they illustrate that the threefold subsurface division of the Clinton into the "Stray," "Red," and "White" is not locally reliable; instead the interfingering sand and shale lithosomes should be mapped in this interval.

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Prospects for Coal Development in Michigan Basin

Coal in the Michigan basin is in thin, relatively discontinuous, laterally variable seams of non-coking, high volatile B and C bituminous rank, with a range of 10, 300 to 12,300 Btu.

The known coalfields range in size from about 100 to 1,500 acres (40 to 60 ha.), mostly in less than 250-acre (100 ha.) areas. Known remaining reserves are generally in beds less than 3 ft (0.914 m) thick. Ash and sulfur content are lower in the northeastern part of the basin, 3 to 9% and 1 to 3%, respectively, in the thicker and more continuous seams which have been mined, but to the south and west these qualities deteriorate to undesirable levels. However, it is possible the rank and quality both might be substantially improved by more modern cleaning technologies than were available at the time of the earlier mining when most of the analyses available were made.

The coal-bearing strata are of Early and lower Middle Pennsylvanian age as determined by marine invertebrate and plant fossil paleontologic techniques. This sequence ranges in thickness from the eroded edges basinward to as much as 650 ft (198.12 m) but the thickness is exceedingly variable owing to its deposition on an erosional surface of several hundred feet of relief which was developed entirely on rocks of varying levels of Mississippian age, and to the post–Middle Pennsylvanian erosion surface. The overlying strata in the center of the basin are consolidated shales, siltstones, and gypsiferous deposits of the "Redbeds" sequence of Late Jurassic age. Peripherally to this thin veneer above the Pennsylvanian in the central part, 300 to 600 ft (92 to 183 m) of unconsolidated Pleistocene gravels, silts, clays, and peat buries the Pennsylvanian over most of the areal extent. The relief on this pre-Jurassic plus pre-Pleistocene surface exceeds 200 ft (61 m) in many places and erosional channels appear to have removed the Pennsylvanian strata including the coals in a number of places.

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Devonian Shale Exploration Rationale Tested in Northeast Tennessee

Devonian shale exploration rationales are characterized by some geologic fracture-creating mechanism, for natural fracture systems are essential to natural gas production, even with advanced stimulation technology. One rationale predicts intense fracturing in the shale wherever proximally associated with the major thrust faults of the Appalachian Valley and Ridge province. Gruy Federal No. 1 Grainger County, TN (DOE EGSP-TN9), tested this rationale. The well penetrated the Saltville thrust fault (stratigraphic throw over 10,000 ft or 3,048 m) and encountered 720 ft (220 m) of Devonian-Mississippian Chattanooga Shale in the lower plate. A total of 220 ft (67 m) of core was extracted from the most highly organic intervals of the shale, and a full suite of wire-line logs was run. Widespread and locally intense fracturing observed in the core and evidenced by the logs vindicates the exploration rationale. By the time this paper is presented the well will have been stimulated and the well test results will be available.

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Facies, Paleoecology, and Depositional Environments of Energy Shale Member (Pennsylvanian) and Their Relation to Low-Sulfur Coal Deposits, Southern Illinois

Thick deposits of Energy Shale (Carbondale Formation, Desmoinesian) are associated with low-sulfur coal deposits in the underlying Herrin No. 6 coal in southern Illinois. The Energy Shale consists of wedges, up to 85 ft (25.9 m) thick, which thin away from the Walshville Channel (interpreted as a major distributary channel deposit in the study area).

Facies recognition and interpretation of depositional environments are based upon lithology, sedimentary structures, vertical and lateral relations, geometry, and paleoecology as well as organic matter content and total sulfur content.

Four facies are recognized in the surface mines studies. The thickest and coarsest facies is adjacent to the Walshville Channel and is characterized by numerous fining-upward channel-fill sequences of sandstone, siltstone, and silty shale. It is interpreted as a series of crevasse distributary channel-fills in the proximal parts of splays. This proximal splay facies grades laterally into shale with abundant plant remains, thin coal beds (splits from the Herrin No. 6 coal) and some siderite concretions. It is interpreted as the distal deposits of crevasse splays. The distal splay facies grades laterally into what is interpreted as an interdistributary bay-fill facies consisting of shale with laterally persistent siderite layers. Sixteen miles (25.8 km) from the Walshville Channel, a zone at the top of this facies is extensively burrowed and contains pectinoid bivalves, indicating some marine influence. The bay-fill facies grades laterally and vertically into shale, containing a moderately diverse marine fauna composed mostly of stunted individuals. It is interpreted as a marginal marine facies.

The Walshville Channel and the crevasse splay facies of the Energy were partly contemporaneous with Herrin peat deposition. The sulfur content of the Herrin No. 6 coal is highest beneath the marginal marine facies (the thinnest) and the proximal splay facies (the thickest) of the Energy Shale.

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Structural Interpretation of Buried Silurian Reefs in Southwestern Indiana

Two or more generations of buried Silurian reefs are present in southwestern Indiana. Possibly all the larger reefs grew until Devonian time. Some may have attained thicknesses greater than those of any other group of Silurian reefs. Strata topping the reefs range from Middle or Late Silurian to Middle Devonian in age. Deep drilling is sparse in southwestern Indiana, and limited geophysical surveys are mostly confidential. Interpretation of the reef province then relies heavily on evaluation of structural deformation (broad sense) of the rocks both encasing and overlying these and other Silurian reefs and of the reefs-proper and their flanks.

The amounts of suprareef drape in strata as young as Pennsylvanian are related to reef thickness, kind of reef, erosion of reef and postreef rocks, height above reef, and counterproductive subreef sagging. Both suprareef draping and subreef sagging are expectable for any given reef. Long-continued diagenesis, even to the present time, was the most significant cause of such structural deformation; subreef soft-sediment deformation penecontemporaneous with reef growth also was a factor. Differential compaction between reef and contemporaneously deposited interreef rocks was the most important diagenetic process. Differential compaction in rocks far above the reefs, acting in concert with lithologic and thickness differences brought about by continued growth of drape structure, had a minor role. Differential solution and recrystallization could have contributed especially to subreef sagging. These interpretations temper some ideas that localized tectonic uplifts influenced both reef siting and suprareef draping and that early cementation resulted in structural stabilization of substrate, reef, and reef flank penecontemporaneous with growth.

The ranges in geologic circumstances that apply—in setting, reef genesis and abortion, erosion or nonerosion and burial of reefs, and postreef attainment of structural clues to reef recognition—suggest that southwestern Indiana has a reef-related reservoir potential that applies differentially within the reef province. The differential extends to the reefs themselves and to individual formations draped over the reefs. This province, surely, is inadequately explored for hydrocarbon potential in sub-Mississippian rocks.

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Coal in Pennsylvania: Geology, Current Production, and Reserves

Pennsylvania is at the northern end of the Appalachian coal basin. Approximately 15,000 sq mi (39,000 sq km) or one third of the state, is underlain by coal measures. The coal is Pennsylvanian to Permian in age, and includes bituminous and anthracite coal found in several separate fields.

The bituminous coals have dips of less than 2°, with some beds dipping up to 8° and rarely exceeding 8°. These steeper dips are found along the flanks of the major Plateau fold structures and in proximity to the Allegheny Front. Bituminous coal in the Broad Top field and in the anthracite basins have dips commonly exceeding 60°.

The earliest record of coal being mined in Pennsylvania was at Fort Pitt (now Pittsburgh) in 1761. To date, more than 22 billion tons of coal have been mined out or lost due to mining. Coal production in 1978 was 80,342,913 net tons of bituminous coal and 5,037,960 net tons of anthracite coal.

Recoverable reserves are estimated at 22 billion tons of bituminous coal more than 28 in. (71 cm) thick, and 8 billion tons of anthracite coal more than 24 in. (61 cm) thick. These estimates assume that all the major coals are continuous throughout their projected area of occurrence, as with the Pittsburgh seam.

However, recent detailed studies on the sedimentology of the Upper Freeport coal in southwestern Pennsylvania indicate that the stratigraphy of the coal-bearing measures may be more complex than previously believed. These units consist of a highly variable sequence of coals, clays, sandstone, shales, limestones, and other rock types occurring in lenses, pods, channel-fills, etc. Because of the presence of these coal-seam discontinuities in some of the coals, the current coal reserve estimates may be significantly inaccurate.

The Pennsylvania Geological Survey is currently cooperating with the U.S. Geological Survey in the National Coal Resources Data System. We are currently in the third year of the program to enter all point-specific data, including coal thickness and quality, into the computer. In addition, coal crop maps for each principal coal seam showing areas of deep and strip mining are being compiled. This program will result in much more accurate estimates of the remaining coal reserves in Pennsylvania.

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Coal Resources of Indiana and Potential Geologic Problems in Their Exploration

Indiana has about 33 billion tons of coal resources, and about 17 billion tons are estimated to be recoverable by present-day mining technology. Coal mining, beginning in the early 1800s and continuing until the late 1930s, was principally underground, but since 1940 mining has been mainly surface. At present only five of the more than 120 active operations are underground, and they produce about 2% of the annual tonnage.

Underground mining of coal in Indiana is expected to increase, since about 15 billion of the 17 billion tons of recoverable coal appear to be recoverable only by deep mining methods. Studies of past and present underground operations in the Springfield Coal Member (V), taking into consideration partings, roof conditions, faults, water problems, and gas concentrations in the coal and roof strata, should prove useful in planning for future operations.

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Coal Resource Studies in Virginia

There are three coal-bearing areas of Virginia: the Richmond and Farmville Triassic basins in the Pied-