well at 69.5 ft, early oil exploration concentrated along Oil Creek in the stretch between Titusville and Oil City, but other areas in northwest Pennsylvania also saw discoveries. Tributaries to the creek had their share of activity. Pioneer, Benninghoff, Cherry, and Wildcat Runs were famous names. Wildcat became the standard word for a rank exploratory well. The 1859 (and later) oil boom rivaled and usually surpassed the excitement of the 1849 gold rush in California according to some adventurers who saw both.

A proliferation of oil strikes in the narrow valley included wells such as the Noble and Delamater ("Golly, ain't that well spittin' oil?"), which produced over 700,000 bbl in 21 months, Buckeye well (1,000 b/d and the first oil from the creek to be exported abroad), the Maple Shade (never stopped flowing even when it burned) and the Phillips well (4,000 b/d). These wells were among a multitude of phenomenal gushers. Most wells had a total depth of less than 500 ft, some less than 200 ft. The drillers, operators, investors, and brokers learned of the local sequence of Upper Devonian Venango sands (First, Second, Third Stray or Gray, and Third) and described their trends as veins or streaks. These beach, bar, and near-shore deposits abruptly pinched out, leaving one wildcatter with a few barrels and a neighboring well with initial gauges in the hundreds or thousands.

This study traces the early major oil strikes down Oil Creek and describes the geology of the shallow sands that they tapped. Period photographs and steel engravings of the 1860s are compared to a photographic essay of the creek as it is today. Many of the famous wells are still there. Oil Creek is a shrine to the unique personality of the oilman and the titan industry, which at the outset, had to cope with rugged conditions and seemingly capricious sands.

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Mapping Paleostuctures from Time-Related Aeromagnetic Lineaments and Photolineaments

A classification of aeromagnetic lineaments has been adapted for use with photolineaments mapped from Landsat and aerial photographs. William Dean Gibbons, a Texas geophysicist, recently defined sets of structurally high, linear, aeromagnetic anomalies for each Phanerozoic period; e.g., N19°W and N71°E for the Cambrian. Assuming that many of these aeromagnetic trends had drag-fold origins, a Cambrian model of a wrench system with drag folds and N19°W and N71°E would have the primary stress direction at N64°W, primary first-order wrench at N86°E, and complementary first-order wrench at N34°W. This model was tested on several Cambrian (Knox) oil fields in Kentucky by mapping dense sets of N34°W, N19°W, N86°E, and N71°E lineaments from aerial photographs and interpreting drag folds from the lineaments. Comparing structural contour maps on the Knox with Cambrian drag-fold maps indicates that drag-fold maps are an approximation of structural contour maps with clusters of drag folds corresponding to closed highs. Similar trials on Kentucky oil fields in the Ordovician also gave encouraging results, indicating that the method has potential in exploration. Several porosity and permeability trends were also identified from time-related lineaments for the Knox and various Ordovician reservoirs.

This procedure for mapping paleostructure has been further tested in the Mid-Continent on structures formed during various periods from the Cambrian to Cretaceous and is being used, with Landsat, for regional exploration and, with aerial photographs, for detailed studies. A current project involves exploration for Pennsylvanian and Permian paleostructures in the Denver-Julesburg basin.

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Depositional Supersequences Among Cenozoic Strata of U.S. Atlantic Continental Margin

Integration of outcrop, borehole, and seismic reflection stratigraphy reveals the broad-scale depositional framework of Cenozoic strata of the U.S. Atlantic margin. The principal feature of the framework is a series of depositional supersequences bounded by interregional erosional unconformities that can be traced from coastal plain outcrops to the continental rise. The Atlantic continental margin is divided into five depositional areas: the Salisbury, Albemarle, and Charleston embayments; a composite of the entire Atlantic coastal plain; and a composite of the Atlantic shelf and slope. The major depositional episodes are early and middle Eocene in all depositional areas, late Eocene in all areas except the Albemarle embayment, early Oligocene on the composite shelf and slope, late Oligocene in all depositional areas but minor in the Salisbury embayment, and early, middle, late Miocene and Pliocene in all areas.

Paleoenvironmental and paleo-oceanographic analyses of the sediments and associated fossil assemblages indicate that alternation of major depositional and erosional episodes is controlled chiefly by the relative position of sea level. Thus, the supersequences correlate with the supercycles of the Vail sea level model. The bounding unconformities, in turn, correlate with the major global unconformities of the Vail model. Local variations among such things as terrigenous sediment supply, subsidence rates, and the position of major geostrophic currents, however, may accentuate or diminish the sea level effects.

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Proposed Model for Interaction Between Basement Structures and Folds in Cover Rocks of Central and Southern Appalachians

Field studies, analysis of side-looking airborne-radar data, and examination of proprietary seismic reflection profiles suggest that, although the Eastern Overthrust belt tectonic regime is thin-skinned, the fold plunges, wavelengths, and frequencies appear to be controlled primarily by a Precambrian basement fault system.

Field studies have shown that thrust faults generally predate or are contemporaneous with associated folds. Thus, the proximity of faults controls, to a large degree, the wavelength of the associated folds. In addition, because faults converge downward toward the major decollements, the shorter the distance between the decollement and the ground surface, the more numerous the faults and, consequently, the narrower the associated fold wavelength. Changed decollement levels, in turn, appear to be related to basement faults.

Abrupt changes in wavelength of folds along strike appear to indicate the presence of cross-strike (lateral) ramps that connect decollements at different stratigraphic levels. The position of lateral ramps appears to be controlled in turn by cross-strike faults in the Precambrian basement, as seen on proprietary seismic data.

A map of Mesozoic basins in the eastern United States shows that Precambrian highs between basins and east-west border faults are aligned with lateral ramps. Mesozoic reactivation is therefore indicated. Later reactivation is suggested by the fact that more than 35% of recent earthquakes are coincident with lateral ramps.

Many lateral ramps can be extrapolated seaward and are exactly coincident in strike and nearly coincident in spacing with transform faults. It is hypothesized that the basement faults acted as zones of least resistance along which modern transform faults developed during episodes of sea-floor spreading.

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Provenance of Selected Sandstones and Mud Rocks of Dunkard Group (Upper Pennsylvanian-Permian) in Ohio, West Virginia, and Pennsylvania

A standard QFL count and a special count of quartz grains indicate that the Dunkard sandstones are rich in quartz and sedimentary and metasedimentary lithic fragments, but poor in feldspar and igneous lithic fragments. Plots of the Dunkard detrital mode on provenance diagrams

reveal a separation of samples into two groups: a geographically restricted "northern" group and a more extensive "southern" group. This discrimination is consistent with paleocurrent and facies distribution data, which delineate two sources of sediment to the Dunkard basin: a dominant southeastern source and a subordinate northern source.

Northern sandstones are rich in nonundulatory, monocrystalline quartz, "stable" polycrystalline quartz, and sedimentary lithic fragments. These sandstones largely reflect a stable cratonic source wherein rocks were formed from multicycle sediments, some of which were ultimately derived from a low-lying craton of granite and/or high-rank metamorphic Precambrian rocks. Southern sandstones are enriched in mud rock and foliated, quartz-mica rock fragments, "unstable" polycrystalline quartz, and polycyclic, monocrystalline quartz reflecting a southeastern source terrane of mixed low-rank metamorphic and sedimentary lithology.

Comparison of the Dunkard detrital mode with modern sands from tectonic settings capable of producing uplifted terranes of supracrustal source rocks reveals that the Dunkard basin was a foreland basin that received sediment from both the adjacent foreland fold-thrust upland and from positive areas on the craton. Low to medium-grade metamorphic and recycled sedimentary detritus, shed from an orogenic highland, diluted contributions of supermature sedimentary and magmatic detritus from the continental lowlands.

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Fluvial Model for Deposition of Basal Pennsylvanian Quartzarenite in Eastern Kentucky and Southwestern Virginia

Sedimentary structures, textures, plant fossils, and the continental character of associated Pennsylvanian strata suggest that basal Pennsylvanian quartzarenite in eastern Kentucky and southwestern Virginia was deposited in a fluvial environment. Along the Kentucky-Virginia border, a southwest-trending paleovalley as much as 400 ft deep and 7 mi wide is cut into Mississippian rocks; it contains the basal quartzarenite of the Middlesboro Member (Pennsylvanian) of the Lee Formation. The arenite is mineralogically and texturally mature, and previous studies have interpreted it as a beach, barrier bar, or barrier island deposit. Those studies resulted in an interpretation of the geologic history of the area that included uplift and erosion of the northwestern part of the basal Pennsylvanian Pocahontas Formation followed by deposition of the Middlesboro arenite by a southeastward-transgressing sea.

Another interpretation of the same subsurface data used to support the coastal marine depositional model is that the Pocahontas was deposited in an interior valley southeast of and subparallel to the Middlesboro paleovalley. In this interpretation, the two paleovalleys are part of the same southwest-trending drainage system, and the Mississippian-Pennsylvanian unconformity, contrary to most presently accepted ideas, probably extends completely across the Appalachian basin. Furthermore, filling of the Middlesboro paleovalley by coarse sand and gravel may have caused damming of the Pocahontas paleovalley at a confluence southeast of the present eastern limit of the Pennsylvanian in southwestern Virginia. If Pocahontas sediments were deposited in a subsiding interior valley blocked by the basal beds of the Middlesboro, then the Pocahontas and Lee Formations are in part lateral equivalents.

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Modern Continental Rifts: Characteristics and Applications to Recognition of Ancient Rifts

Characteristics of modern continental rifts can provide a checklist of expected features in ancient rift systems: (1) distinctive morphology and dimensions as long, linear, sinuous structures up to thousands of kilometers in length and tens of kilometers in width; (2) high heat flow, resulting in extrusive and intrusive igneous bodies and hot-spring deposits; (3) small volcanoes within and large volcanoes outside only certain parts of rift systems; (4) complex stress fields that combine elements of extension, compression, shear, and torsion; (5) complex internal faulting; (6) gravity highs over intrusive mafic rocks and gravity lows over sedimentary rocks; (7) high seismicity, which leaves a record of earthquake-induced sedimentary structures; (8) progressive basin abandonment because of "rift-jumping"; (9) reactivation through time; (10) individual basins within rift

systems formed by complexes of tilted-fault blocks, grabens, and horsts; (11) interfingering sedimentary deposits from slope, riverine, valley-floor, and lacustrine environments; (12) large and small rift-valley lakes, only some of which exhibit high biological productivity and anoxic bottom waters depositing organic-rich muds; and (13) deposits of the precursors of coal, petroleum, gas, and minerals that bear such elements as copper, lead, zinc, phosphorus, barium, or uranium.

The combination of these critical features helps to identify ancient rift systems. However, crust weakened by rift-forming processes may be overprinted by later tectonic events that tend to obscure important details in ancient rifts such as the Newark rift system of eastern North America.

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Petroleum as an Ore-Bearing Fluid: A Hypothesis

Each of the many organisms from which petroleum is generated concentrates a large number of elements. Of 75 elements recognized in organisms, Co, Cu, Mo, Pb, and Zn are among the 41 identified as participating in metabolic reactions and tissue formation. Many of the important "ore-forming elements" are fixed into metalloproteins such as cobalamine (Co), cytochrome oxidase (Fe, Cu), alcohol dehydrogenase (Zn), and xanthine oxidase (Mo, Fe). Most proteins including metalloproteins degrade between 60° and 70°C. Until that critical temperature is reached, such metals are bound in the tissues; after that, the metals are free to move from the tissues. It is also within this temperature range that petroleum begins to be generated.

Besides forming parts of metalloproteins, metals also attach to organisms and organic matter by other processes, including attachment to metabolic wastes, to decay products such as humic acids, to surface-active compounds of bacteria, and to organic remains in sediments. The attached metals may be locked in and on the organic matter until it is converted into liquids.

Metabolically used elements such as Co, Cu, Mo, Pb, and Zn are among the 50 recognized in petroleum. It is possible that metals such as these begin as part of the organic remains, catalyze the generation of petroleum, and then are carried by petroleum to reservoir rocks that can also serve as host rocks for metallic concentrations.

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Mapping of Fracture Zones by Helium Emanometry and Possible Relationship of Helium Anomalies to Hydrocarbon Reservoirs in Western Pennsylvania

Helium is ubiquitous within the earth's crust. Local helium concentrations in the subsurface are observed in association with ores containing uranium and thorium, oil and gas reservoirs, and thermal fluids. In addition, permeable fracture zones tend to intensify local concentrations of helium because of its relative ease of migration along these conduits. A survey of helium in soil-gas samples was conducted across a previously mapped fault zone and a drilling-defined hydrocarbon reservoir in Greene and Fayette Counties, southwestern Pennsylvania, to demonstrate the utility of such surveys for mapping fracture zones and for locating hydrocarbon reservoirs. In the study area, a northwest-trending fracture zone cuts across both an area of hydrocarbon accumulation and an area thought to be relatively barren of hydrocarbons. The survey indicated that the helium content of the soil was anomalously high in a 30-m wide zone above the mapped fault and fracture system. Similar results were obtained from traverses made across both the accurately mapped fault zone and the hypothesized extensions of that zone. These data support the concept that helium can be used to locate fault and fracture zones where location is precluded by more conventional mapping procedures. Although helium surveys have delineated known hydrocarbon reservoirs in other areas, this preliminary survey, which consisted of a few traverses rather than an extensive grid pattern, failed to produce a significant anomaly above a known reservoir in southwestern Pennsylvania. This may be due to the low density of sample distribution and the high average background helium value for these traverses.

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Faulting in Triassic Gettysburg Basin, Pennsylvania and Maryland