

ORIGIN OF DISCONTINUITIES IN COAL-BEARING STRATA AT ROARING CREEK (BASAL PENNSYLVANIAN OF INDIANA)

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ABSTRACT

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Basal Pennsylvanian coal-bearing strata exposed along Roaring Creek, west-central Indiana, exhibit extreme lateral discontinuity. Coal seams abruptly change in thickness and elevation; they split, grade into shale, are cut out by channels and disrupted by soft-sediment deformational structures. Initial sediments were laid down by a network of southwest-flowing streams that traversed a deeply channelized upland surface of Mississippian carbonate rocks. Channels aggraded rapidly as uplands were worn down, so the region changed through time from uplands to upper deltaic plain. Local environments included channels, localized point bars, small natural levees and crevasse splays, overbank deposits, and swamps. Differential compaction and subsidence, slumping stream banks, and possibly collapsing sinkholes influenced sedimentation. As a consequence, coals are too discontinuous for economical mining, although they are locally thick and high in quality.

INTRODUCTION

The banks of Roaring Creek provide unusually complete exposures of basal Pennsylvanian strata. These rocks display great lateral variability, and in many places, disruption by large-scale soft-sediment deformation. Coals are highly discontinuous: they abruptly pinch and swell, sharply rise and fall in elevation, split, grade into shale, and are cut out by channels. These features have fascinated geologists for more than a century, but they have frustrated coal miners (Hobbs, 1872; Hopkins, 1895; Ashley, 1898).

Rocks at the study site are typical of basal Pennsylvanian strata through-

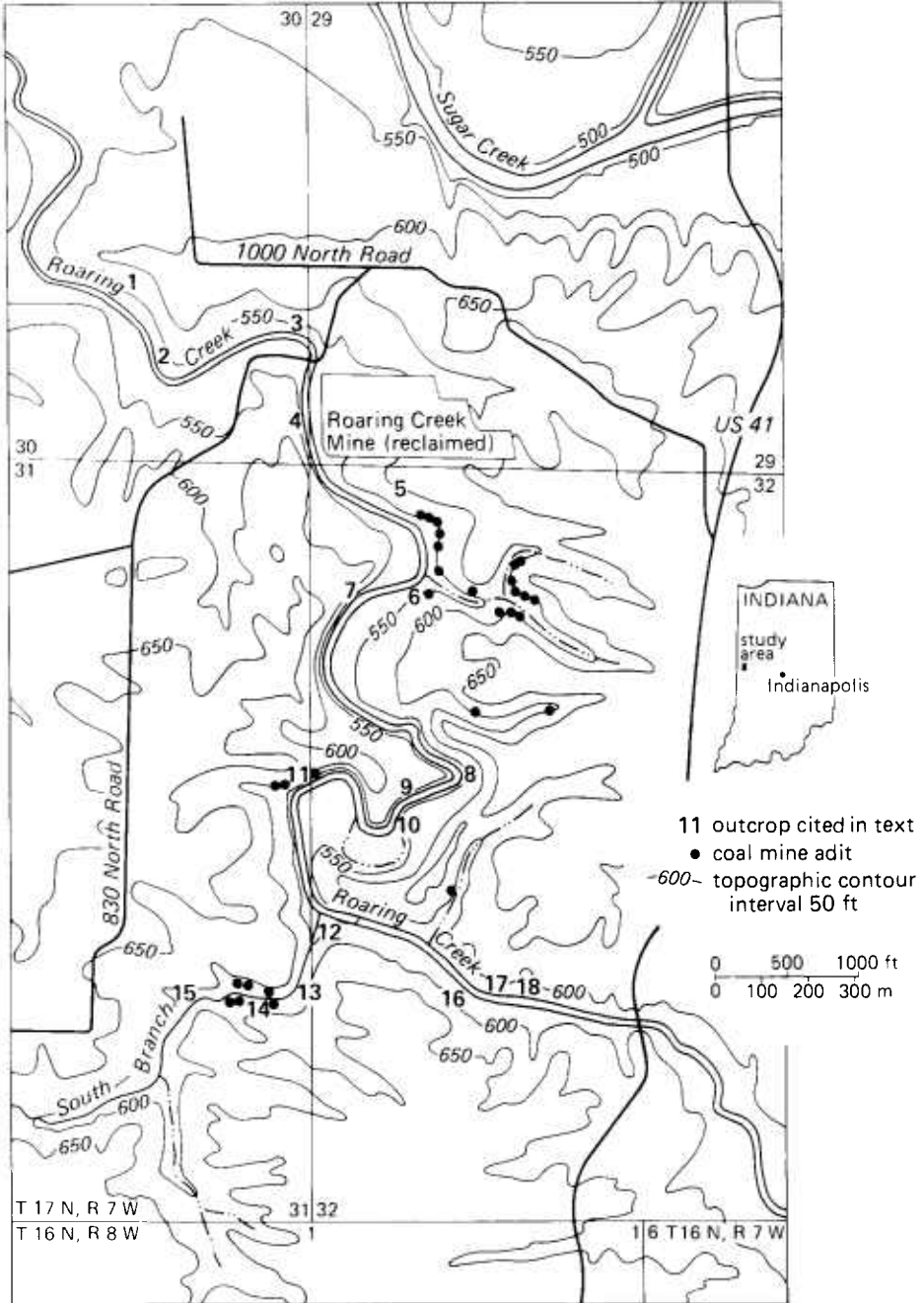


Fig.1. Location map.

out the Illinois Basin. Their lateral variability reflects deposition of stream deposits rapidly aggrading on a deeply channelized pre-Pennsylvanian surface. Through time, as the valleys filled and the divides wore down, the Roaring Creek area and the rest of the basin underwent transition from uplands to alluvial valleys, and then to deltaic plains. Not until Desmoinesian (middle Pennsylvanian) time was the basin level enough that extensive, laterally continuous coals and other rock units could develop.

LOCATION AND GEOLOGIC SETTING

The study area comprises the lower reaches of Roaring Creek and its tributaries, approximately 9 miles (14 km) north of Rockville, Parke County, west-central Indiana (Fig.1). Roaring Creek and adjacent streams occupy narrow steep-walled valleys with meanders entrenched 100–150 ft (30–45 m) below the upland till plain. Bedrock is exposed extensively in the valley walls and stream beds. Formerly, it was exposed on the highwalls of the Roaring Creek Mine, a surface coal mine.

Roaring Creek lies near the northeastern margin of the Illinois Basin, where Pennsylvanian sedimentary rocks dip westward at 25 ft per mile (1 in 210). No significant tectonic faults or folds are known in the vicinity. Glacial till, outwash, and loess of Pleistocene age mantle bedrock on the uplands.

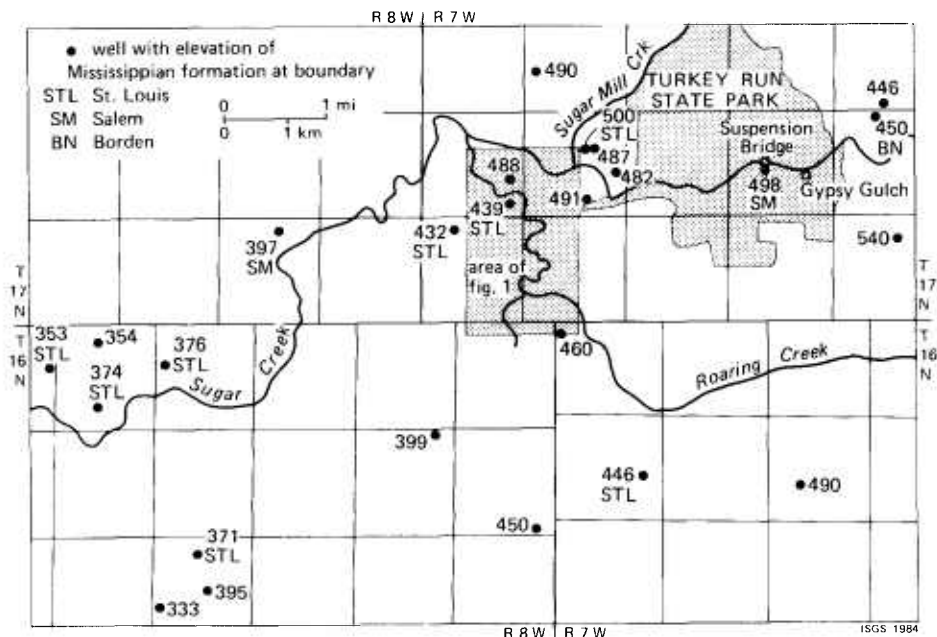


Fig.2. Elevation of Mississippian-Pennsylvanian boundary (in ft) in and near study area.

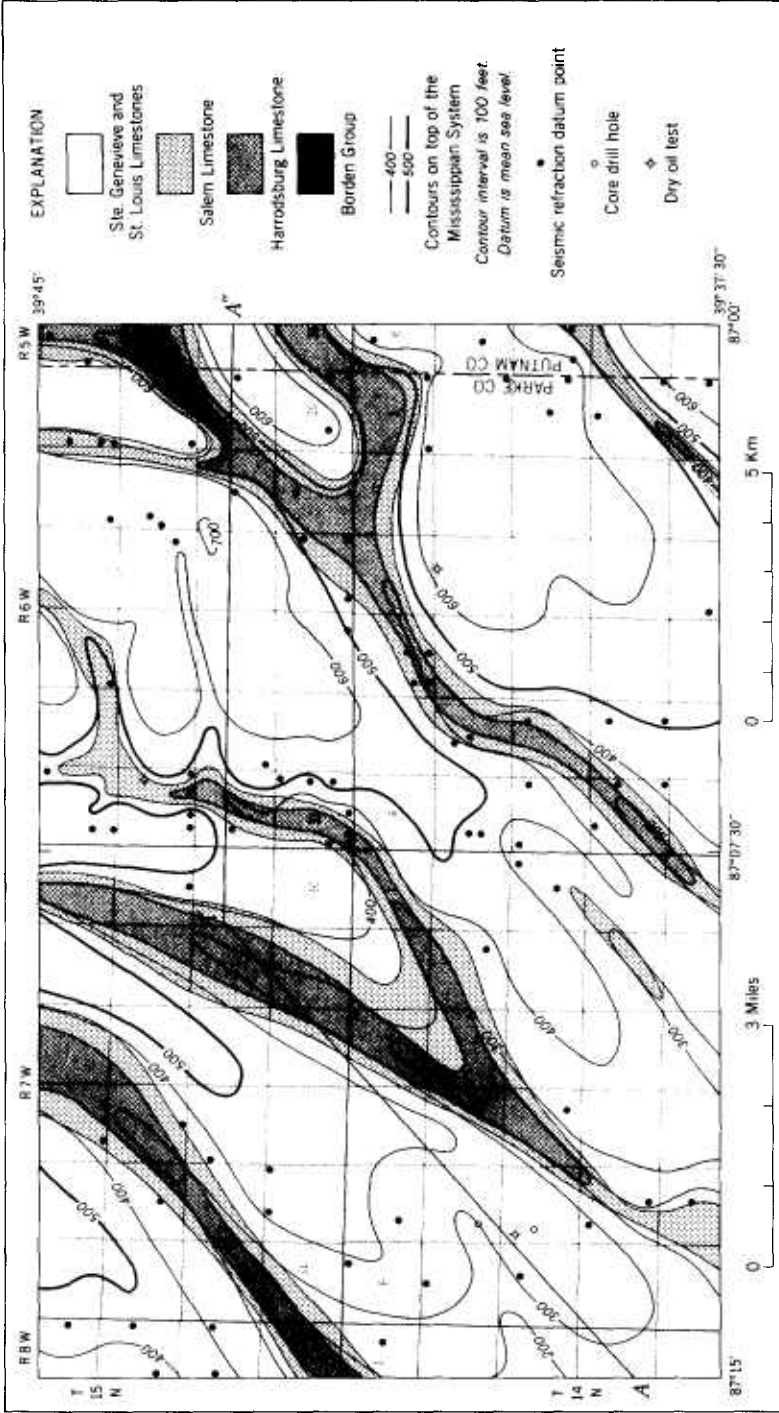


Fig. 3. Pre-Pennsylvanian geology and contours on top of rocks of Mississippian System in Catlin and Mansfield Quadrangles. From Hutchison, 1976.

STRATIGRAPHY

A major unconformity exists at the base of the Pennsylvanian System throughout the Illinois Basin. The pre-Pennsylvanian surface was uplifted, exposed subaerially, and tilted southwestward; anastomosing streams eroded valleys as deep as 450 ft (135 m) (Bristol and Howard, 1971). In the immediate study area, scattered drill holes and surface exposures reveal at least 100 ft (30 m) of relief on the erosional surface (Fig.2). Hutchison (1976) mapped subparallel southwest-trending valleys 1/4 to 1 1/2 miles (1/2 to 2 1/2 km) wide and up to 250 ft (75 m) deep in southern Parke County, where more data are available than near Roaring Creek. At Roaring Creek basal Pennsylvanian rocks rest on Valmeyeran (Middle Mississippian) carbonates, which in turn overlie fine-grained deltaic clastics of the Borden Group (Fig.3).

Pennsylvanian rocks along Roaring Creek belong to the Mansfield and Brazil Formations of the Raccoon Creek Group of Indiana (Fig.4). These strata, correlative with the Caseyville and Abbott Formations of Illinois, are considered to be of late Morrowan and Atokan age.

Sandstone, shale, siltstone, coal, and underclay crop out on Roaring Creek. No limestones, other marine strata, or invertebrate fossils have been found. Locally plant megafossils are abundant but seem to have little value for working out biostratigraphic relationships. Correlations are based on lithologic properties and miospore assemblages from the coals.

Three coals are widely traceable in the study area (Figs.4, 5, and 6). The lowermost, coal A, has a miospore flora similar to that of the Mariah Hill Coal Bed in the Mansfield Formation (Peppers, 1982). In some places, sandstone containing rounded granules and pebbles of white quartz, characteristic of the Mansfield Formation, overlies coal A. Coals B and C are younger than the conglomeratic sandstone and contain miospore floras like those of the Lower and Upper Block Coal Members, respectively, of the Brazil Formation (Peppers, 1982). Sandstones interbedded with coals B and C contain conspicuous mica and feldspar, which is a normal characteristic of the Brazil. Cuticular coal-shale ("paper coal") occurs in the upper part of coal C at several localities.

A fourth coal (coal D in Fig.6) was reported at location 6 by Henry Gray (Indiana Geological Survey, unpublished field notes), but no longer is visible. Coal-test drilling shows as many as five seams; additional coals appear in some locations below coal A.

SEDIMENTOLOGY

Pennsylvanian strata along Roaring Creek were originally fluvial sediments of upland alluvial valleys and upper deltaic plains. Specific environments where sediments accumulated included channels, point bars, natural levees, crevasse splays, flood plains, and swamps.

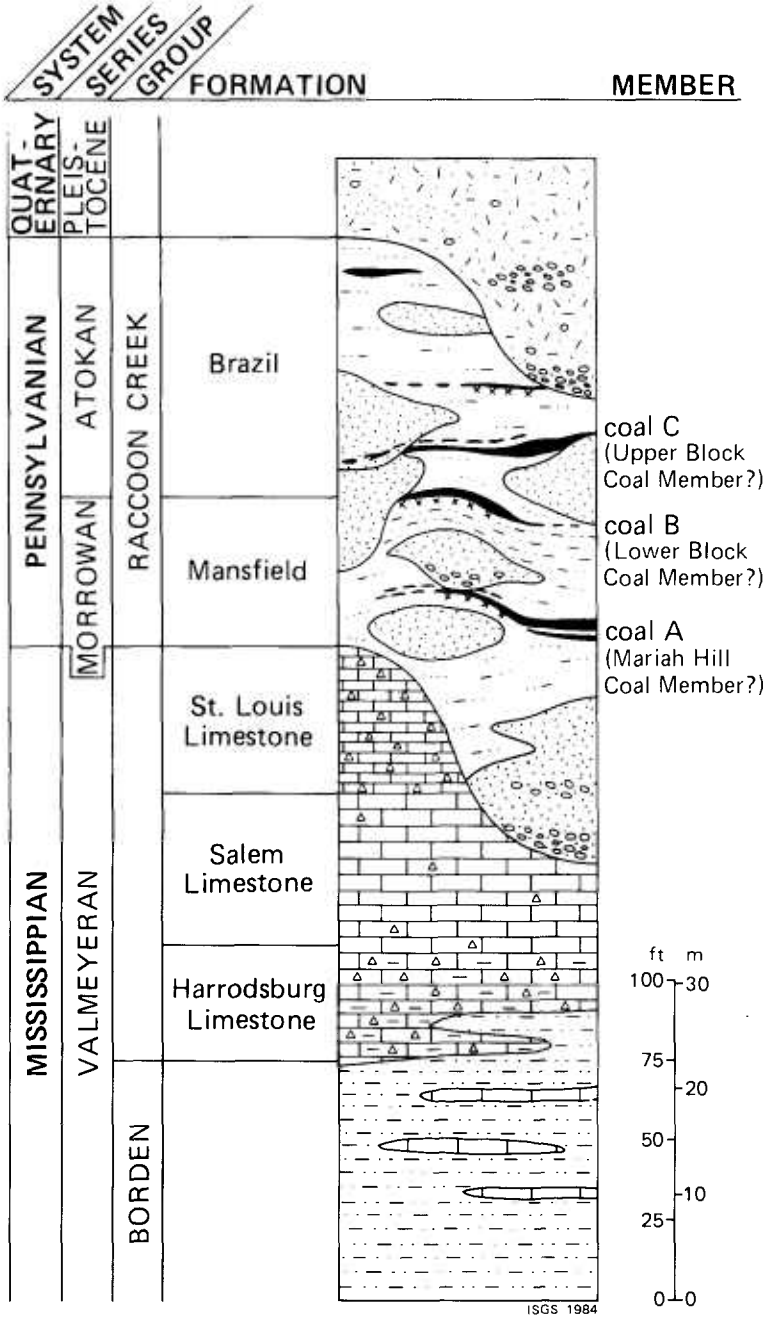


Fig.4. Generalized stratigraphic column for study area.

Channels and point bars

Sandstone lenses, commonly 20–50 ft (6–15 m) thick, crop out widely as steep to vertical bluffs; they probably are channel-fill deposits. These sandstones have sharp, irregular basal contacts that truncate bedding of underlying rocks. Channel-lag conglomerates with clasts of shale, siderite, coal, and (in Mansfield sandstones) quartz granules and pebbles occur in the lower part of many sandstones. Stringers of coal found near the base of sandstone overlying coal suggest that channels eroded and transported partly coalified peat; casts and coalified bark of driftwood logs also are common. Occasionally in situ fossil tree stumps are present. Thick sandstones may display one or more internal scour surfaces, which are recognized by truncation of bedding and/or lag deposits (Figs. 5 and 6) — evidence of aggradation and lateral migration of streams. Both trough and tabular cross-bedding are prevalent. Contorted and overturned cross-bedding appears in several outcrops. Orientation of cross-bedding indicates dominantly westward- to southward-flowing currents, corresponding with the regional flow of streams on the pre-Pennsylvanian erosional surface.

Compared to channel-fill deposits, point-bar sediments are poorly represented at Roaring Creek. Shaly, fine-grained sandstone with planar, irregular or ripple-marked bedding is found in a few places at the top of channel-fill sequences. Such rocks may represent laterally accreted point bars developed in meandering rivers (Collinson, 1978; Blatt et al., 1980; Coleman et al., 1982). However, the scarcity of normal point-bar deposits suggests that vertical aggradation, typical of braided streams, dominated (Pryor and Potter, 1979).

Natural levees

Few natural levees have been identified at Roaring Creek. Probably the best case is the carbonaceous shaly sandstone beneath the channel-fill conglomeratic sandstone at location 3 (Fig. 5). This rock is thoroughly bioturbated and contains abundant plant debris, including fossil roots. Weak horizontal alignment of mudstone and organic debris suggests originally laminated sediment. Sideritic nodules are common. Another possible levee deposit is the sandstone below slumped coal B at location 7 (Fig. 6). The sandstone contains thin laminae of shale and occasional sideritic concretions, and it shows both wavy and flaser bedding characterized by small-scale cross-lamination and climbing ripples. The above features all are common in natural levees of the modern Mississippi River (Coleman, 1976).

Crevasse splays

Crevasse-splay deposits have not been firmly identified at Roaring Creek. Between coals B and C at the now-reclaimed Roaring Creek Mine upright

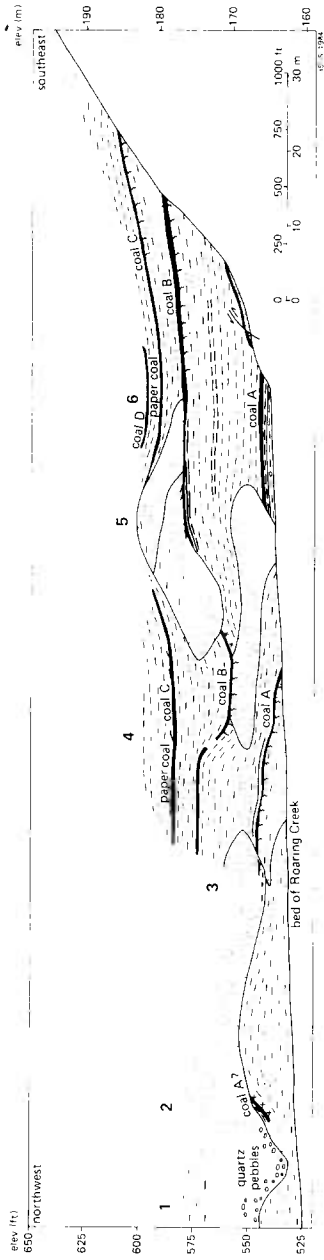


Fig. 5. Northwest-southeast profile along lower section of Roaring Creek. Numbers refer to locations plotted in Fig. 1.

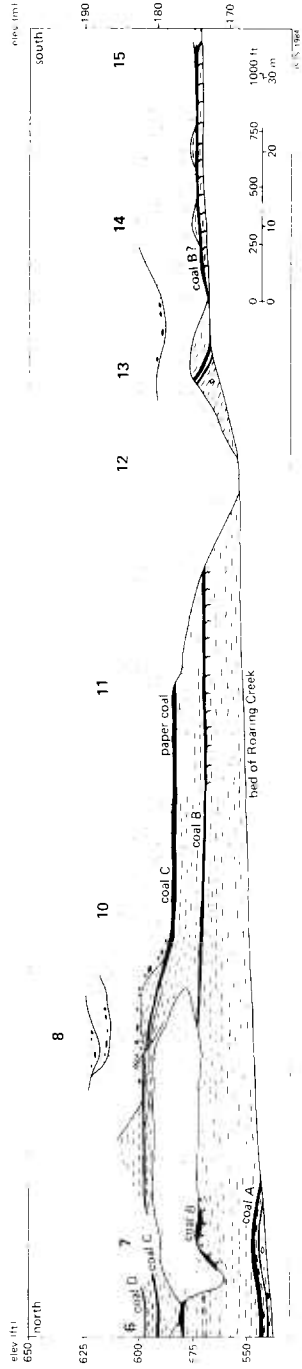


Fig. 6. North-south profile along upper section of Roaring Creek. Numbers refer to locations plotted in Fig. 1.

fossil trees were found in poorly bedded to massive sandy mudstone (Egert and Phillips, 1982). The trees certainly were buried rapidly: sedimentation from a breached natural levee is a likely cause but not the only possible one. Other possible crevasse splays are represented by thin lenses of sandstone within thick shale at location 4; however, these sandstones resemble small channels with erosional bases, cross-lamination, and numerous root molds and burrows near the top. They occur in shales that appear to have originated as natural levees or as overbank deposits.

Floodplains

Shales, typical floodplain sediments, represent roughly one-third of the rocks exposed in the study area. The 35-ft-thick (11 m) shale above coal A at location 6 is an especially good example. The lower portion of this sequence contains abundant compression fossils of leaves and other fragile plant parts that could not have been transported rapidly or far from their source. The shale becomes sandier upward and contains at least three paleosols — structureless zones of white to blue-gray claystone that locally contain fossil roots. These paleosols apparently formed in poorly drained areas and may represent swamps in which peat failed to accumulate. Alternating zones of root material and leaf material may reflect cycles of drying (in situ vegetation) and flooding (transported vegetation) (DiMichele, 1980). Reducing conditions during floods may be recorded in zones of siderite nodules, especially those zones or nodules associated with thin, poorly developed paleosols just below coal B. Eventual subsidence of the floodplain below water table led to development of a peat swamp (coal B).

Incomplete sequences of overbank deposits occur above coal C at locations 4 and 6, and above coal B at locations 4, 8, and 16 (Figs.5 and 6). All are medium to dark gray mudstones or siltstones containing varying amounts of plant material and, in some cases, paleosols.

Swamps

Swamp deposits at Roaring Creek include coal seams and certain underclays and carbonaceous shales. The coals are highly discontinuous: they grade abruptly, both vertically and laterally, into clastic sediments. Early Pennsylvanian swamps in the study area must have been localized and mostly short lived.

All three coals vary markedly in thickness and elevation. Coal C reaches a maximum of about 2 ft (0.6 m); coals A and B attain more than 3 ft (0.9 m) in some places. Seams may change as much as 30 ft (9 m) in elevation within a lateral distance of a few hundred feet (Figs.5 and 6). Thickness is not consistently related to elevation. For example, coal A thins rapidly as it rises in the side-ravines east of location 6 (Fig.5); whereas coal B, which also rises eastward, maintains constant thickness. Moreover, coal A

decreases from 3 ft (0.9 m) at location 6 to less than 1 ft (0.3 m) at location 4, although its altitude remains nearly constant.

Coals generally are clean, bright, and blocky where they are thickest, becoming shaly, dull, and laminated as they pinch out. Exceptions are common: coal A at location 6 is split into 2 1/2-ft (0.8 m) and 1/2-ft (0.2 m) benches separated by 3 ft (0.9 m) of coaly shale. Coal C has similar structure at location 8. These splits consist of very thin laminae of gray shale and more or less equal laminae of degraded to well-preserved, apparently autochthonous plant material. Splits probably accumulated during long periods of intermittent influxes of clastic sediment into the swamps. Rapid lateral gradation from bright to shaly coal can be seen at several places, especially in coal B. Coal A interfingers with sandstone at location 2 (Fig. 5). Here the most likely explanation is that a stream in the swamp interrupted deposition of peat.

Cuticular coal-shale, or "paper coal", is found in the upper part of coal C except in a few places where the top of the seam evidently was eroded. Paper coal is composed largely of cuticle — the thin waxy, organic layer that coats leaves and stems to restrict loss of water and to protect against injury and disease. In coal C, this cuticle was derived entirely from one species of the pteridosperm *Karinopteris*. Since cuticle resists bacterial degradation, it may be concentrated selectively in weathered or oxidized peat. The peat that became coal C, therefore, may have been exposed subaerially for a time. Other environmental factors might have induced *Karinopteris* to produce thicker cuticle than normal. Neavel and Guennel (1960) suggested that periodic invasions of sea water into the swamp favored plants with thick cuticle. They cited abnormally high concentrations of boron and nickel in coal C as evidence of marine incursions. Objecting to this theory, Eggert and Phillips (1979) pointed out that no marine fossils have been found and the coal is low in sulfur, which is a characteristic of freshwater peat.

Rooted claystones underlie the coals of Roaring Creek in places. At least some of the underclays may have formed in swamps where peat did not accumulate. Preservation of peat requires continuous submergence followed by burial. Plant material exposed to air rapidly oxidizes and disintegrates. In the modern Mississippi delta, for example, some swamps dry out in late summer and fall. Sediments in such swamps consist of mud or silt thoroughly reworked by plant roots and burrowing animals, and are full of small secondary nodules of calcite and siderite (Coleman et al., 1982). Such deposits, if lithified, would closely resemble underclays at Roaring Creek.

Where the coals lack rooted underclays, they commonly overlie shales with abundant plant compressions and laminae of vitrain. Such shales may have developed in swamps receiving large quantities of detrital mud from flooding rivers. Coal stringers, and possibly split or shaly portions of thicker seams, may have originated as detrital plant material or floating mats of peat.

In summary, coal-forming swamps at Roaring Creek were small, discon-

tinuous, and subjected to frequent changes in water level and influx of clastics. At times they dried out; at other times floodwaters brought in mud and silt. Subsidence and compaction were irregular and intermittent, and erosion by penecontemporaneous channels was common.

SOFT-SEDIMENT DEFORMATIONAL STRUCTURES

Along Roaring Creek, nearly all large outcrops reveal deformational structures, including sharply warped bedding, contorted laminations, faults, and slumping that varies from micro- to outcrop-scale. All these structures apparently formed before the sediments lithified.

Differential compaction probably accounts for many structures, ranging from minor faults and flexures to large-scale changes in elevations of coal seams. Figures 5 and 6 show several coals deformed around lenticular channel-fill sandstones.

Large-scale slumping is apparent at location 2 (Fig.7). Coal A (?), along with its rooted underclay and the underlying silty mudstone, pitches steeply downward toward the northwest. The coal and underclay are eroded at the southeast end of the exposure. Cross-bedded conglomeratic sandstone, undoubtedly a channel deposit, overlies the coal. Sandstone dikes penetrate the coal from above, and siltstone dikes pierce it from below. Pseudonodules or "ball and pillow" structures up to 2 ft (0.6 m) long occur in laminated siltstone near the middle of the outcrop.

Similar features appear at location 7 (Fig.8). This outcrop may be the one described and sketched by Hobbs (1872, p. 372). Here coal B is overlain by argillaceous sandstone and underlain by rooted underclay and laminated siltstone (natural levees). The strata are sharply flexed, dipping 45 degrees at the east side of the exposure. Toward the west, large contorted sandstone dikes pierce the coal; both coal and underclay were stretched apart along the hinge of the fold. In contrast, the dipping coal to the east was compressed, as indicated by small, tightly crumpled folds and thrust faults.

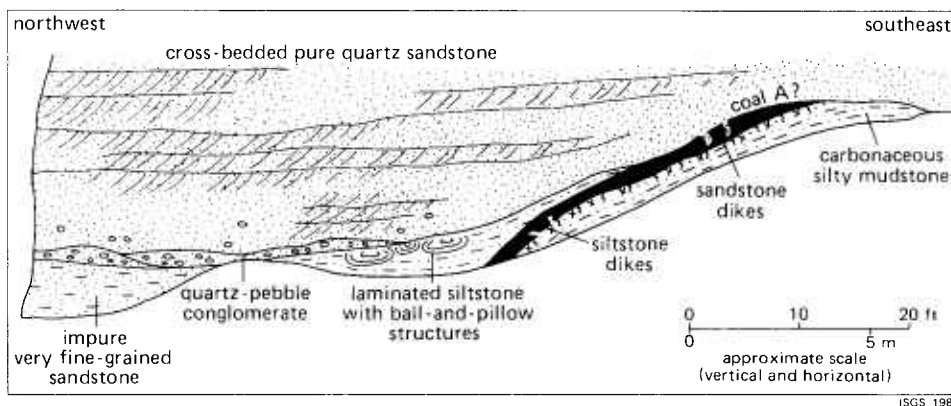


Fig.7. Slumped strata at Outcrop 2.

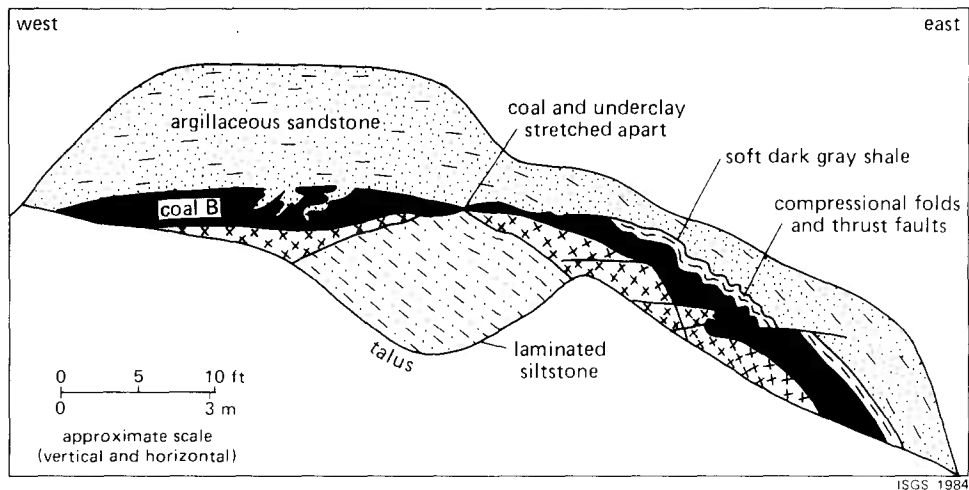


Fig.8. Slumped strata at Outcrop 7.

These slumps clearly took place in unlithified sediments. Today the rocks, especially coal, are brittle; yet deformation, particularly of the clastic dikes, pseudonodules and contorted folds, was dominantly plastic. Failure evidently was sudden, as support gave way beneath sediments. Semi-pliable peat stretched and tore apart and sand and silt squeezed into the fissures to form clastic dikes. Streams undercut their banks, which then collapsed into the channels. This is especially likely at location 2, where slumped sediments are partially eroded and overlain by channel-fill deposits. Other causes, however, such as sinkholes opening in Mississippian limestone, cannot be ruled out.

A different slumping is shown at location 16 (Fig.9). Here, large listric normal faults (up to 20 ft. (6 m) of throw) offset a sequence of shale, siltstone, coal, and underclay. Downthrown blocks are tilted backwards, toward the footwall blocks. The faulted strata are erosionally truncated by sandstone containing large rafted mats of peat. East of location 16 this sandstone occupies a channel eroded below the bed of Roaring Creek. Here slumping was initiated by eroding riverbanks; the undermined blocks rotated backwards as they slid to the bottom of the channel.

Undercut stream banks cannot account for the peculiar structure at location 9 (Fig.10). Strata from both flanks — shale from the east and sandstone, coal, and shale from the west — are warped downward in the center, as if they were drawn into a vortex. The coal and sandstone rapidly thin and grade into shale away from the disturbed area. Coal B overlies the entire structure, virtually undisturbed except for two small faults. In this case, collapse of a Mississippian sinkhole appears to be a plausible cause of deformation. The area may have subsided intermittently, allowing accumulation of peat, sand, and mud in a gradually deepening depression. Successive movements tilted older sediments as new materials were laid down above. Whatever its cause, the action was almost complete by the time coal B was deposited.

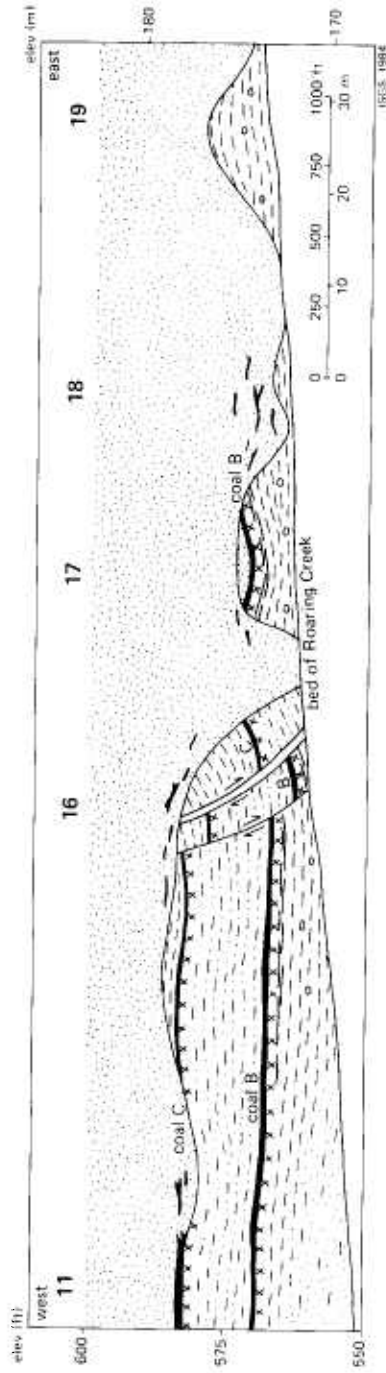


Fig. 9. West-east profile along Roaring Creek. Numbers refer to locations plotted in Fig. 1.

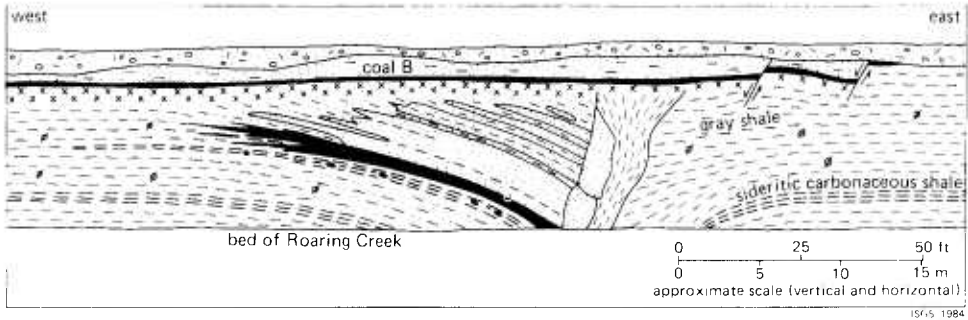


Fig.10. Deformed strata at Outcrop 9.

COAL RESOURCES

Coal has been mined along Roaring Creek since about 1872. Most of the dozens of early mines were small drifts operated for local domestic use. The Roaring Creek Mine, which closed in 1979, was the only surface mine in the study area.

Exposures of locally thick, low-sulfur coals along Roaring Creek tempt the prospective miner, but numerous discontinuities severely restrict exploitation. Thick overbuden, abrupt splitting and gradation of coal to shale, pinch-outs, channels, and sharply dipping seams all render large-scale mining impractical. Without improved economic conditions, even small-scale mining is not feasible. Large reserves of thick, relatively continuous coals in nearby parts of Illinois and Indiana make Roaring Creek even less attractive as a mining site.

DISCUSSION

The extremely variable rocks at Roaring Creek indicate a rapid buildup of sediments on a deeply channelized pre-Pennsylvanian surface, in uplands and upper alluvial valleys. This setting contrasts markedly with the vast, level coastal plain dominated by laterally migrating deltaic systems that prevailed by Middle Pennsylvanian time.

The Mississippian sea floor of the study area was uplifted several hundred feet and tilted southwestward; braided streams cut deep valleys into the exposed carbonates. As the first Pennsylvanian sediments accumulated in southern Illinois and southeastern Indiana, the area of Roaring Creek still was undergoing erosion. The valleys aggraded rapidly as the uplands were worn down; meanwhile, the entire Illinois Basin gradually subsided, raising base level again.

Earliest sediments, largely channel-fill sands and gravels, were confined to valley bottoms. Mississippian rocks still lay exposed on ridges. Streams at first were almost straight and could not meander. In time, the valley floors were built up while the divides were worn down and buried in sedi-

ments. The channels began to migrate laterally to a limited degree. Natural levees made their appearance; low-lying areas behind the levees received crevasse-splay and overbank sediments, while actively subsiding localized depressions became coal-forming swamps.

Differential compaction strongly influenced subsequent sedimentation. Clays and muds compacted considerably; whereas sands, confined to lenticular channel deposits, underwent much less compression. Thus, areas over buried channels tended to remain high, and adjacent surfaces sank, becoming catchment basins for sediment. Undercut stream banks collapsed, and sink-holes developed in the subjacent Mississippian limestone, further deforming the sediments.

Meanwhile, the southern part of the Illinois basin was reduced to a nearly level deltaic plain. Large meandering rivers traversed virtually continuous swamps and floodplains, periodically transgressed by the sea. Cyclical sedimentary processes were becoming dominant. Such conditions did not reach the Roaring Creek area until after Brazil deposition, if ever; the record has been erased by post-Pennsylvanian erosion.

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