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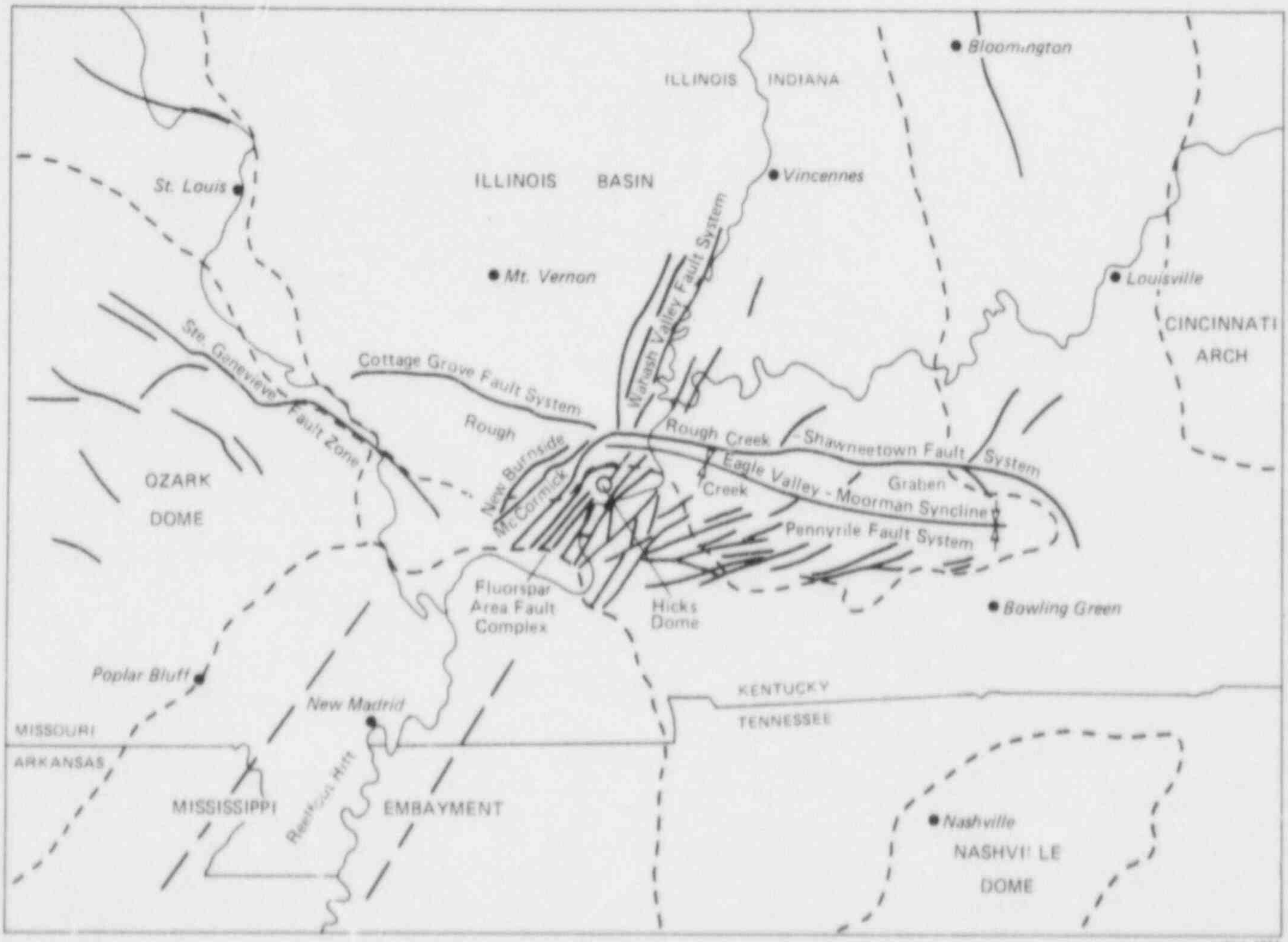
STRUCTURAL GEOLOGY OF SOUTHEASTERN ILLINOIS AND VICINITY

W. John Nelson
Donald K. Lumm



Illinois Department of Energy and Natural Resources
STATE GEOLOGICAL SURVEY DIVISION

Prepared for
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1a. Simplified geologic map of Rudement, Equality, and Shawneetown Quadrangles.
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SUMMARY

What are the hazards of living and building near the zones of bedrock faults that riddle the southeastern tip of Illinois and adjacent parts of Kentucky and Indiana? Is southern Illinois in danger of cataclysmic earthquakes comparable to the New Madrid event that devastated large areas of the central Mississippi Valley early in the 1800s?

To assess the seismic risk in southern Illinois, we investigated the nature, extent, age, origin, and current state of seismic activity of all bedrock faults in the complex area where the west-trending Rough Creek-Shawneetown and Cottage Grove Fault Systems intersect the northeast striking Fluorspar Area Fault Complex and Wabash Valley Fault System. Our specific goals were to determine if:

- the Fluorspar Area Fault Complex connects with the Wabash Valley Fault system.
- the Shawneetown Fault joins the Cottage Grove Fault System.
- any of these faults has been active during the Quaternary.

We focused our attention on southeastern Saline and south-central Gallatin Counties where all these fracture zones converge. Because no detailed studies of structural geology had been made in this area for more than 50 years, we began our investigation by mapping the region in detail.

On the basis of our study, we concluded that southern Illinois and adjacent areas currently are subject to a compressional stress field in which the major axis is oriented east to east-northeast. North-trending thrust faults of small magnitude, observed in coal mines, may be forming in response to these stresses, but the large fault systems are neither active nor likely to become reactivated in this modern stress field. Modern earthquakes in Illinois are the result of these present compressional forces, which apparently are more concentrated in the New Madrid area.

Few bedrock faults are properly oriented to be reactivated under east-west compression: the stresses will have to form new faults, because they cannot be relieved by slippage along old faults. Thus, the danger of earthquakes in Illinois probably is no greater along bedrock faults than away from these faults.

The area we studied is underlain by more than 15,000 feet of Paleozoic sedimentary rocks ranging in age from middle Cambrian through late Pennsylvanian. Permian sediments evidently were deposited, but subsequently removed by erosion. Paleozoic bedrock is overlapped by poorly consolidated Cretaceous and Tertiary sediments in the Mississippi Embayment; elsewhere it is mantled by glacial, lacustrine, alluvial, and aeolian deposits of Quaternary age.

High-angle, dip-slip faulting characterizes the Rough Creek-Shawneetown Fault System (RC-SFS). Most faults are normal or vertical, but the master fault apparently is a high-angle south-dipping reverse fault along most of the system's length. We believe that the faults developed between Early Permian and Late Cretaceous time by means of vertical uplift of the southern block and the subsequent return of that block to approximately its original position.

The Eagle Valley-Moorman Syncline developed as a drag fold during the second, downward movement of the southern block. Evidence from surface geology indicates that contrary to some reseachers' assertions, neither horizontal compression nor strike-slip motion played a significant role in the genesis of the modern Rough Creek-Shawneetown Fault System. This fault system follows an ancient zone of weakness that was recurrently active prior to the Permian, but no evidence exists for Quaternary slippage along this zone.

The Cottage Grove Fault System is a right-lateral wrench fault that developed in late Pennsylvanian to early Permian time, as determined by radiometric dates of associated ultramafic dikes. Near-surface faults terminate north of the Rough Creek-Shawneetown Fault System, and do not connect eastward with it as has occasionally been asserted. The Wabash Valley Fault System, a zone of horsts and grabens bounded by high-angle normal faults, formed as a result of horizontal extension (rifting), also in late Pennsylvanian to early Permian time; larger-scale rifting to the south at the same time induced the right-lateral shearing on the Cottage Grove Fault System. Several faults of the Wabash Valley Fault System intersect the Rough Creek-Shawneetown Fault System, but none cross it.

The Fluorspar Area Fault Complex has the most complicated history of all the fracture zones in the region. The first stage of its evolution probably was large-scale rifting contemporaneous with the Cottage Grove Fault System and the Wabash Valley Fault System; the rifting was quickly followed by development of a northwest-trending arch and emplacement of peridotite dikes and explosion-breccias, including the great cryptovolcanic structure of Hicks Dome. Later, the same faults were reactivated and new ones formed when the southern block of the Rough Creek-Shawneetown Fault System rose and fell. Some Fluorspar Area Fault Complex fractures continued to slip in Cretaceous and possibly early Tertiary time, but the system appears to be quiescent today.

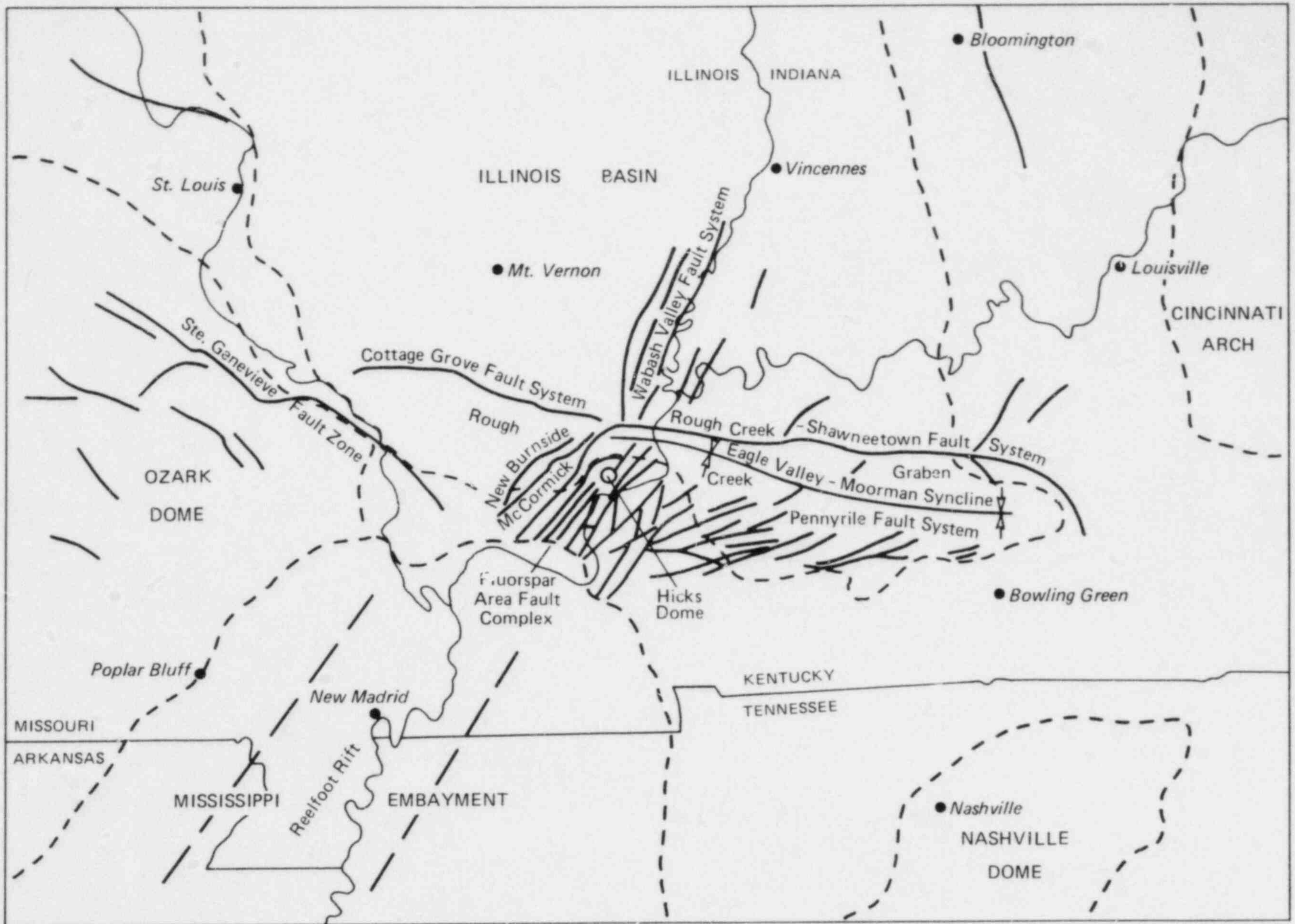
ACKNOWLEDGMENTS

This research was carried out under a grant from U.S. Nuclear Regulatory Commission, grant number 1-5-24465, title NRC 04-81-016. It was part of a larger investigation, involving numerous institutions under grant or contract to the NRC, and aimed at determining the potential seismicity of the region within a 200-mile radius of New Madrid, Missouri, where catastrophic earthquakes occurred in 1811 and 1812. The overall goal of this "New Madrid study group" is to provide background information that will lead to the safe location and construction of nuclear facilities around areas subject to earthquakes.

During our work on the project Thomas C. Buschbach was extremely supportive as advisor and coordinator to the New Madrid Study Group. Peter X. Sarapuka handled the often painful details of paperwork with great competence and forbearance.

Access to exposures in active mines and to exploratory data from mining companies was vital to the study. The members of the mining fraternity, almost without exception, were extremely generous with their time, facilities and information in support of our investigation. Individuals deserving special praise and thanks include Rick Dempsey, Rick Ferguson, Larry Spencer and the late Dick Grassl of Pyro Mining Company, George Evans and Ken Lindsay of Peabody Coal Company, Bob Diffenbach of Ozark-Mahoning, George Hargraves of AMAX Coal Company, Kris Stegelman of Island Creek Coal Company, and Don Hastie of Hastie Trucking, Inc. Several of our fellow-workers from the Illinois State Geological Survey made important contributions: James Baxter, stratigraphic and structural interpretation; Stephen Danner, field mapping; Howard Schwalb, subsurface data and structural interpretation; and Christopher Stohr, field mapping and air-photo interpretation.

Finally, we must mention the citizens of Gallatin and Saline County who gave permission (expressed or implied) to tramp across their land in search of outcrops, and who often provided valuable information and insights on local geology and lore.



ISGS 1984

FIGURE 1. Regional tectonic setting of study area.

INTRODUCTION

PURPOSE AND SCOPE OF REPORT

During the winter of 1811-1812, the central Mississippi Valley was shaken by one of the greatest series of earthquakes ever felt in North America. Centered near the pioneer village of New Madrid, Missouri, the quakes were felt as far away as Boston. They rang church bells in Richmond, Virginia and threw down chimneys in Cincinnati and St. Louis. Devastation was almost total in the epicentral region. According to contemporary accounts the ground rose and fell like waves at sea, tearing open fissures and triggering landslides; the river was nearly hurled from its bed, tossing boats ashore and swallowing islands. Whole sections of the flood plain were uplifted as other areas subsided, forming swamps and lakes such as Reelfoot Lake, where upland forests had formerly grown. The loss of life, fortunately, was slight (most fatalities apparently were caused by drowning on the river) because the area was thinly populated and the houses mostly log cabins that withstood the shocks long enough for the inhabitants to get outside (Fuller, 1912). Were such earthquakes to recur today, the casualties and destruction of property would be appalling.

Geologists and geophysicists have since established that the New Madrid area is a zone of ongoing seismic activity. Within a recent 4-year period, Stauder (1982) recorded 731 tremors, of which several were strong enough to cause localized damage. These quakes are attributed to a buried fault zone known as the Reelfoot Rift (fig. 1). The rift apparently is an ancient zone of weakness that has been active throughout much of geologic time. The nature and extent of the Reelfoot Rift thus is a matter of pressing concern to inhabitants of the central Mississippi Valley.

Occasional earthquakes occur in Illinois, particularly in the southern portion. While none to date has been truly destructive, several have damaged property and alarmed the population. People naturally are concerned about these quakes and their pattern of recurrence. Is southern Illinois in danger of cataclysmic shocks comparable to the New Madrid events?

The bedrock of southern Illinois is riddled with faults. A regional map (fig. 1) reveals two major trends of fractures: east-west and northeast-southwest. The Cottage Grove Fault System and Shawneetown Fault Zone cross Illinois from west to east; the Rough Creek Fault System continues eastward into Kentucky. North of the Shawneetown Fault Zone, the Wabash Valley Fault System extends north-northeastward along the Illinois-Indiana boundary, while to the south the multitudinous fractures of the Fluorspar Area Fault Complex project--in seemingly ominous fashion--directly toward the Reelfoot Rift and New Madrid. Little wonder, then, that some geologists have assumed the worst. For example, Heyl (1972) labeled the combined Fluorspar Area Fault Complex-Wabash Valley Fault System as the "New Madrid Fault Zone"--implying that at any moment this zone may let loose with Magnitude 8 earthquakes. The Shawneetown Fault Zone also is said to be active (Heyl and Brock, 1961; Heyl et al., 1965). If so, what is the hazard of living and building near these faults?

To assess the seismic risk of southern Illinois, we conducted this study investigating the nature, extent, age, origin, and state of seismic activity for all bedrock faults. Specific goals were to determine:

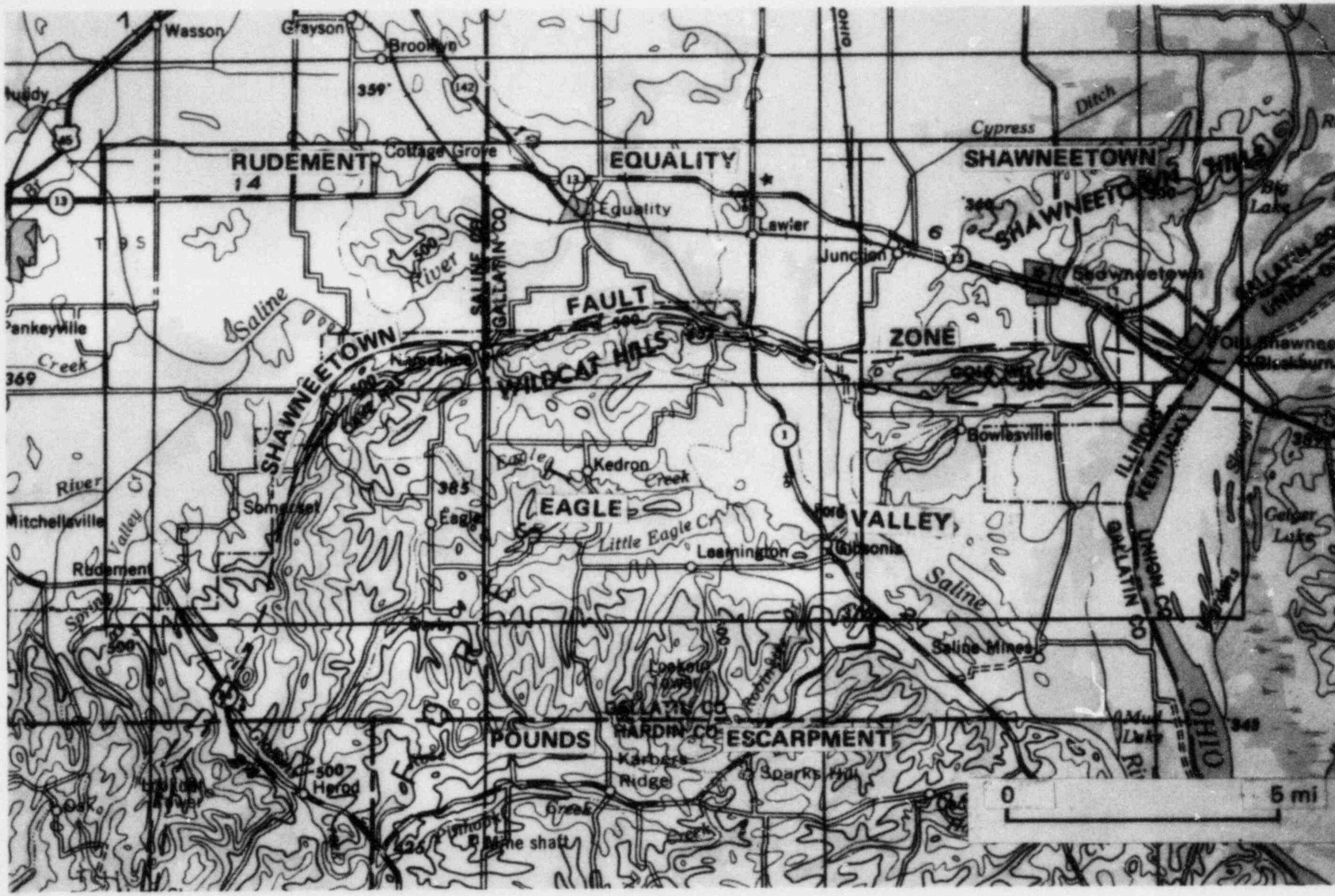


FIGURE 2. Shawneetown Fault Zone and boundaries of Rudement, Equality, and Shawneetown 7½-minute quadrangles (from USGS Paducah topographic map (scale, 1:250 000).

- whether the Fluorspar Area Fault Complex connects with the Wabash Valley Fault System.

- whether the Shawneetown Fault Zone joins the Cottage Grove Fault System.

- whether any of these faults has been active during the Quaternary.

We focused our attention on southeastern Saline and south-central Gallatin Counties, where all of these fracture zones converge. Because no detailed studies of structural geology had been made in this area for more than 50 years despite the concern about earthquakes, our first step was to map the region in as much detail as newly-available data would allow.

GEOGRAPHIC SETTING

Our area of immediate interest comprises the Rudement, Equality, and Shawneetown 7.5-minute U.S.G.S. Quadrangles in southeastern Saline and southern Gallatin Counties, Illinois (fig. 2). The three quadrangles form a rectangle approximately 8 1/2 miles north to south by 20 miles east to west. The easternmost quadrangle, Shawneetown, includes the Ohio River and a small area in Kentucky already mapped by Palmer (1976). The study area takes in nearly all of the Shawneetown Fault Zone and portions of the Fluorspar Area Fault Complex and Wabash Valley and Cottage Grove Fault Systems that approach or intersect the Shawneetown Fault Zone.

PHYSIOGRAPHY

The study area includes portions of the Central Lowland and Interior Low Plateaus Provinces (fig. 2). The lowland lies north and west of the Shawneetown Fault Zone; broken and tilted plateaus rise south and east of the faults. The lowland consists of level to gently rolling plains, underlain by lacustrine and alluvial sediments of Pleistocene age; isolated bedrock hills stand like islands above the plains. Elevations of the plains range from about 340 to 375 feet above sea level; bedrock islands locally reach 550 feet or higher. Pleistocene loess (windblown silt) mantles the bedrock, particularly in the Shawneetown Hills, where it reaches several tens of feet thick; elongate ridges of windblown sand occur southeast of Junction. Surface exposures of bedrock in the lowlands are limited to artificial cuts and strip mines for coal.

Marking the northern border of the Interior Low Plateaus Province is the range of hills that lies immediately south of the Shawneetown Fault Zone and extends westward from the Ohio River to the eastern Rudement Quadrangle, where it turns abruptly southwestward. Its highest elevations in the study area are 923 feet on Cave Hill, 768 feet in the Wildcat Hills, and 690 feet on Gold Hill. These hills consist of resistant lower Pennsylvanian and Chesterian (upper Mississippian) sandstones uplifted along the Shawneetown Fault Zone; the strata are tilted at 5^{0} to 30^{0} (locally steeper) southward and eastward, away from the fault zone. Well-developed cuestas and hogbacks have steep slopes or escarpments facing the fault zone and gentler dip-slopes deeply dissected by ravines, on the side away from the faults. Natural exposures of bedrock are numerous, except near the western end of Gold Hill, where there is a thick blanket of loess and aeolian sand.

Along the southern edge of the mapped area, from Eagle Creek to the Saline River, is another dissected upland area composed of Lower Pennsylvanian sandstone. These rock layers dip northward at less than 10^{0}, thus forming the southern limb of a syncline (Wildcat and Gold Hills represent the northern limb of this syncline). The elongate lowland along the Synclinal axis is known as Eagle Valley; it gives its name to the Eagle Valley Syncline. The physiography of Eagle Valley is similar to that of the lowlands north of the Shawneetown Fault Zone: bedrock hills composed of middle Pennsylvanian sandstone are surrounded by level plains of alluvial and lacustrine deposits; hills of windblown sand and loess rise east of the Saline River. As in the northern lowlands, natural exposures of bedrock are rare in Eagle Valley.

The master stream of the region is the Ohio River, flowing southward along the eastern edge of the Shawneetown Quadrangle. The Saline River is a southeast-flowing tributary to the Ohio. The North Fork enters the Saline at Equality; the Middle and South Forks merge near the center of the Rudement Quadrangle. Another permanent stream of note is Eagle Creek, meandering eastward among the bedrock hills of Eagle Valley to the Saline River. All of these streams are superimposed on bedrock structure. Although many of the streams have been artificially straightened and channelized in attempts to control flooding and bring more land into agriculture, large areas of the bottomlands still become submerged after heavy rains.

The only natural lakes are sloughs, abandoned channels of the various streams. Several sloughs occur along the Saline River in the Rudement Quadrangle. Glen O. Jones Lake is a man-made lake in a narrow valley on Horseshoe Creek. Other artificial ponds result from coal-mining activities, or were dug to water livestock or wildlife.

CLIMATE

Southern Illinois lies in the warm, humid temperate belt. According to Wallace and Fehrenbacher (1969), the average daily maximum temperatures range from 45^{0}F in January to 92^{0}F in July; average daily minimum temperatures for the same months are 26^{0}F and 67^{0}F. Extreme recorded temperatures (through 1969) were -23^{0}F and $+113^{0}$F. Average annual precipitation is about 45 inches, including 15 inches of snow. Spring is the wettest season and autumn the driest; most summer rain falls in brief showers or thunderstorms.

Because of the warm, humid climate most bedrock is covered with residual soil and vegetation, except on steep slopes and in ravines. Limestone weathers rapidly by solution and rarely appears at the surface except in deep ravines; outcrops of shale are even more rare. Although sandstones are the ridge-formers, only thick-bedded to massive sandstones crop out away from streams. Without artificial exposures and drill-hole information, we would know little or nothing of bedrock geology over large portions of the study area.

LAND USE

Agriculture is the major activity in Saline and Gallatin Counties. Level bottom lands are intensively planted in corn, soybeans, and winter wheat. Moderately sloping terrain, as in Eagle Valley and the Shawneetown Hills, is widely used for grazing. Many of the hilltops, including Cave, Wildcat, and Gold Hills, formerly were farmed, but all these farms have been abandoned. Steep slopes and hilltops now are mostly forested, primarily with hardwoods such as oak and hickory. Much of Cave and Wildcat Hills, and some low-lying areas as well, belong to the Shawnee National Forest and are maintained for recreation and conservation. The remaining land is privately owned.

Coal mining has continued on a large scale for more than 100 years and has conspicuously altered the landscape. The earliest mines, dating to pre-Civil War days, were shallow underground operations, but, beginning in the 1930s, strip mining came into prominence. At least five different seams of coal have been mined by stripping in the study area. Some mines were contour-stripping operations in which the miners excavated the coal around the circumference of a hill (for example, on Colbert Hill and in the hills near Rocky Branch School, in the Rudement Quadrangle). Elsewhere, as on the gently rolling terrain north of Somerset (Rudement Quadrangle), area mining was practiced: as the name implies, area mining removes the coal from a large area of ground, below the level of drainage, without regard to surface topography. Most land strip-mined before the early 1960s has not been reclaimed, so the highwalls are still accessible for geologic study. These highwalls often provide excellent views of structural features in areas where exposures of bedrock otherwise are lacking. Modern mining law, however, dictates that highwalls be buried and land be restored to original contour after mining. Therefore, active mines must be visited while mining is in progress in order to examine geologic features.

Two small surface mines, one small (drift) underground mine, and one large (slope) underground mine were in operation within the study area when this report was written.

Other activities of geologic significance include oil and gas exploration and production, and quarrying of stone. Approximately 150 test holes for oil and gas have been drilled within the three quadrangles of interest. Logs for most holes are on file at the Illinois State Geological Survey (ISGS); they provide vital subsurface data. Quarrying has been small in scale, for local use, but the abandoned pits provide some of the best available exposures of the Shawneetown Fault Zone.

Incorporated towns within the study area are Shawneetown (population 1,742) and Equality (population 732). Paved highways include Illinois Route 1 (north-south) and Illinois Route 13 (east-west), and small segments of Illinois Routes 34 and 142. Most other roads in the three quadrangles are of well-graded gravel. An automobile can usually be driven within a mile of any point in the study area.

GEOLOGIC SETTING

The area under investigation is located near the southern closure of the Illinois Basin (fig. 1). The Rough Creek-Shawneetown Fault Zone divides the larger Illinois Basin into the Fairfield Basin (north) and the Eagle Valley-Moorman Syncline (south). Within the Illinois Basin, sedimentary rocks of Cambrian through Pennsylvanian age are overlapped by unconsolidated Pleistocene sediments. Bordering the Illinois Basin on the west is the Ozark Uplift, where Precambrian crystalline rocks locally occur at the surface. The Cincinnati Arch, with Ordovician rocks exposed along its crest, separates the Illinois Basin from the Appalachian Basin to the east. Paleozoic rocks are buried beneath partially lithified Cretaceous and Tertiary deposits in the Mississippi Embayment, a northward projection of the Coastal Plain Province.

PREVIOUS RESEARCH

The first geologist to explore our study area was Cox (1875). Writing on the geology of Gallatin County, he remarked on the "axis of disturbance or upheaval that crosses it, in an east and west direction." This is, of course, the Shawneetown Fault Zone. Cox described many exposures of tilted or fractured strata along the fault; some of these outcrops are no longer accessible for study. Cox's concepts of stratigraphy and structural geology have been revised considerably through the years, but they laid the groundwork for all subsequent investigations.

By far the most comprehensive examination of our area was that of Butts (1925). His report includes a geologic map (scale 1:62,500) covering all of the Rudement, Equality and Shawneetown Quadrangles, plus the rest of Saline and Gallatin Counties due south of these quadrangles. Stratigraphy, structural geology, and economic geology are covered in his text. Butts' discussion of faults is rather cursory, but he had only limited surface exposures and very few subsurface data from which to work. Butts did not speculate on the origin or tectonic significance of the faults; he limited his remarks to field observations.

Geology of the Illinois fluorspar district is discussed and mapped at 1:24,000 in a series of three ISGS Circulars (Baxter, Potter, and Doyle, 1963; Baxter and Desborough, 1965; and Baxter, Desborough, and Shaw, 1967). The area covered extends from the southern edge of our mapping area to the Ohio River (Illinois-Kentucky state line). The Fluorspar Area Fault Complex and southern terminus of the Shawneetown Fault Zone and their relationship to mineralization, are treated in detail. In addition, Trace (1974) and Hook (1974) provided excellent structural overviews of the Illinois-Kentucky fluorspar district, and Klasner (1982) mapped the area where the Shawneetown Fault Zone joins the Fluorspar Area Fault Complex.

The entire state of Kentucky has been mapped geologically on 7.5-minute quadrangles. Many of the geologic quadrangles include cross-sections illustrating the structure of fault zones. The Grove Center Quadrangle, immediately east of Shawneetown, was mapped by Palmer (1976).

Geologic quadrangle maps are not available for the territory north and west of our study area, mostly because the cover of Pleistocene deposits hides all but a few scattered exposures of bedrock in those quadrangles. Quaternary deposits of Illinois were mapped by Lineback et al. (1979).

The Cottage Grove Fault System was mapped (scale about 1:100,000) and described in detail by Nelson and Krausse (1981). The faults are known from numerous exposures in underground coal mines and also from test drilling. The Wabash Valley Fault System in Indiana was discussed by Ault et al. (1980) and mapped at a scale of approximately 1:31,680 on six separate maps by Tanner, Stellavato, and Mackey (1981). Bristol and Treworgy (1979) mapped Wabash Valley faults in Illinois and discussed the fault system as a whole.

In addition to the above published sources, unpublished manuscripts and field notes on file at the ISGS contain much useful information on our area of interest.

METHOD OF STUDY

FIELD MAPPING

The entire Rudement, Equality, and Shawneetown 7.5-minute Quadrangles were mapped geologically (plate 1a) for this report. We visited almost every exposure of bedrock--natural and artificial--during our surficial mapping. We examined the highwalls of all abandoned strip mines and made repeated visits to active mines, since virtually none of these mines existed during the early 1920s when Butts mapped. Mines provide excellent views of structural attitude of the rocks; in a number of cases, faults are visible in the highwalls.

We used U.S. Geological Survey 7.5-minute topographic maps as base maps in areas having little or no structural complexity; for complexly faulted sections, we enlarged these maps 2 to 3 times. In some places we used a portable altimeter to determine altitude, especially in strip mines where topography has been altered.

Ground work was supplemented by stereoscopic study of aerial photographs taken by the U.S. Department of Agriculture during the 1950s. These summertime photos are not ideal for geologic interpretation, but in spite of the dense vegetation, a number of linear features, interpreted as faults, could be detected on the photographs. Many linear features revealed on aerial photographs are not apparent on the ground or on topographic maps.

Mapping focused on faults and related tectonic structural features, and on identification of bedrock-stratigraphic units. Surficial deposits were mapped in places where they dominate the landscape and/or completely mask the bedrock. For identification of surficial sediments we relied mainly on published work of others, primarily Heinrich (1982) and Lineback et al. (1979).

SUBSURFACE MAPPING

The structure-contour map of the Rudement, Equality, and Shawneetown Quadrangles (plate 2) is based upon the logs of several thousand wells, almost none of which were available to Butts (1925). Most of the wells are coal-test borings; also included are roughly 150 tests for oil and gas, and a few water wells and foundation borings. In compiling plate II, we also used maps provided by coal companies that were based upon thousands of drill holes, spaced as closely as 100 feet apart. Such maps cover a large portion of the Eagle Valley Syncline and structurally complex areas near Cottage Grove and Equality. Extremely accurate placement of faults and igneous intrusions is possible with these maps.

The unequal distribution of datum points on plate II reflects economic geology. Because coal is found in rocks of middle Pennsylvanian age, coal companies have not explored the hills rimming Eagle Valley, where these rocks have been eroded. Petroleum test holes are concentrated north of the Shawneetown Fault Zone; few operators have explored the region south of the fault zone because it is widely regarded as unproductive. This belief persists in spite of the fact that many significant finds have been achieved within and south of the Rough Creek Fault System in Kentucky.

The Springfield--formerly Harrisburg (No. 5)--Coal Member was selected as a contouring horizon because it is the most common target for coal exploration and is reported on more logs than any other stratum. In some regions, drilling penetrated only to the younger Herrin (No. 6) Coal Member; beyond the outcrop of the Springfield Coal, the deeper Davis and Dekoven Coal Members were tested. In such cases the elevation of the Springfield Coal was extrapolated. Fortunately, these coal seams are nearly continuous throughout the study area, and the thicknesses of the intervals between the seams are remarkably consistent. Contoured elevations projected from data on Herrin, Davis, and Dekoven Coals probably are accurate within 25 feet throughout the study area. Beyond the outcrop of the Davis Coal the elevation of the Springfield Coal had to be extrapolated from the elevation and structural attitude of lower Pennsylvanian or upper Mississippian marker beds mapped in the field. Mapping is naturally less accurate in such areas; accordingly, the contour interval on plate II increases from 50 feet inside the Davis outcrop to 100 feet outside the Davis cropline, giving an optical impression of lesser dip in these areas.

GEOPHYSICAL SURVEYS

During the spring of 1983 a large portion of the study area was surveyed with a portable magnetometer and gravimeter. The field work was conducted by Kevin Strunk of Southern Illinois University at Carbondale, who was assisted by the authors; Strunk and his academic advisor, Dr. Larry Malanconico, made the data reduction. We also had the opportunity to view several proprietary seismic sections across the Rough Creek-Shawneetown Fault System in Illinois and western Kentucky. These reveal several faults and show the deep structure of the Eagle Valley-Moorman Syncline, but do not allow definitive interpretation of the deep subsurface structure of the Rough Creek-Shawneetown Fault System, because of interference among reflectors within the fault zone.

INVESTIGATIONS OUTSIDE IMMEDIATE STUDY AREA

We visited a number of localities outside the Rudement, Equality, and Shawneetown Quadrangles to obtain additional information on faults. All currently active fluorspar mines and one abandoned prospect pit in Hardin and Pope Counties, Illinois, were visited. These mines include four underground operations and two open pits. Two mines and the abandoned prospect pit are in vein deposits, where mineralization follows northeast-trending fault zones in the Fluorspar Area Fault Complex. The mine workings provide nearly continuous exposures of the fault zones for up to several thousand feet along strike and show a wealth of structural detail. The other three mines are exploiting bedded-replacement deposits and contain only small faults and fractures, but such structures rarely are visible in natural exposures.

Nelson and Krausse (1981), delineating the Cottage Grove Fault System, did extensive, detailed mapping of faults in underground coal mines of Saline and Williamson Counties. In the current study we examined new exposures of faults at several of these mines, and also checked surface mines, roadcuts, and railroad cuts. Samples of igneous rocks from drill cores and outcrops of dikes in the Cottage Grove Fault System were submitted to Geochron Laboratories of Cambridge, Massachusetts for potassium-argon age determination. We also examined faults in several underground coal mines in Union and Webster Counties, Kentucky, including faults in portions of the Rough Creek and Wabash Valley Fault Systems, and small faults in the Moorman Syncline. Coal companies provided maps and drill-hole information that yielded additional information on geologic structure.

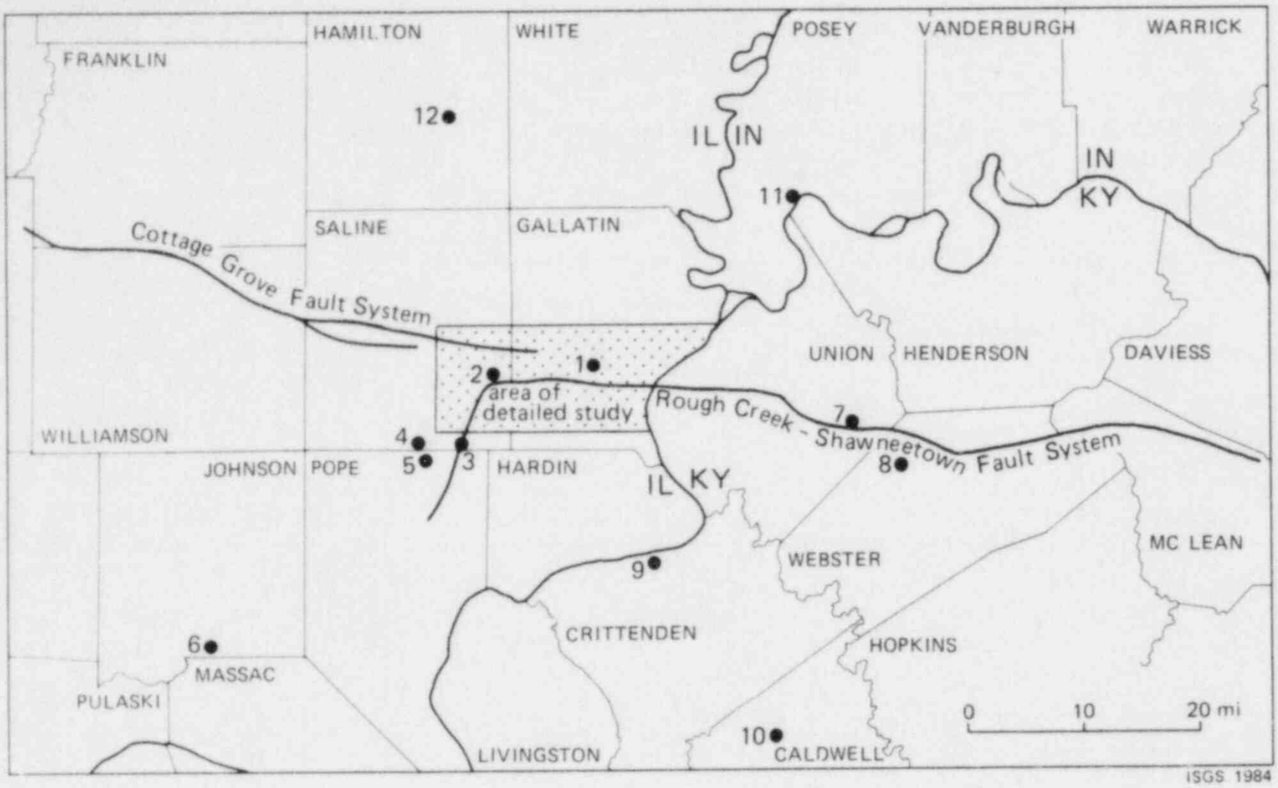


FIGURE 3. Location of wells listed in table 1.

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1. Texaco, J.M.Walters No. 1, SW¼ NE¼ SW¼ Sec. 29, T. 9S, R. 9E, Gallatin Co., IL. Tops by Howard Schwalb.
2. John Dunnill, Margaret Karsch No. 1, 1150 ft from N.L., 675 ft from E.L., Sec. 35, T. 9S, R. 7E, Saline County, IL. Tops by Howard Schwalb.
3. Texota, King No. 1, NE¼ SE¼ Sec. 32, T. 10S, R. 7E, Saline County, IL. Tops by driller and Y. Lasemi.
4. Texas Pacific, John Wells No. 1, 460 ft from N.L., 660 ft W.L., Sec. 34, T. 10S, R. 6E, Saline County, IL. Tops by Y. Lasemi.
5. Texas Pacific, Mary Streich Comm. No. 1, 1815 ft from S.L., 2310 ft from E.L., Sec. 2, T. 11S, R. 6E, Pope County, IL. Tops by Elwood Atherton.
6. Texas Pacific, Farley et al. No. 1, 680 ft from N.L., 730 ft from W.L., SE¼ Sec. 34, T. 13S, R. 3E, Johnson County, IL. Tops by Howard Schwalb.
7. Ashland Oil, Camp Breckinridge No. F-1-F, Sec. 15-N-21, Union County, KY. Tops by Howard Schwalb.
8. Exxon Corp., Choice Duncan No. 1, 1200 ft from N.L., 2460 ft from E.L., Sec. 5-M-22, Webster County, KY. Tops by Howard Schwalb.
9. Shell Oil, Davis No. 1, Sec. 17-L-16, Crittendon County, KY. Tops by Mary McCracken and Howard Schwalb.
10. Sun Oil Co., Stephens No. 1, Sec. 9-I-19, Caldwell County, KY. Tops by Howard Schwalb.
11. General Electric No. 2 Disposal Well, Sec. 9, T. 7S, R. 13W, Posey County, IN. Tops by Howard Schwalb.
12. Texaco, Cuppy No. 1, SE¼ SW¼ Sec. 6, T. 6S, R. 7E, Hamilton County, IL. Tops by Elwood Atherton and Tom Buschbach.

STRATIGRAPHY

The bedrock of the study area comprises at least 15,000 feet of Paleozoic sedimentary rock overlying Precambrian basement presumably composed of crystalline rocks. All of the Paleozoic systems except the Permian are represented. The succession begins with transgressive Cambrian sandstone, which is succeeded by Croixan (upper Cambrian) through Valmeyeran (middle Mississippian) limestone and dolomite, some with abundant chert and lesser amounts of sandstone and shale. These strata were almost all deposited in marine waters of shallow to moderate depth, on a stable cratonic platform subject to periodic, gentle, regional uplift and subsidence. The Chesterian (late Mississippian) marked the beginning of cyclical sedimentation in which alternating layers of limestone, shale, and sandstone were deposited in marine and coastal environments. After a hiatus caused by the retreat of the sea from the area, deposition began again in the Pennsylvanian Period: first, thick basal fluvial sandstone and shales, then further cyclical deposits of deltaic shale and sandstone alternating with shallow marine limestone and minable beds of coal. Deposition probably continued into the Permian, but strata of this age have been eroded from the study area. Ultrabasic igneous rock was injected as narrow dikes and sills during early Permian time.

The Mesozoic and Cenozoic Erathems are unrepresented in the study area save for scattered remnants of latest Tertiary gravels in the Shawneetown Hills. The Pleistocene glaciers did not quite reach our area, but lacustrine sediments up to 150 feet thick accumulated in the lowlands while windblown silt and sand mantled large areas of the uplands. The most recent sediments in the study area consist of alluvium of the Ohio River and its tributaries.

PRECAMBRIAN ROCKS

No direct information is available on the Precambrian basement because no wells have yet reached it in our study area, and the nearest outcrops lie 120 miles to the west in the Ozark region. Nevertheless, several lines of evidence allow us to make some reasonable inferences on the nature of the ancient substrate. Precambrian rocks in the St. Francois Mountains of Missouri consist mainly of granite and rhyolite cut by intrusions of diabase. In Illinois 16 deep borings reached basement, which was found to consist of granite, granodiorite, rhyolite, and granophyre, in that order of abundance (Bradbury and Atherton, 1965). A new deep well in southeastern Hamilton County (well 12, fig. 3), the closest well to our area to reach basement, encountered pink granite at a depth of 12,967 feet. Thus, it appears likely that acidic intrusive and extrusive rocks underlie the Paleozoic strata in our study area.

The depth to basement in the immediate study area is at least 15,000 feet and probably considerably more. The Texas Pacific oil test (well 5, fig. 3, and table 1), immediately southwest of our study area in Pope County, went to 14,920 feet without reaching basement, while the Exxon well in Webster County, Kentucky (well 8, fig. 3, and table 1) was short of Precambrian at 15,200 feet. These are the deepest holes in Illinois and western Kentucky, respectively. Seismic profiles in Union and Webster Counties, Kentucky, indicate that basement is as deep as 25,000 feet at the axis of the Moorman Syncline (Norman Hester, personal communication, 1983). This Precambrian deep is further confirmed by gravity and magnetic surveys (Lidiak and Zietz, 1976;

ERA	SYSTEM	SERIES	GROUP	FORMATION	THK. (ft)
CENOZOIC	QUATERNARY	PLEISTOCENE		loess, alluvial and lacustrine deposits.	0-150
CENOZOIC	TERT.-QUAT.	PLIO.-PLEISTO.		Mounds Gravel	0-20
PALEOZOIC	PENNSYLVANIAN	MISSOURIAN	McLeansboro	Bond	0-125
			McLeansboro	Modesto	375-475
		DESMOINESIAN	Kewanee	Carbondale	350-400
			Kewanee	Spoon	350-400
		ATOKAN	McCormick	Abbott	300-400
		MORROWAN	McCormick	Caseyville	250-450
	MISSISSIPPIAN	CHESTERIAN		Many (see fig. 6)	900-1200
		VALMEYERAN		Ste. Genevieve-others	150-200
				St. Louis Ls.	400 ±
				Salem Ls.	400 ±
				Ullin Ls.	300 ±
				Ft. Payne	200 ±
	DEVONIAN	UPPER	New Albany	undifferentiated	200-400
		MIDDLE		Lingle Ls.	0-100
				Grand Tower Ls.	100-350
		LOWER		Clear Creek Chert	250-450
				Backbone Ls.	30-50
				Grassy Knob Chert	200-550
				Bailey Ls.	200-450
	SILURIAN	NIAGARAN / ALEXANDRIAN		three formations	150-350
	ORDOVICIAN	CINCINNATIAN	Maquoketa	undifferentiated	200-425
		CHAMPLAINIAN	Galena	undifferentiated	15-130
			Platteville	undifferentiated	500-600
			Ancell	Joachim / Dutchtown	250-950
			Ancell	St. Peter	50-200
			Knox Megagroup	Everton Dolomite	50-600?
		CANADIAN	Knox Megagroup	undifferentiated	1800-3600
	CAMBRIAN	CROIXAN	Knox Megagroup	Eminence Dolomite	350-900
				Potosi Dolomite	800-1000
				Franconia Ss.	900-1350
				Eau Claire Dolomite	800-2700
			Potsdam Sandstone Megagroup	Mt. Simon Ss.	0-700?
		MIDDLE AND LOWER?		pre-Mt. Simon (Mermet Ss., Rome, Conasauga?)	564 +
PRECAMBRIAN					

ISGS 1984

FIGURE 4. Generalized stratigraphic column for study region.

TABLE 1. Sub-Mississippian formations penetrated by deep wells in and near the study area (see fig. 4 for identification).

Formations	Well Numbers											
	1	2	3	4	5	6	7	8	9	10	11	12
DEVONIAN SYSTEM	1,860	768+	845+	2,065	1,802	1,525	1,750	1,766	1,916	1,769	1,375	1,522
New Albany Group	385	278	369	350	320	206	366	304	400	302	305	257
Lingle Limestone	64	70					92	86	46	44	0?	38
Grand Tower Limestone	355	68	349				242	290		266	345	101
Clear Creek Chert	390	352+	27+	1,715	1,482	1,319	288	285		488		360
Backbone Limestone	50	*					24?	30	1,460	52	725	30
Grassy Knob Chert	530						292?	400		200		565
Bailey Limestone	186						446	371		457		
SILURIAN SYSTEM	290			248+	358	337	220	154	350	165	475	328
Moccasin Springs Fm.	124							59		53		171
St. Clair Limestone	90							55		76		63
Sexton Creek Limestone	76							40		36		94
ORDOVICIAN SYSTEM	1,590+				?	5,553	2,300+	3,300	5,145	4,138	1,545+	?
Maquoketa Shale Group	238				232	237	342	373	225	418	315	200
Galena Group	114				760	92	108	37	95	15	116	127
Platteville Group	576					584	562	500	610	535	546	562
Joachim/Dutchtown Fms.	480				690	593	420	220	555	950	344	266
St. Peter Sandstone	50				190	65	50	160?	71	?	115	152
Everton Dolomite	122+				?	312	570?	136	3,589	2,310	103	62
Knox Megagroup (in part)					6,350**	3,660	250+	1,874				
CAMBRIAN SYSTEM						4,724+		5,530+	416+	4,500		4,324+
Eminence Formation						870		860	360	660		
Potosi Dolomite						1,030		790	56+	900		
Franconia Formation						440		1,190?		1,340		
Eau Claire Formation					920	1,160		†2,690+		‡1,700+		823
Mt. Simon Sandstone					150+	660						None
Pre-Mt. Simon						545+						Precambrian granite
TOTAL DEPTH	7,688	2,683	3,172	6,200	14,942	14,284	8,594	15,200	8,821	12,960	7,980	13,051

*Well cut fault and went into Pennsylvanian at 2,380 ft. Probably additional faults in hole (note abnormally thin Grand Tower Limestone).
**"Knox" in this well includes undifferentiated Cambrian and Ordovician between St. Peter Sandstone and Eau Claire Formation.
†Igneous rock 14,440-14,450 ft.
‡Igneous rock 12,110-12,130 ft.

Soderberg and Keller, 1981; Schwalb, 1982; and Hildenbrand et al., 1982). Soderberg and Keller (1981) refer to the Precambrian trough as the Rough Creek Graben and believe it to be bounded on the north and south by fault scarps, precursors of the Rough Creek-Shawneetown and Pennyrile Fault Systems, respectively.

CAMBRIAN SYSTEM

Throughout much of the upper midwest the basal Paleozoic deposit is a quartzose to arkosic transgressive sandstone of Croixan (late Cambrian) age, called the Lamotte Sandstone in the Ozarks and the Mt. Simon Sandstone eastward (fig. 4). It rests on an irregular, knobby Precambrian surface and is absent over some of the buried hills, as in the Hamilton County well (well 12, fig. 3, and table 1). In southern Illinois, the Mt. Simon is assigned to the Potsdam Sandstone and is equivalent to the Potsdam Sandstone of New York State.

The Rough Creek Graben contains a thick succession of sediments older than the Mt. Simon Sandstone. The deep oil test drilled by Texas Pacific in southern Johnson County, Illinois (well 6, fig. 3, and table 1), first cut about 660 feet of Mt. Simon, then passed through 564 feet of coarse-grained reddish arkose containing layers of red and green shale, and bottomed in this material without reaching basement. Another well near the eastern end of the Rough Creek-Shawneetown Fault System in Grayson County, Kentucky, encountered a thick succession of marine shales, containing trilobites indicating middle Cambrian age, beneath the Eau Claire (Howard Schwalb, personal communication, 1983). Mt. Simon Sandstone was not recognized in the latter well. The seismic sections in western Kentucky indicate as much as 8,000 feet of Cambrian deposits (Norman Hester, personal communication, 1983). Deep drilling in southeastern Missouri, eastern Arkansas, and western Tennessee reveal similar extremely thick pre-Mt. Simon deposits in a deep Cambrian trough, probably a graben or rift zone, beneath the Cretaceous and Tertiary sediments of the Mississippi Embayment (Ervin and McGinnis, 1975; Houseknecht and Weaverling, 1983). This north-trending trough, called the Reelfoot Rift, intersects the Rough Creek graben in southern Illinois.

The Croixan (upper Cambrian) and Canadian (lower Ordovician) rocks above the Mt. Simon Sandstone, including the Everton Dolomite (fig. 4), are classified as the Knox Dolomite Megagroup. Outside the boundaries of the Rough Creek Graben and the Reelfoot Rift, the Knox generally consists mainly of dolomite and dolomitic sandstone with chert and small amounts of shale and siltstone. The Knox thickens abruptly and changes to shale, probably of deep-water marine origin, in the Rough Creek and Reelfoot troughs (Schwalb, 1982; Houseknecht and Weaverling, 1983). The thickening and facies change is most pronounced in the basal Knox (Eau Claire Formation) and becomes less marked upward.

Thus, the Reelfoot and Rough Creek troughs evidently opened in early Cambrian or possibly late Precambrian time, and were invaded by the sea, into which the surrounding uplands shed vast amounts of clastic detritus. The troughs filled rapidly with sediment, but still were deep during the late Cambrian, when the ocean spread onto the craton and deposited Lamotte/Mt. Simon sand. Not until Ordovician time were these trenches generally leveled enough to receive shallow-water carbonates. Although no direct evidence has been obtained as to the nature of the boundaries of the Reelfoot Rift and Rough Creek Graben, these boundaries are generally presumed to be faults. They definitely were lines of weakness in the crust, and are precursors of faults that experienced recurrent movements in Paleozoic and subsequent time.

ORDOVICIAN SYSTEM

Sedimentation continued from Cambrian into Ordovician time with no apparent hiatus or marked change in the character of the rocks. The systemic boundary, therefore, is difficult to identify from well records. The Ordovician portion of the Knox Megagroup, including the overlying Everton Dolomite, consists of shallow-water carbonates within and outside the Rough Creek Graben. Overlying the Everton is the widespread and readily-recognized St. Peter Sandstone, which is composed of very well-sorted quartz sand deposited in shallow water during a marine transgression. The St. Peter ranges from 50 to 200 feet thick (table 1; fig. 4), and typically is overlain by 1000 feet or more of limestone and dolomite and topped by the Cincinnatian (upper Ordovician) Maquoketa Shale Group, which ranges from 200 to a little more than 400 feet thick.

SILURIAN SYSTEM

Strata assigned to the Silurian System range from about 150 to 475 feet thick, as identified from well logs and cuttings (table 1). Three formations commonly are recognizable: the Moccasin Springs and St. Clair of Niagarian age, and the Sexton Creek Limestone of Alexandrian age. The Moccasin Springs typically is reddish, very silty or argillaceous limestone or calcareous siltstone; the St. Clair is fairly pure limestone and the Sexton Creek is cherty limestone. The Edgewood Limestone, which underlies the Sexton Creek in southern Ilinois, also may be present, but has not been differentiated in any of the wells examined for this report.

DEVONIAN SYSTEM

The Devonian System consists of numerous formations having an aggregate thickness of 1500 to 2000 feet in the vicinity of the study area (table 1). Lower and Middle Devonian strata are composed mainly of very cherty limestone; some units are formed mostly of bedded chert. Clastic sediments are sparse in this part of the section, although the Dutch Creek Sandstone Member of the Grand Tower Limestone was identified in some wells. Clear Creek Chert comes to the surface in the vicinity of Hicks Dome, about 10 miles south of the study area, and is the oldest rock to crop out in the region. Lower and Middle Devonian carbonates sometimes are lumped, along with carbonates of the Silurian System, into the Hunton Limestone Megagroup.

The Upper Devonian, in contrast, is an interval of dark gray, greenish-gray, and black shales assigned to the New Albany Shale Group. This interval, evidently laid down in fairly deep water, represents the finest detritus washed out of the Catskill deltaic complex during the Acadian Orogeny in New England. New Albany shales are easily recognized in well cuttings, on radioactive logs, and in outcrop. The oldest bedrock actually exposed within our

FIGURE 5. Siliceous limestone of the Ft. Payne Formation, dipping steeply southward in a narrow fault slice in the Shawneetown Fault Zone (at the Horseshoe Quarry, Rudement Quadrangle).

immediate study area is believed to be New Albany Shale; it is found in an abandoned roadstone quarry at Horseshoe (NE 1/4 NE 1/4 NE 1/4, Sec. 36, T. 9S., R. 7E.) Rudement Quadrangle, Saline County. The shale dips vertically in a narrow fault slice on the north wall of the cut near the northwest corner of the quarry. The highly fractured shale is hard, brittle, and silty and contains small irregular phosphatic nodules. Such lithology is typical of portions of the New Albany Shale, but similar dark shale (generally very thin) occurs within the Valmeyeran Fort Payne Formation.

MISSISSIPPIAN SYSTEM

Fort Payne Formation

The Fort Payne Formation, of Valmeyeran age, is exposed only at the Horseshoe Quarry, where it is usually a dark gray, highly silicified, silty limestone (fig. 5). It lies in fairly regular beds, ranging from less than an inch to about a foot thick, occasionally separated by partings of black siliceous shale. Most of the original carbonate has been replaced by dull to vitreous silica. Such silicification, typical through much of the Ft. Payne, makes the formation relatively resistant to erosion. The 150 feet or more of Ft. Payne at Horseshoe Quarry probably is less than the total thickness of the formation. The rock is faulted and thoroughly fractured; it dips at 40° to 90° from horizontal. It occupies a narrow fault slice in the heart of the Shawneetown Fault Zone.

Ullin, Salem, and St. Louis Limestones

Overlying the Ft. Payne Formation, in ascending order, are the Ullin, Salem, and St. Louis Limestones, which constitute the middle portion of the Valmeyeran Series. Deposited on a carbonate shelf, in shallow to moderately deep marine water, these formations contain little or no terrigenous material and variable amounts of secondary chert. We found no outcrops of the Ullin, Salem, or St. Louis in our study area, but they probably lie directly beneath the alluvium near Horseshoe, and possibly along the north side of the Wildcat Hills. The units are difficult to distinguish on geophysical logs; careful study is required to separate them in well cuttings. The contacts apparently are conformable and gradational in the study area. The Ullin is roughly 300 feet thick; the Salem and St. Louis average about 400 feet thick each.

Ste. Genevieve Limestone

Typically a light to medium gray, coarse biosparite or oolitic limestone, the Ste. Genevieve records shoaling conditions toward the end of Valmeyeran time. Beds of sandstone and sandy limestone in the upper part of the formation reflect the beginning of cyclical deposition that prevailed subsequently during the Chesterian Epoch. Also present are partings of greenish shale and nodules of chert. The Ste. Genevieve typically is thick-bedded to massive in outcrop.

The upper portion of the Ste. Genevieve Limestone is exposed in an abandoned quarry at the north edge of the Wildcat Hills in the SE 1/4 NW 1/4 SE 1/4,

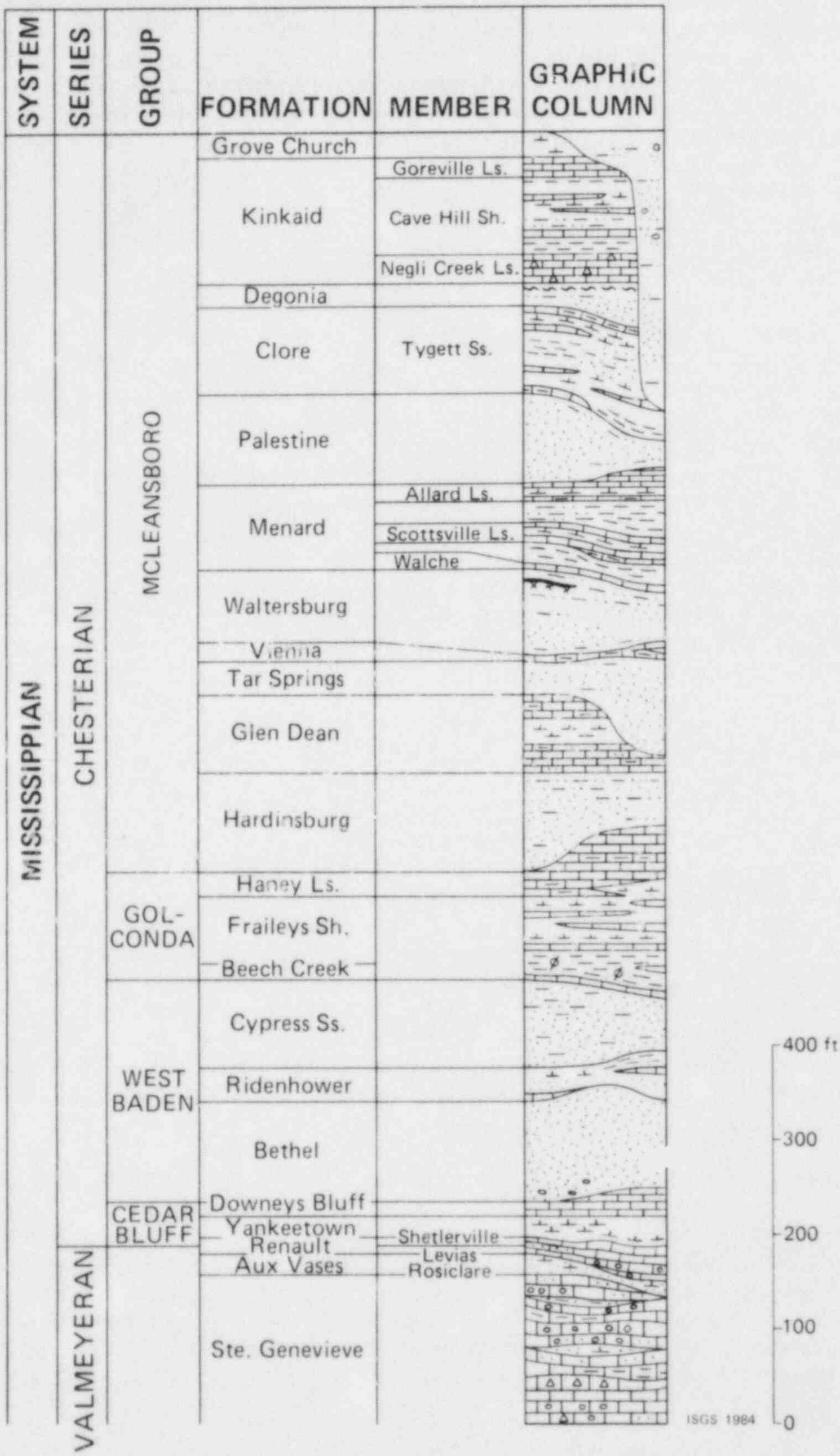


FIGURE 6. Generalized stratigraphic column of the Chesterian Series (Chesterian-Valmeyeran boundary after Swann, 1963). Many geologists still include the Renault Limestone and Aux Vases Sandstone in Chesterian.

Section 27, T. 9S., R. 8E., Equality Quadrangle. This steeply tilted limestone lies within a fault slice of the Shawneetown Fault Zone. Float and obscure outcrops identified as Ste. Genevieve also occur near the road junction adjacent to Sulphur Springs Church, in the SW 1/4, Section 34, T. 9S., R. 7E., Rudement Quadrangle, also within a steeply dipping fault slice. Ste. Genevieve Limestone is the deepest formation ordinarily penetrated by oil drilling in the area. Its thickness ranges from about 120 to 180 feet.

Formations of the Chesterian Series

The Chesterian Series, roughly 1,000 feet thick in southeastern Illinois, comprises numerous formations of marine shale and limestone alternating with shallow-marine, coastal, fluvial, and deltaic sandstone and shale (fig. 6). This alteration reflects large-scale fluctuation of shoreline and fluvial depocenters, conditions that prevailed during the Pennsylvanian Period as well. Traditionally, the base of the Chesterian Series was placed at the base of the Aux Vases Sandstone, but Swann (1963) reclassified the Aux Vases and the Levias Member of the Renault Formation as Valmeyeran, on the basis of fossil evidence. Nevertheless, some stratigraphers, among them Jennings and Fraunfelter (1983), still prefer to include the Levias and Aux Vases with the Chesterian.

Within the area mapped on plate 1, Chesterian rocks crop out in fault slices and tilted blocks on the north and west sides of Cave Hill and on the north side of the Wildcat Hills and Gold Hill. The most complete succession is found along Three Springs Hollow (Sec. 35, T. 9S., R. 7E.), where rocks from the Kinkaid Limestone through the Cypress Sandstone are exposed. Numerous electric logs of oil test holes showing the entire Chesterian Series were available, and we used these to help in correlating and identifying units at the surface.

Chesterian sandstones are topographically prominent and tend to form ridges and hogbacks. Typically they are fine to very fine-grained, well-sorted mature quartz arenites or orthoquartzites, tightly cemented with silica and iron oxide. None of them has sufficiently distinctive lithologic character to permit formational identification from a single exposure; indeed, these sandstones can be difficult to distinguish from lower Pennsylvanian sandstones. Upper Chesterian sandstones can, however, be differentiated from lower Chesterian sandstones in a general way. Sandstones of Degonia, Clore and Palestine Formations are thin (5 to 20 feet) and typically weather yellowish-gray to yellowish-brown; they are very fine grained, thin bedded, shaly, and often ripple marked. Tar Springs and older sandstones are thicker overall, often thick-bedded to massive, and white or very light gray on fresh surfaces. All of the sandstones, especially those of the Waltersburg and Hardinsburg Formations, vary markedly in thickness within the study area, display a range of facies, and grade laterally into shale or siltstone.

Limestones are the most useful units for piecing together Chesterian stratigraphy in the field, because many have distinctive characteristics; however, they are rarely exposed except in ravines. A general upward transition is seen from Ste. Genevieve-like light-colored, crystalline, bioclastic or oolitic limestones in the lower Chesterian to darker, finer-grained, denser limestones of the upper part of the series. General lithology, thickness, and

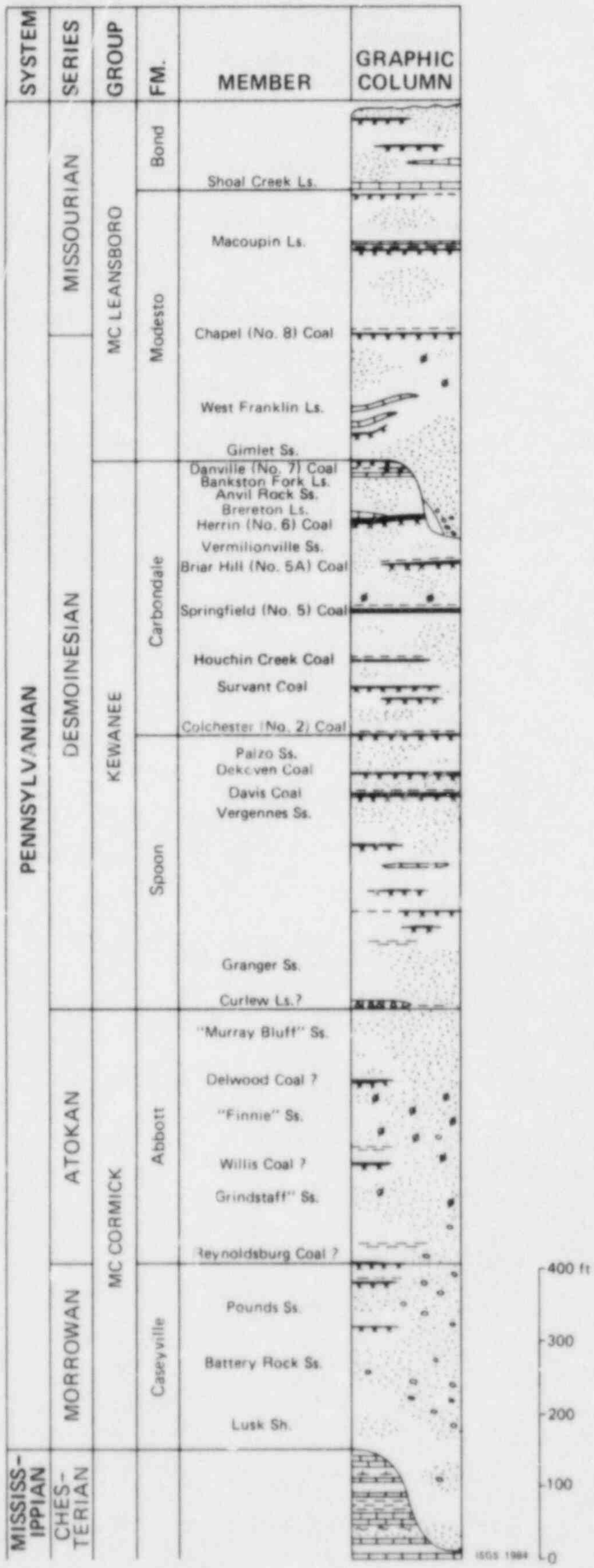


FIGURE 7. Generalized stratigraphic column of Pennsylvanian System.

character of the beds, fossils, and secondary features such as chert nodules all are useful criteria for identifying Chesterian limestones.

Shales crop out only along streams and, rarely, on very steep slopes. Dark gray or greenish-mottled, platy, siliceous shales are most characteristic; red shale is diagnostic of the Degonia Formation as seen in well cuttings. Gray silty shales and siltstones also occur, but are nearly identical to some Pennsylvanian rocks. Thin coal seams are rare; the only ones we found are in the upper part of the Waltersburg Formation along a ravine east of Three Springs Hollow.

Structural complexity, paucity of exposures, and thinness of some formation necessitated grouping some of the Chesterian formations together for mapping purposes. In a few areas of complicated structure we could not identify the units reliably and have therefore mapped these places as undifferentiated Chesterian.

A major unconformity marks the base of the Pennsylvanian System throughout the Illinois Basin (Bristol and Howard, 1971). Within the study area the hiatus is less profound than in most places: basal Pennsylvanian strata rest on uppermost Chesterian rocks. A few subsurface records indicate that the Grove Church Shale, the youngest identified Chesterian formation, may be present beneath the unconformity. In most wells and surface exposures, basal Pennsylvanian rocks overlie the Goreville Limestone or Cave Hill Shale Members of the Kinkaid Limestone. The major exception is in the Inman Channel (Howard, personal communication, 1983) in the Shawneetown Quadrangle, where pre-Pennsylvanian erosion locally removed strata down to about 30 feet above the base of the Clore Formation. The maximum relief on the unconformity thus amounts to about 250 feet.

At all exposures examined, the Mississippian and Pennsylvanian strata are concordant. Thus, there is no evidence, such as Ekblaw (1925) found in the Alto Pass area of southwestern Illinois, for post-Chesterian pre-Pennsylvanian tectonic movement.

PENNSYLVANIAN SYSTEM

Caseyville Formation

The basal Pennsylvanian of southeastern Illinois is assigned to the Caseyville Formation (fig. 7). Composed largely of thick and massive sandstone that is very resistant to erosion, the Caseyville forms all of the highest hills of the study area. A nearly continuous escarpment of Caseyville sandstone marks the upturned rim of the Eagle Valley Syncline south and east of the Shawneetown Fault Zone, through Gold Hill, the Wildcat Hills, Cave Hill, and from there southwestward to the limit of the mapping area. A similar south-facing escarpment marks the southern limb of the Eagle Valley Syncline a short distance south of the quadrangles surveyed.

The Caseyville Formation includes siltstone, shale, and thin, discontinuous seams of coal, but sandstone normally constitutes more than half of the thickness of the formation. No limestone or rocks containing marine fossils were observed in the study area, although such rocks have been reported elsewhere in Illinois. Petrography, fabric, and sedimentary structures indicate a dominantly fluvial and deltaic origin for the Caseyville (Palmer and Dutcher, 1979). The cyclicity that is characteristic of Chesterian and younger Pennsylvanian strata is not much in evidence in the Caseyville.

The cliff-forming, channel-phase Caseyville sandstones are often 100 feet or more thick. Commonly they are so massive that structural attitudes are difficult to determine. Large-scale crossbedding is prominent in many exposures. A diagnostic feature of the Caseyville is the presence of well-rounded pebbles of white quartz (occasionally quartzite, chert, and hematite) up to 1/2 inch in diameter, either scattered throughout the sandstone or concentrated as lay conglomerates up to several feet thick. Such pebbles do not occur elsewhere in the stratigraphic section, although scattered quartz granules are found in some places in the next younger Abbott Formation (and reportedly in the Chesterian Bethel Sandstone, not observed in our study area). Otherwise, Caseyville sandstones range from very fine to very coarse-grained and are clean, mature quartz arenites or orthoquartzites, cemented by silica or iron. Mica, clay, feldspar, and dark grains, common in younger Pennsylvanian sandstones, are rare in the Caseyville. Fine-grained Caseyville sandstone can be confused with Chesterian but not with younger Pennsylvanian sandstone.

Siltstone and shale of the Caseyville range from medium to dark gray or brown to black and commonly contain more mica and carbonaceous debris than do Chesterian rocks, but they cannot be distinguished reliably from other fine-grained Pennsylvanian rocks.

We have identified and mapped for the first time three members of the Caseyville Formation in the study area. The basal Lusk Shale Member, a few tens of feet to about 200 feet thick, is largely sandstone in many exposures. Lusk sandstone is generally very fine to fine-grained orthoquartzite in irregular strata ranging from a few inches to 3 or 4 feet thick. Locally it is a ledge-former. Overlying the Lusk is the massive, channel-phase Battery Rock Sandstone Member, which forms continuous cliffs from south of Bald Knob to the northern face of Cave Hill. The overlying Pounds Sandstone Member has a similar character but is less prominently exposed than the Battery Rock in most areas. A poorly exposed shaly interval normally separates the Pounds from the Battery Rock, but near the summit of Cave Hill the two massive units appear to have merged. Near the eastern end of Gold Hill the members cannot be identified, and the exposed Caseyville consists largely of shale, with beds of argillaceous sandstone and thin coals.

The top of the Caseyville Formation is defined as the top of the Pounds Member, which in most places is easy to recognize in the field, but difficult to place in most well records.

Abbott Formation

Like the Caseyville Formation, the Abbott Formation (fig. 7) is composed largely of resistant sandstone, which forms ridges and cuestas. It crops out in a broad belt on the southern dip-slope facies of Gold, Wildcat, and Cave Hills, and on the north-dipping slope at the southern edge of the study area. The Abbott also is found west of the Shawneetown Fault Zone in the southwestern portion of the Rudement Quadrangle (plate 1).

Abbott sandstones are less massive and less mature than those of the Caseyville. The Abbott contains more mica, feldspar, and clay than the Caseyville, and these components become progressively more abundant upward in the formation. Scattered quartz granules and pebbles occur locally in the lower part of the Abbott. Ironstone cement and Liesegang banding are prominent, particularly in the middle part of the formation.

The remainder of the Abbott consists of siltstone, shale, and thin local coals, similar to those of the Caseyville Formation.

In mapping the areal geology of the fluorspar district, Baxter el al. (1963, 1965, and 1967) distinguished three sandstone members: The Grindstaff, Finnie, and Murray Bluff in the Abbott. Although we could recognize features of these units in many exposures, we found that we could not reliably map these members in our area. Rapid lateral facies changes are common; in some exposures the Abbott is almost entirely sandstone, but elsewhere large portions of the formation grade to shale. Furthermore, recent work by Peppers and Popp (1979) suggests that the Grindstaff and Finnie Sandstones at their type sections actually are the same sandstone. This is not surprising, considering that Abbott Sandstones apparently were deposited by meandering, shifting streams.

The upper boundary of the Abbott Formation is defined as the top of the Murray Bluff Sandstone; however, because of the previously mentioned facies variations and the fact that the members cannot be positively identified in the field, this contact cannot be placed precisely in most areas, and is shown with a broken line on most of plate 1a. Similarly, well records can provide only approximate placement of the Spoon-Abbott contact.

Spoon Formation

The Spoon Formation contains more shale and less sandstone than the Caseyville and Abbott and therefore is less prominent topographically than the the latter two formations. Spoon sandstones locally form prominent hogbacks in the inner range of hills surrounding the Eagle Valley Syncline, but large areas of outcrop belt are concealed by Quaternary alluvial and lacustrine deposits.

Sandstone in the Spoon can be distinguished from that of the Abbott on the basis of abundant coarse mica, feldspar, carbonaceous debris, and clay matrix in the latter. Secondary iron is less prominent in the Spoon than in the Abbott. In these respects the Spoon sandstone does not differ significantly from younger Pennsylvanian sandstone. The thickest sandstones are generally in the lower portion of the Spoon, but rapid lateral changes in thickness and facies are the rule.

During Spoon time the sedimentary regime gradually changed from one dominated by fluvial processes to the "cyclothemic" alteration of marine and nonmarine strata characteristic of the middle Pennsylvanian. The Spoon is the oldest Pennsylvanian formation to contain limestone in the study area. The "Curlew Limestone" of Butts (1925) appears as abundant float of white to yellowish-orange chert containing molds of large productid brachiopods, crinoids, gastropods, and other marine fossils; it was found on several hilltops near Somerset and also in Horseshoe Hollow southwest of Glen O. Jones Lake in the

Rudement Quadrangle. Whether this is actually the Curlew Limestone Member, as now defined, is uncertain, but it lies near the base of the Spoon Formation and provides the most reliable field indicator of the Spoon-Abbott contact. Other thin limestones in the Spoon were identified in well logs, but none can be correlated with named members.

Coal is much better developed in the Spoon than in older Pennsylvanian rocks. Coals of the middle shaly portion of the Spoon are thin and discontinuous, and cannot be correlated, but the Davis and Dekoven Coal Members (fig. 7) are virtually continuous in our study area and throughout much of the Illinois Basin. These coals are widely exposed in abandoned surface mines in the Eagle Valley Syncline and central Rudement Quadrangle, and are identified in hundreds of coal-test borings.

Carbondale Formation

The Carbondale Formation is characterized by minable coal seams and marine black fissile shales and limestones that exhibit great lateral continuity; however, the bulk of the formation is composed of deltaic and marginal-marine shale, siltstone, and sandstone. Natural exposures are rare, but portions of the Carbondale are extensively exposed in surface mines and are known from thousands of coal-test records, many of which include core descriptions. The Carbondale Formation underlies the central portion of the Eagle Valley Syncline and also the region north of the Shawneetown Fault Zone, where it is largely concealed by Quaternary deposits.

The Colchester (No. 2) Coal Member marks the base of the Carbondale Formation in Illinois. The coal is only a few inches thick but is continuous throughout the study area and readily identified on geophysical logs. The Springfield (No. 5), Briar Hill (No. 5A), and Herrin (No. 6) Coal Members have been mined widely and also are easy to identify. The Springfield Coal, 4 to nearly 6 feet thick, was selected as structural datum for plate II; it is mined at the surface and underground. The Briar Hill Coal is 1 to 3 feet thick and has been strip-mined in conjunction with the Springfield seam. The Herrin Coal, which has been mined underground and at the surface, normally is 3 to 4 1/2 feet thick, but locally is thin or absent as a result of erosion in paleochannels. Too thin for commercial mining, but widely recognizable in drill records are the Survant and Houchin Creek (No. 4) Coal Members--formerly the Shawneetown and Summum (No. 4) Coal Members. The top of the Carbondale Formation is defined as the top of the Danville (No. 7) Coal Member, which is less than 2 feet thick and widely eroded at the base of the overlying Modesto Formation.

Modesto Formation

Except for the fact its coal seams are too thin for commercial mining, the Modesto Formation is lithologically similar to the Carbondale. The Modesto occurs at the core of the Eagle Valley Syncline and in the northern part of the study area, where it is largely covered by Quaternary sediments. A massive channel phase of the Gimlet Sandstone Member (fig. 7) however, is topographically prominent in Eagle Valley, where it caps many hills. The base of the Gimlet is eroded into the Carbondale Formation, below the level of the Herrin Coal in places. Most of the areas that Butts mapped as Anvil Rock

Sandstone (Carbondale Formation) actually are Gimlet. Cliffy exposures up to 50 feet high, commonly with large-scale crossbedding, are found around Maher Hill in the Equality Quadrangle.

Bond Formation

The youngest bedrock in the study area belongs to the Bond Formation, of Missourian age. It has been identified only in the subsurface at the eastern end of the Eagle Valley Syncline and in the grabens north of Shawneetown. The Shoal Creek Limestone Member, which marks the base of the Bond, is easy to pick in well records. Overlying the Shoal Creek is up to 125 feet of shale and sandstone having thin layers of coal and limestone.

PERMIAN SYSTEM

No rocks of Permian age have been identified in Illinois, but their original presence in the study area can be inferred. Kehn, Beard, and Williamson (1982) reported Permian rocks, identified on the basis of fusulinids, in a drill core in eastern Union County, Kentucky. These rocks, assigned to the Mauzy Formation, are preserved in a narrow graben within the Rough Creek Fault System. Approximately 390 feet of Mauzy are present in the type-section core, but structural projections indicate that up to 1300 feet of Permian may occur in the deepest part of the graben. The contact of the Mauzy Formation with underlying Pennsylvanian rocks apparently is conformable.

The existence of post-Pennsylvanian rocks up to several thousand feet thick (now eroded) was previously inferred from coalification studies in the southern part of the Illinois Basin (Damberger, 1971 and 1974).

TERTIARY SYSTEM

The only Tertiary materials recognized to date in the study area are scattered outliers of the Mounds Gravel in the Shawneetown Hills, north of the Shawneetown Fault Zone (Butts, 1925). The Mounds is composed of well-rounded pebbles of chert and vein quartz, weathered to a brown or yellow color. It occurs near the tops of hills near an elevation of 500 feet, overlies bedrock, and is covered by Pleistocene loess. Its maximum thickness is probably less than 20 feet. This gravel represents erosional remnants of extensive deposits in the Mississippi Embayment. The Mounds Gravel is believed to be partly Pliocene and partly Quaternary in age.

QUATERNARY SYSTEM

Sediments of Pleistocene age cover Paleozoic bedrock in most of the study area, including all of the lowlands and large portions of the uplands. Our mapping of them is based largely on published works, especially Heinrich (1982). We have mapped Quaternary materials in plate I only where they create the dominant landform (as on alluvial flats and in sand dunes), and/or where they completely mask the bedrock. Most areas mapped as bedrock are, in fact, mantled by Quaternary sediments over 90 percent or more of their area. Some classes of sediments, such as talus, have not been mapped at all. Boundaries of most mapped Quaternary units are gradational and, to a large degree, arbitrary.

The classification that follows is, for the most part, generic. Our examinations rarely were thorough enough to enable us to distinguish the formally named stratigraphic units of the Pleistocene Series. Reference to these formal names will be made occasionally, as appropriate. Readers desiring more information on Quaternary deposits should consult Willman and Frye (1970) and Lineback et al. (1979).

Glacial deposits

No sediments believed to have been deposited directly by or from glacial ice are known within our study area. The southernmost limit of glaciation (Illinoian Stage) is placed a few miles north of our maps (Lineback et al., 1979). The mass of the Shawnee Hills probably blocked the flow of the ice to some degree. About 25 miles west of Rudement, in Johnson County, Illinois, the glaciers achieved their southernmost advance in North America.

Deposits of silty clay containing fragments of weathered bedrock were observed in the highwall of an active strip mine near Cottage Grove, just off the north edge of the Rudement Quadrangle. This material looked similar to some glacial till, but its identity is by no means certain. Nothing else resembling glacial till was noted within the three quadrangles of interest.

Lake deposits

Continental glaciers repeatedly advanced and retreated across the Great Lakes States during the Pleistocene Epoch. Each time the ice sheets withdrew, enormous volumes of sediment-laden meltwater coursed down the valleys of the ancestral Mississippi, Ohio, and Wabash River valleys. The outwash sediments rapidly aggraded, choking the channels of the rivers and causing the waters to back up, forming slackwater lakes. Such lakes repeatedly covered large areas of southern Illinois. Lowlands in our area of interest were flooded by part of what has been called Lake Saline (Frye et al., 1972; Heinrich, 1982).

The former bed of Lake Saline is filled with clay and silt and smaller amounts of sand and gravel to depths approaching 150 feet. The surface of these lake deposits, virtually level, stands about 355 to 370 feet above sea level. Perhaps the best impression of the lacustrine beds can be gained in the northwestern part of the Rudement Quadrangle. The rounded, isolated bedrock hills near Cottage Grove rise like islands above the flat surface of the lake plain.

Heinrich recognized at least five distinct sedimentary units, three of them Illinoian and two Wisconsinan, within the deposits of Lake Saline. We made no attempt to distinguish these units in mapping. Because the lake deposits in most places are capped with a veneer of Holocene alluvium and cultivated soils, information on lacustrine sediments comes only from scattered well records and from a few artificial cuts, mostly where the Saline River has been channelized.

Maumee Flood sediments and other fluvial deposits

Slackwater lakes were held in place by valley-fill deposits of sand, gravel, and other unconsolidated materials. Occasionally these natural dams failed, and lacustrine waters were released in great torrents, profoundly reshaping the landscape. One notable event of this type was the Maumee Flood, which occurred about 13,000 years ago (Heinrich, 1982). The floodwaters entered our area about two miles north of Shawneetown, skirting the Shawneetown Hills in a channel 2 to 2 1/2 miles broad (fig. 8). Turning southward at Junction, the torrent forced its way through the half-mile gap between the Wildcat Hills and Gold Hill, and from there followed the present course of the Saline River down to the Ohio. As the flood waters receded they left behind a channel more than 100 feet deep in places, filled with sand and gravel. Many subtle depositional features, including transverse and longitudinal bars, still can be recognized (Heinrich, 1982). These features cross several bedrock faults; tectonic implications will be discussed later in this report.

The Maumee floodwaters followed, in part, an older channel of the Ohio River. This old course flowed southwestward, around the northwest side of the Shawneetown Hills, and turned abruptly eastward at Junction to cut between the Shawneetown Hills and Gold Hill. Apparently this channel dates to pre-Illinoian time (Heinrich, 1982). Up to 150 feet of sand and gravel, containing fossil logs, has been encountered in wells between Gold Hill and Shawneetown. The sands are an important source of groundwater in the area.

Numerous gaps in structurally controlled bedrock ridges indicate an older drainage superimposed upon the bedrock. The gaps between Gold Hill and the Shawneetown and Wildcat Hills are the widest, but many others can be recognized. Horseshoe Gap, 500 feet wide and nearly 200 feet deep, is the most spectacular. Many others can be recognized in central Eagle Valley, especially between the Gimlet Sandstone ridges from Maher Hill eastward. Insignificant, mostly intermittent streams occupy these flat-bottomed cuts today. No evidence exists as to when or how they were eroded. We may speculate that they were made by streams superimposed on Mounds Gravel or other Tertiary sediments, or perhaps on early Pleistocene outwash terraces that stood considerably higher than any modern terrace remnants.

Loess and windblown sand

Most of the uplands in the study area are mantled with firm, compact silt that in some places is deep enough to hide all bedrock. Loess was deposited at several times during the Pleistocene Epoch when broad alluvial flats covered with outwash sediments lay exposed to the wind. As today, prevailing winds then blew from the west, so loess deposits generally are thickest on the east sides of major streams.

Loess is thin and rather sporadic in the Rudement and most of the Equality Quadrangles. Undisturbed loess 2 to 3 feet, occasionally 5 feet or thicker, is found on relatively flat areas along divides on Cave Hill, the Wildcat Hills, and hills in Eagle Valley. On the slopes most of the loess has been eroded and either bare rock, or slope wash and alluvium can be seen. The rounded hills north of the Shawneetown Fault Zone bear thicker loess, up to 20 feet. This thicker silt possibly was derived from the bed of Lake Saline, which repeatedly was drained and exposed to the wind.

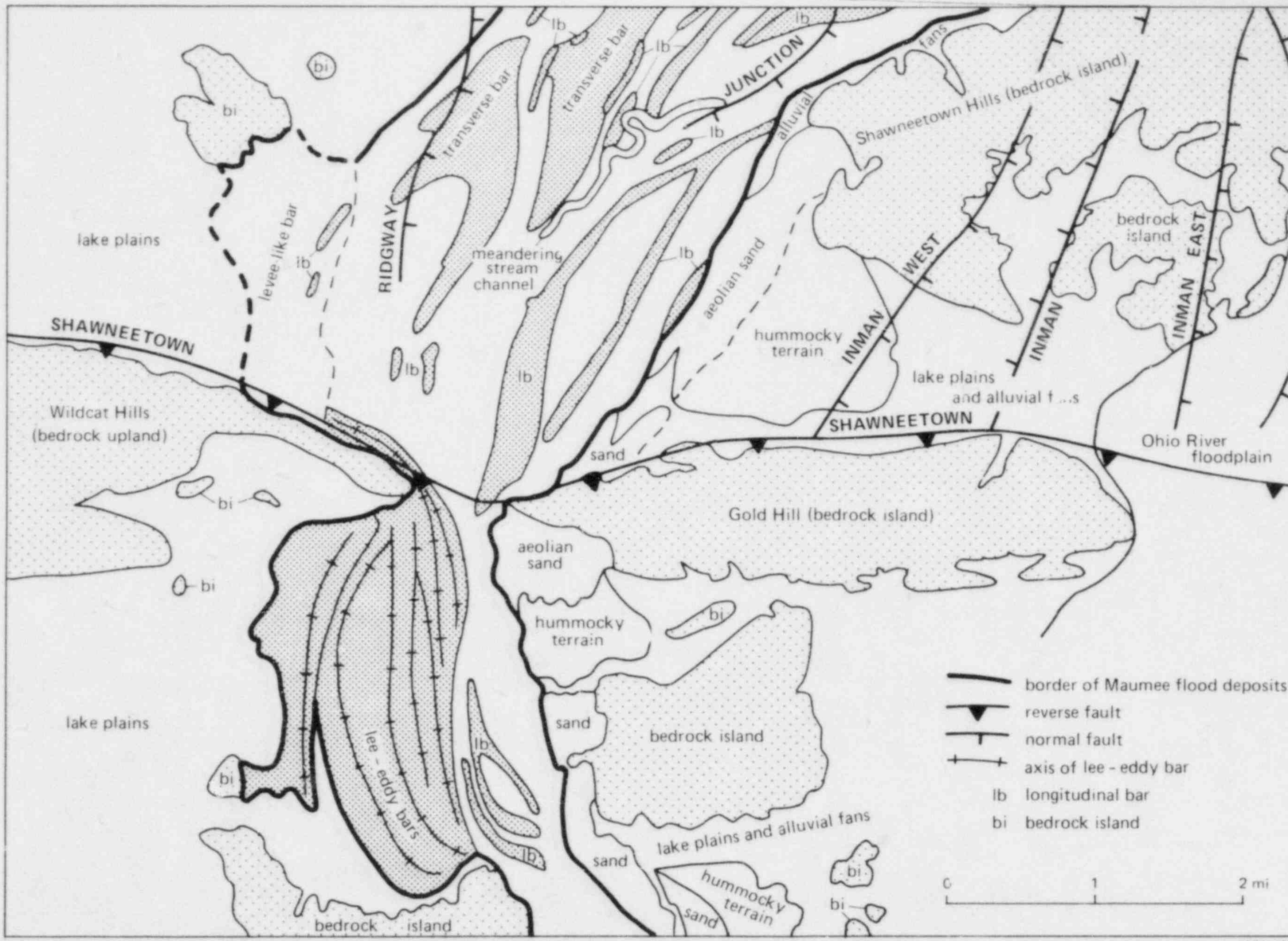


FIGURE 8. Maumee Flood deposits and faults in Shawneetown Quadrangle, Gallatin County, Illinois (after Heinrich, 1982).

Thick loess, probably 15 to 20 feet of it, mantles the narrow eastern spur of the Wildcat Hills east of Illinois Route 1. Here the source of silt clearly was the adjacent Maumee Flood plain. East of the Maumee Flood channel the windblown deposits reach their greatest thickness. Prominent sand dunes line the eastern side of the flood course from the southwest end of the Shawneetown Hills across Gold Hill nearly to the southern edge of the Shawneetown Quadrangle. Longitudinal ridges of sand are very prominent around McGhee and Kanady Cemeteries, north of Gold Hill. Very thick dunes cover the west end of Gold Hill itself. Quarry pits near the NW corner of Section 5, T.10 S., R.9 E. reveal sand deposits 30 feet thick that do not reach bedrock. Nearby, the topographic map shows two small natural depressions, evidently blow-outs between dunes.

The sand grades rapidly eastward into silt. The Shawneetown Hills are almost entirely mantled with loess. Many roadcuts reveal 10 to 15 feet of silt that does not reach bedrock. Similar or greater thicknesses cover the western end of Gold Hill and the hills to the south (where not disrupted by strip mining). Loess thins eastward on Gold Hill; ravines contain sufficient bedrock exposures to map structure. Westward, and in the southern foothills, hogbacks and fault-slice ridges retain their characteristic form, but the bedrock is buried.

Loesses in the study area include the Loveland Silt of Illinoian age and the Roxanna Silt and Peoria Loess of Wisconsinan age. The first two silts, more thoroughly weathered, are reddish-brown; the third is grayish-brown or yellowish-brown. Most of the loess we observed appears to be Peoria Loess. Older, reddish silts underlying Peoria Loess can be seen in a few roadcuts and strip mines, but we made no effort to distinguish the various loesses in mapping.

Alluvium

Materials mapped as alluvium range from coarse, unsorted rock debris in ravines to fine silt and clay on the modern Ohio River flood plain. Most of these deposits probably are of Holocene age, but some may date from earlier in the Pleistocene.

Distinguishing between alluvium and lacustrine sediments is difficult in the field: any mapped boundary would be quite arbitrary. As noted previously, most lake sediments are covered by at least a veneer of Holocene alluvium. Furthermore, the materials left by Lake Saline were brought there by streams, so lacustrine and alluvial sediments must intergrade and interfinger. We have avoided the problem by not distinguishing alluvium from lake deposits on plate 1a.

Talus and colluvium

Talus and colluvium are found on all slopes in the study area except those covered with thick loess or aeolian sand. These materials were not mapped, even though they hide large areas of bedrock and locally make significant landforms. Some talus/colluvium at the foot of escarpments on Cave, Wildcat, and Gold Hills may be 100 feet or thicker. They form cones, or coalescing fans, deeply dissected by modern ravines. Beneath cliffs of Caseyville sandstone, huge blocks up to the size of a house commonly have detached themselves and slid many hundreds of feet from their original positions. These can be mistaken for outcrops, and mapped as such, if the surrounding area is not thoroughly scouted.

Surface mines

All areas in which the land has been disturbed by surface mining or quarrying are designated on plate 1a. Mines are shown regardless of the degree of reclamation (if any). The boundaries of mines were taken from company maps, when available; otherwise, they were mapped on the basis of aerial photographs and field inspection.

Plate 1a also shows the entrances of active and abandoned coal mines observed in the field. This mapping is not comprehensive, because time has erased traces of many old mines. The most complete references for coal mining (including mined-out areas) are given in the Illinois Coal Mines series published by the ISGS.

IGNEOUS ROCKS

Intrusive bodies of ultrabasic igneous rock have been encountered in an underground coal mine and in drill holes in our area of interest (plate 2). No surface exposures are known in the study area. The igneous bodies include several dikes, one sill, and several rocks of unknown form and extent. These intrusives are part of a system that covers large portions of Gallatin, Saline, Hardin, and Williamson Counties, Illinois, and Caldwell, Crittenden, and Livingston Counties, Kentucky. The rocks have been described as lamprophyres and mica peridotites (Koenig, 1956). In our three quadrangles they intrude rocks of Chesterian through Pennsylvanian (Carbondale and Modesto) age. Radiometric dating indicates early Permian age for the igneous rocks themselves (Zartman et al., 1967).

Igneous dikes, and the system as a whole, trend northerly to northwesterly. The magma intruded along fractures in the Cottage Grove Fault System and other faults that have the proper orientation. Sills appear to be offshoots of dikes, following weak zones of shale (Howard Schwalb, personal communication, 1983).

Four dikes are mapped on plate 1a. The one near Cottage Grove (Sec. 10, T. 9S., R. 7E., Rudement Quadrangle) and one of two near Equality (Sec. 4 and 9, T. 9S., R. 8E., Equality Quadrangle) are plotted from very closely-spaced holes drilled by a coal company for the express purpose of delineating the intrusions. The dike at Cottage Grove is at least 500 feet long but no more than a few tens of feet wide. It is virtually straight, trending N 20° W. When projected, it very nearly lines up with a dike that was encountered in an underground coal mine three miles to the north. We obtained a core sample of peridotite from this dike, and submitted it to Geochron Laboratories, Cambridge, Massachusetts, for potassium-argon age determination. Geochron returned an age of 261 ± 9 million years, a result that closely agrees with ages reported by Zartman et al. (1967) for intrusive rocks southeast of our study area.

The dike north of Equality is more than 4,000 feet long and bears N 10^{o} W. Like the Cottage Grove dike, this intrusion is only a few tens of feet wide. No samples were obtained, and no data on possible extensions of the dike are available. A second dike was penetrated by several coal-test borings about one mile east-southeast of the first dike. Logs of the holes indicated that coal close to the igneous body had been coked. Such contact metamorphism has been widely observed in coal mines (Clegg, 1955).

The fourth dike, the easternmost such intrusion in Gallatin County, was struck during mining at the B. and W. Coal Company Mine (Sec. 13, T. 9S., R. 9E., Equality Quadrangle). A coal company official mentioned the dike to Jack A. Simon (ISGS, unpublished field notes, 1962) and stated that the heating value of the coal close to the intrusion was abnormally high. The mine map indicates that the dike lies along a fault with 4 feet of offset and strikes N 10^{o} E. The fault/dike is immediately west of the Ridgway Fault, a north-trending segment of the Wabash Valley Fault System.

An oil-test hole in Section 23, T. 9S., R. 7E., Rudement Quadrangle, penetrated 60 feet of peridotite at the horizon of the Fraileys Shale, Golconda Group (Chesterian). The section was expanded by the thickness of the igneous rock, indicating that the intrusion is a sill. Near the location of the well, we observed a north-northwest-trending fault on the highwall of an abandoned strip mine, but no igneous rock accompanies the fault to the surface.

Two other deep borings in our area have encountered igneous rock. Intrusions of unknown form invade the Waltersburg Sandstone and Golconda Group in a well in Section 13, T. 9S., R. 7E., Rudement Qudrangle. This well is about 1/2 mile south of the Cottage Grove master fault. Within the Shawneetown Fault System in Section 31, T. 9S., R. 8E., Equality Quadrangle, another well penetrated numerous bodies of igneous rock. The log of this well, unfortunately, is rather questionable, and the stratigraphic section considerably disrupted by faulting.

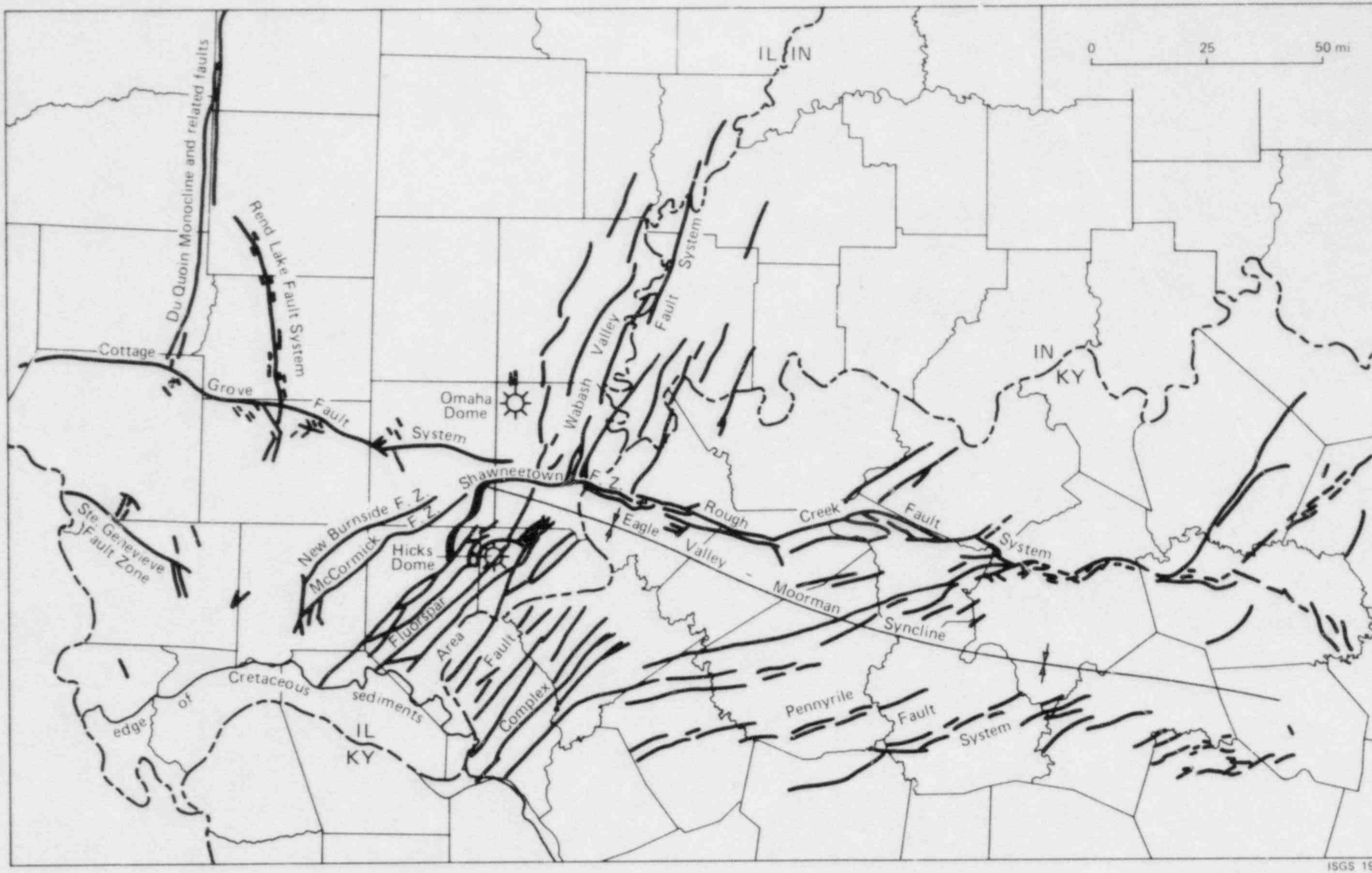


FIGURE 9. Structural features of southern Illinois, southwestern Indiana, and western Kentucky.

STRUCTURAL GEOLOGY

ROUGH CREEK-SHAWNEETOWN FAULT SYSTEM

The Rough Creek-Shawneetown Fault System (fig. 9) is a continuous and integral structure; however, this fact was not always recognized. Disjointed terminology arose because early geologists, working in different regions, thought they were dealing with separate structures.

Faults were first observed near the Ohio River in Illinois and Union County, Kentucky. The name "Shawneetown Fault" originated with David Dale Owen (1856). Brokaw (1916) and others later called it the "Gold Hill Fault," but Butts (1925) reverted to the older usage. This subsequently was modified to Shawneetown Fault Zone, reflecting the compound nature of the break. Meanwhile, other geologists mapped structural dislocations, variously interpreted as an anticline or a fault zone, near the eastern end of the system in Ohio and Grayson Counties, Kentucky. Charles J. Norwood (1876) apparently was the first to apply the name "Rough Creek Anticline" to this feature. By the time the link between the Shawneetown and Rough Creek elements was established, the separate names were well fixed by long usage. Numerous variants of these names have arisen through the years. Some geologists refer to the entire system as "Rough Creek Fault Zone, System, or Lineament," but most preserve the dual nomenclature in one form or another.

In this report we will follow the current policy of the Illinois State Geological Survey, which is to apply "Rough Creek-Shawneetown Fault System" to the system as a whole, "Shawneetown Fault Zone" to the portion of the system in Illinois, and "Rough Creek Fault System" to the part in Kentucky.

Shawneetown Fault Zone

The Shawneetown Fault Zone (SFZ) extends westward about 15 miles from the Illinois-Kentucky state line to the north end of Cave Hill in the Rudement Quadrangle, where it turns sharply to a heading of S 15° W and continues another 12 miles or so to merge with the Fluorspar Area Fault Complex in northern Pope County (fig. 10). All but the southernmost 6 miles of the SFZ are included in the area of intensive study (plates 1a and 2). The segment south of the Rudement Quadrangle was mapped by Baxter, Desborough, and Shaw (1967).

The width of the SFZ varies from several tens of feet to nearly a mile and a half. One fault appears to be continuous for the full length of the zone, and because this fault generally lies at the northern or northwestern front of the zone, we call it the front fault. The front fault has the greatest vertical displacements in the SFZ - as much as 3500 feet in places. Strata south and southeast of the front fault have been uplifted; because the uplifted rocks are largely resistant Lower Pennsylvanian and Chesterian sandstones, they form a prominent fault-line scarp.

Numerous smaller secondary faults branch away from the front fault. Most of them lie south of the front fault, but a few are north of it. Many secondary faults join the front fault at both ends, but some connect only at one end (as mapped at the surface). On some secondary faults the block toward the front

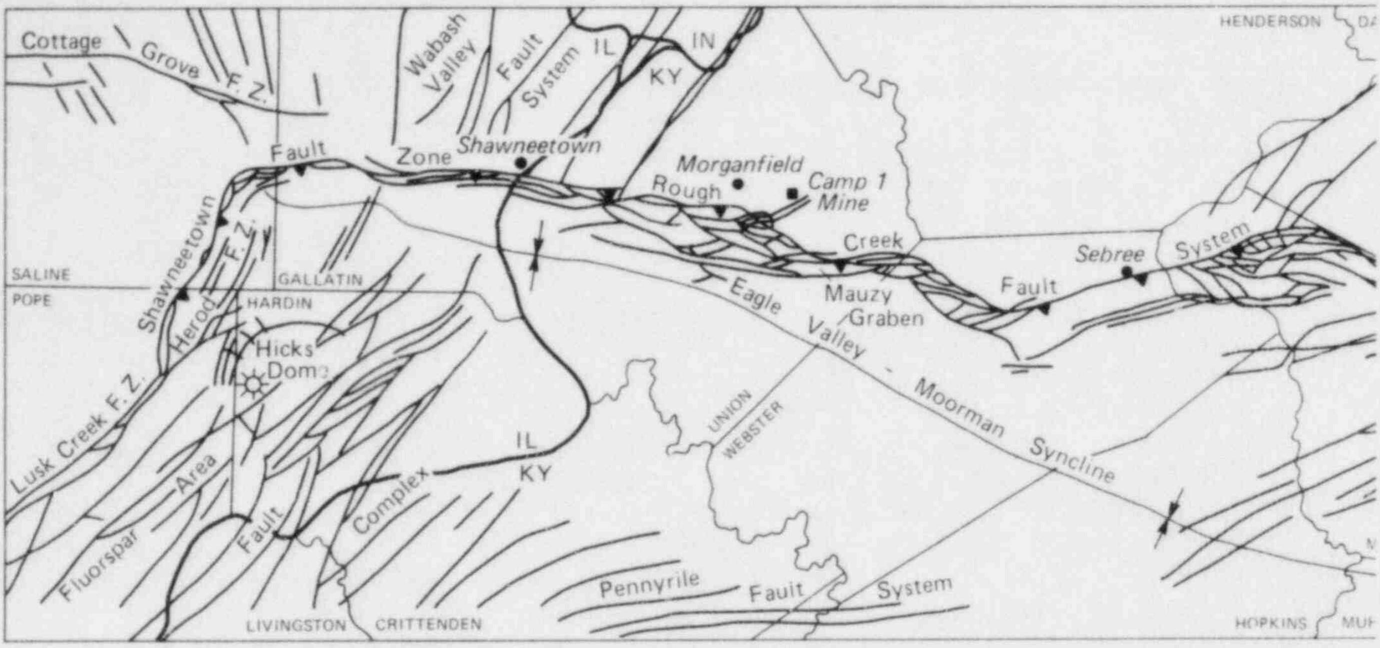


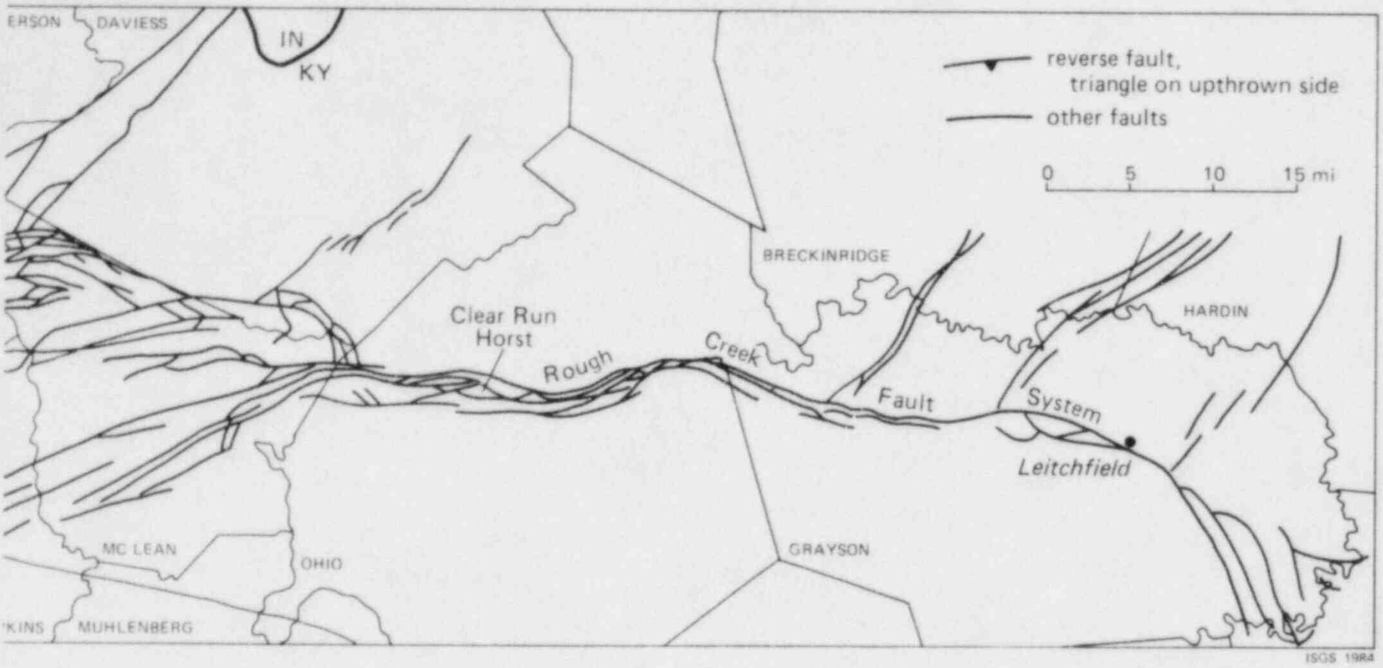
FIGURE 10. Rough Creek-Shawneetown Fault System and associated structures (adapted from Schwalb and Potter, 1978 and Treworgy, 1981).

fault is drownthrown; on others this block is upthrown. Displacements generally are in the hundreds of feet, but a few secondary faults have more than 1000 feet of offset. The front fault and the secondary faults together outline narrow blocks or slices of rock, most upthrown, but some downdropped. Almost invariably the rocks in these slices are tilted southward or southeastward, away from the front fault. The dips of bedding in these slices vary from less than 10^{0} to vertical and even overturned: most are in the range of 25^{0} to 55^{0}.

Also included in the Shawneetown Fault Zone are several detached faults south and east of the front fault and not connected with the front fault at the surface. Among these are the faults on the east side of Horton Hill, the Jones Fault (Rudement Quadrangle), and the Ringold South Fault (Shawneetown Quadrangle). Displacements range from a few tens to a few hundreds of feet, with the side away from the front fault downthrown.

Attitudes and movement of faults. All large faults and most small faults and fractures in the Shawneetown Fault Zone are vertical or steeply dipping. Only in highly deformed areas along major faults have we seen subordinate fractures inclined less than 50^{0} to the horizontal.

The front fault is marked in many places by linear, jagged, spinelike ridges ("quartzite reefs") of recrystallized and brecciated sandstone. These tabular bodies appear to be vertical or steeply dipping. Furthermore, the mapped trace of the fault is practically straight, even where it crosses highly uneven topography (plate 1a). This fact indicates that the fault zone is



nearly vertical: an inclined fault would curve as it crosses ridges and ravines.

The John C. Dunhill No. 1 Margaret Karsch well (Well 2, table 1, fig. 3) apparently penetrated the front fault at a depth of 2380 feet. The fault brought Clear Creek Chert (lower Devonian) over Caseyville or Abbott Formation (lower Pennsylvanian), signifying reverse displacement of approximately 3500 feet. The Karsch well was drilled roughly 750 feet south of the buried surface trace of the front fault. Geometric construction thereby indicates that the plane of the fault dips approximately 72° southward.

Available exposures of secondary faults all show steep dips. The fault between the Ringold and front faults, at the east end of Gold Hill, is vertical or nearly so, and subsidiary slickensided surfaces along the trend of this fault dip 55° northward. A fault displacing Caseyville sandstone and shale in the abandoned quarry immediately west of Illinois Rt. 1 and south of the Saline River dips vertically. Inclinations of 70° were measured on small faults in Caseyville sandstone on the east side of the ravine south of Negro Spring Salt Well. One-half mile north of Horton Hill, in a north-flowing ravine, a slickensided fault surface dips 58° eastward.

The traces of secondary faults run straight or display constant curvature across hilly terrain, indicating steep or vertical attitudes--as is the case for the front fault.

Most small faults and joints in the study area are vertical or nearly so. Joints typically are perpendicular to bedding and may strike parallel with adjacent faults or form orthogonal or rhomboidal patterns. Where rocks are steeply tilted, one set of joints thus may make a low angle to the horizon. Such joints may have developed before tilting, and subsequently were rotated to their present attitude. Except in intensely deformed areas, examples of low-angle fractures that clearly developed in that position are rare. Slippage along bedding planes, as indicated by gouge or slickensides, is unusual except close to large faults.

Most geologists have described the main Shawneetown Fault - our front fault - as a reverse fault inclined to the south. Our findings confirm that interpretation. The best evidence is found in the Margaret Karsch well. Additional support is provided by the fact that numerous wells, spudded short distances north of the front fault and drilled to considerable depths, did not penetrate the fault. Thus, the fault must be either nearly vertical or inclined to the south as a reverse fault close to these borings.

All secondary faults observed in the field are normal or essentially vertical. Several drill holes cut secondary faults; all are normal faults, as indicated by missing section in logs. Repeated section, diagnostic of reverse faulting, has not been reported except on the front fault.

Slickensides and mullion plunge vertically, or nearly so, down the dips of fault. Some large, complex faults bear several sets of slickensides having a variety of orientations, but vertical ones are most conspicuous. Drag folds also indicate dip-slip; their axes are horizontal and strike parallel with adjacent faults. Good examples of drag flexures can be found at the Horseshoe Quarry. Had strike-slip faulting taken place, fold axes should strike obliquely to the faults and plunge vertically.

The tilted strata in the fault slices of the Shawneetown Fault Zone (SFZ) also strike parallel with the faults in most cases, further indicating primarily vertical, dip-slip displacements.

Magnitude of displacement. The front fault has the largest displacements in the SFZ. At the Horseshoe Quarry it juxtaposes Ft. Payne/New Albany strata with Caseyville Sandstone, for a stratigraphic separation of roughly 3100 feet. In the Margaret Karsch well the offset is 3500 feet, with Lower Devonian rocks faulted against lower Pennsylvanian. The front fault has about 2100 feet of throw at the abandoned strip mine in NW 1/4 NW 1/4, Section 4, T. 10S., R. 7E., Rudement Quadrangle, where Davis and Dekoven Coals of the Spoon Formation are found in fault contact with Lower Chesterian limestone. Elsewhere, the front fault shows from 700 to 2500 feet of vertical offset.

Most secondary faults have 100 to 800 feet of throw. The largest offsets occur in complexly faulted areas north and northwest of Cave Hill, where the SFZ bends from a westerly to a south-southwesterly heading.

Casual inspection of the SFZ as a whole gives the impression that the southern block is upthrown. Certainly the escarpment of Caseyville sandstone, on the upturned rim of the Eagle Valley Syncline, stands higher than its buried counterpart north and west of the SFZ. The difference in elevation is 1400 to 1700 feet along Gold Hill, about 1300 feet in the Wildcat Hills, 1500 feet at Cave Hill, and roughly 500 feet at Bald Knob. We took these measurements from points directly facing each other across the complex, interconnected fractures that make up the main part of the Shawneetown Fault Zone (SFZ); we ignored detached secondary faults such as the Ringold South and Jones Faults.

However, if the reference points are moved about 2 miles away from the actual fracture zone, eliminating the influence of the upwarped limb of the Eagle Valley Syncline and of local deformation in the immediate fault zone, the large offset disappears. Strata lie at the same, or lower, elevation in the Eagle Valley Syncline as they do 2 or 3 miles north of the SFZ. The cross-sections shown in plate 1b illustrate this point clearly. In the eastern Shawneetown Quadrangle, strata are higher north of the fault zone than to the south. Cross-section C-C' shows the Springfield Coal 150 feet above sea level north of the front fault and 250 feet below sea level south of the Ringold South Fault. The coal continues to drop in elevation southward, to 700 feet below sea level along the axis of the Eagle Valley Syncline.

Thus, we see that the great vertical offsets in the SFZ took place within the zone rather than across it. Individual faults have very large displacements, bringing slices and blocks far from (usually above) their original positions, but the rocks north and south of the fault zone show little or no relative uplift.

Nature of deformation. Rocks within and adjacent to the Shawneetown Fault Zone display a wide range of deformational structures, ranging from widely-spaced simple fractures to intense brecciation, mylonitization, and recrystallization. Most of the rocks fail because they are brittle; however, incompetent shales, coals, and claystones may exhibit ductile behavior.

Rocks adjacent to the front fault and other large faults are steeply dipping. Dips measured in the Ft. Payne siliceous limestone at the Horseshoe Quarry range from 42^{0} south to vertical. The New Albany black shale in the same quarry, immediately adjacent to the front fault, dips 80^{0}S to 80^{0}N (overturned). Vertical beds of Chesterian limestone and sandstone can be observed on the north side of the stream just east of the abandoned strip mine in the N 1/2 SE 1/4 NW 1/4 NW 1/4, Section 3, T. 10S., R. 7E., Rudement Quadrangle. In the abandoned quarry just west of the new Rt. 1 and south of the Saline River, NE 1/4 NW 1/4 NE 1/4, Section 35, T. 9S., R. 8E., thick-bedded Caseyville sandstone dips 65 to 70^{0} south, but crossbedding and small unconformities indicate that the beds are overturned. These dips rapidly diminish south and west of the faults. Few complete exposures are available to show whether the change in dip was accomplished by folding or by faulting and rotation of blocks, but in most cases the latter process appears to have dominated. Where folds can be observed in the surface rocks, they are generally broad and gradual. These Pennsylvanian and Chesterian sandstones evidently could not accommodate much ductile deformation. Even on the gentle flexures, the sandstones tend to be conspicuously fractured.

Fractures are prevalent in the fault zone and have many orientations (plate 1a). They occur in all hard lithologies but are most prominent in sandstone and limestone. Generally the major set of fractures strikes parallel to the strike of bedding, and a secondary set trends approximately parallel with dip. These orientations, in turn, are parallel and perpendicular to nearby faults and/or to the SFZ as a whole. Less commonly, fractures trend obliquely to strike of beds and to faults. In steeply-tilted blocks and fault slices, rhomboidal jointing may be developed. Three or more sets of fractures may occur in intensely deformed areas, as in the Ft. Payne and New Albany exposures in the quarry at Horseshoe.

Shattered or brecciated sandstone commonly is found in major fault zones, especially along the front fault. The trace of the front fault in places is marked by jagged spine-like ridges of brecciated sandstone, similar to the "quartzite reefs" found along major faults in the Fluorspar Area Fault Complex (Weller et al., 1920). Such sandstone is so totally recrystallized that it resembles a metamorphic quartzite in hand specimen.

Severely sheared and contorted coal and shale have been observed along large faults in a few localities, notably in the abandoned quarry on the west side of Illinois Route 1 just south of the Saline River, and in the gully at the south end of the strip mine in Section 3, T. 10S., R. 7E., Rudement Quadrangle. A ravine near Level Hill Cemetary (SE 1/4 SW 1/4 NE 1/4, Sec. 36, T. 9S., R. 8E., Equality Quadrangle), reveals claylike gouge mixed with fine particles of coal and sandstone.

Fractures and fault breccias often are mineralized, normally with white calcite in limestone and with silica in sandstone. Small amounts of fluorite, barite, and metal sulfide appear in brecciated rock along the front fault from Stone Face southward. The fact that most fault zones are fully "healed" by mineral deposits suggests that recent movements have not taken place along the fractures.

Regional structure of the Shawneetown Fault Zone. In the Shawneetown Quadrangle the Shawneetown Fault Zone (SFZ) consists of several west-trending subparallel, branching faults outlining a zone 0.7 to 1.4 miles wide (plates 1a and 2). These faults separate a series of upthrown blocks, all tilted southward (sec. C-C', fig. 12; plates 1b and 2). Strata north of the fault zone dip gently northeastward and are broken by faults of the Wabash Valley Fault System. South of the SFZ, rocks dip southward and southeastward into the Eagle Valley syncline.

The SFZ is considerably narrower in the Equality Quadrangle than in the Shawneetown Quadrangle. It is about 1/2 mile wide at most, and less than 1/4 mile in some places. The zone is mapped as a single fault in the western part of the quadrangle, where the structure is hidden by surficial materials and drilling is sparse.

The SFZ attains its greatest complexity and magnitude of displacement in the section from Horseshoe to Cave Hill, where the zone curves from a westerly to a south-southwesterly heading. From the NE 1/4, Section 9, T. 10S., R. 7E., southward to the edge of the quadrangle, the fault zone is narrow and the throw steadily diminishes.

At Horseshoe the SFZ is about 1/2 mile wide and comprises at least five faults that define narrow upthrown slices. The blocks in the center of the zone are relatively the most uplifted (sec. A-A', fig. 11; plate 1b). The southernmost fault of the zone is the only one directly visible in outcrop. Its plane, as exposed on the steep slope just west of the road at the north

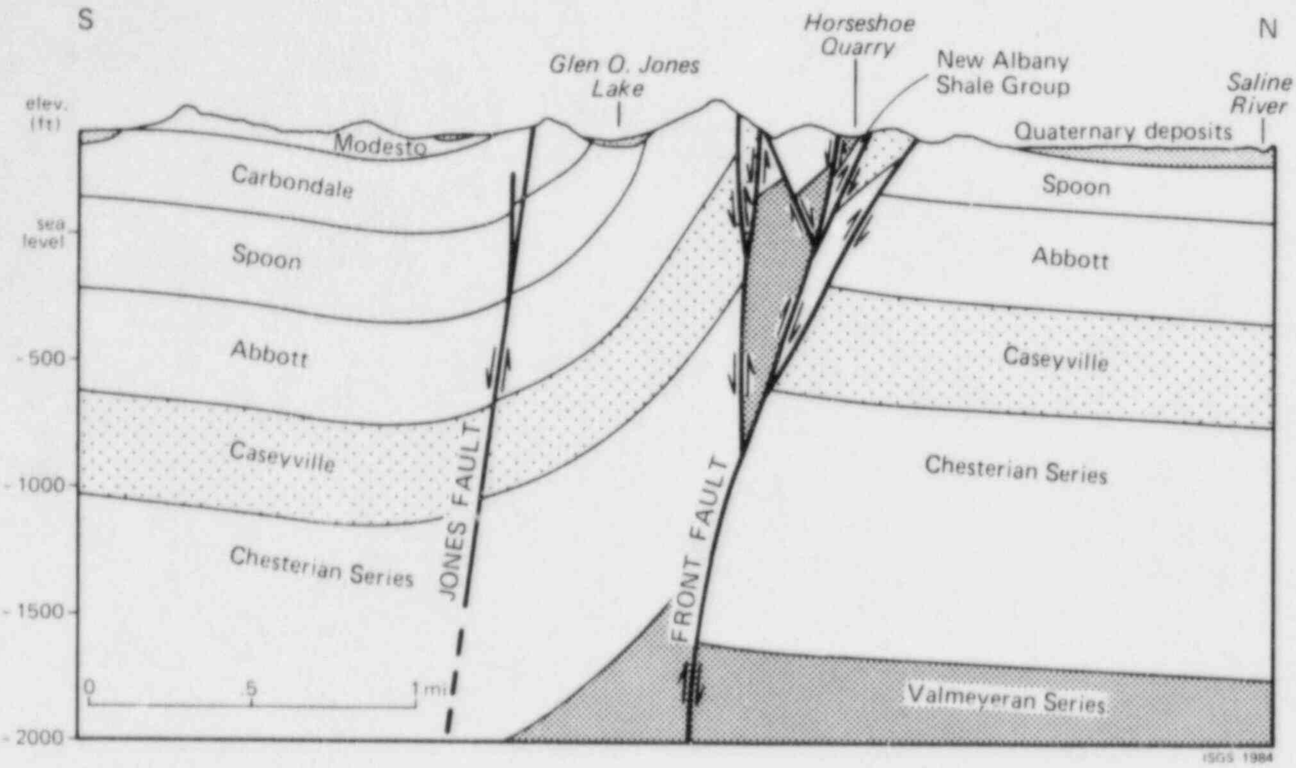


FIGURE 11. Cross section of Shawneetown Fault Zone along Saline-Gallatin County line (see Section A-A', plate 1b).

end of Horseshoe Gap, is essentially vertical. The fault brings steeply dipping, brecciated Caseyville sandstone on the north against fractured but gently dipping Abbott sandstone on the south.

A complex braided pattern of faults characterizes the SFZ near Sulphur Springs Church. Faults outline slices of Chesterian and lower Pennsylvanian rocks that dip at angles ranging from 10^{0} to vertical. Bedding generally strikes parallel with the long axes of fault slices which, in turn, are more or less parallel with the overall trend of the fault zone. Exceptions do occur: in the small triangular block southeast of Sulphur Springs Church, Palestine and Menard strata strike perpendicular to the major faults nearby.

The actual structural pattern undoubtedly is more complicated than we have mapped. Outcrops are rare among the talus and colluvium of Caseyville sandstone from the cliffs atop Cave Hill, and stratigraphic identification of units in narrow fault slices is highly problematic. In particular, the area mapped as undifferentiated Chesterian rocks in Sections 3 and 4 contains many faults having a variety of orientations; these faults are too closely spaced and complicated to map at the scale used for plate I.

South of Section 9 the SFZ apparently consists of a single fault (the front fault), or at most, a narrow fault zone. Strata east of the fault are upturned, generally juxtaposing Caseyville and uppermost Chesterian rocks on the east with Abbott Formation on the west. Incomplete exposures in ravines suggest that the zone of intensely deformed rock varies from several tens to more than 100 feet wide.

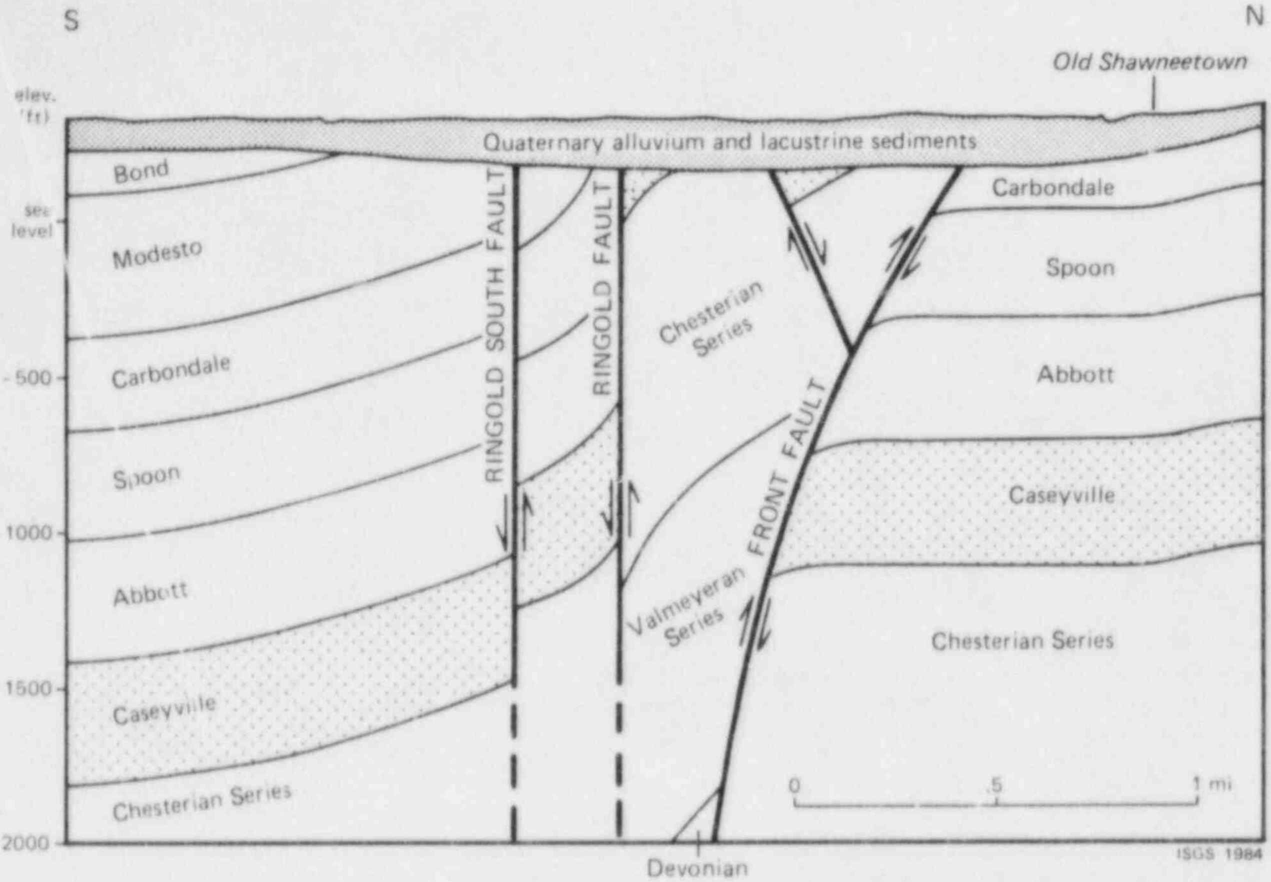


FIGURE 12. Cross section of Shawneetown Fault Zone just west of Ohio River (see section C-C', plate 1b).

The fault zone widens in Section 21, T. 10S., R. 7E., splitting a pronounced anticline along its crest. Butts (1925) mapped this as the "Shawneetown Anticline" and showed the fault as dying out about 1/2 mile north of Bald Knob; however, we have found the fault zone to be continuous. The anticline is not quite symmetrical: strata dip as steeply as 60^{o} on the west limb and 40^{o} on the east limb; dips rapidly diminish away from the faulted axis on both limbs. Along the axial crest are thoroughly fractured, steeply tilted Chesterian strata that cannot be identified as to formation. Relative vertical offset across the axial fault zone is slight, possibly less than 100 feet: to the north, Caseyville Formation is faulted against Kinkaid Limestone; to the south, Kinkaid Limestone butts against Clore and Degonia Formations.

This little area, perhaps more than any other, reveals movement within the fault zone, rather than relative offsetting of blocks on opposite sides, as characteristic of the Shawneetown Fault Zone (sec. D-D', plate 2). In simplest terms, a narrow, elongate slice of Mississippian rocks has punched upward through covering Pennsylvanian strata. The relative upthrow of the block east of the fault zone is negligible by comparison.

Individual faults. We considered several faults in the Shawneetown Fault Zone important enough to merit individual names, and we will describe these newly named faults and several smaller structures.

The front fault (discussed previously) was given an informal, descriptive name rather than a formal geographic one because of its apparent regional, rather than local, significance to the overall structure of the Rough Creek-Shawneetown Fault Zone.

Ringold and Ringold South Faults. These faults, which lie near the southern edge of the SFZ in eastern Gallatin County, are named, in this report, for Ringold Church in Section 4, T. 10S., R. 9E. (plate 1a). The Ringold South Fault is well-defined by drilling (sec. C-C', fig. 12; plate 1b). Its displacement decreases westward from several hundred feet at the Ohio River to zero in the W 1/2 Section 3, T. 10S., R. 9E. The Ringold Fault is not as well-delineated as the Ringold South Fault; however, large differences in elevation of key beds between outcrops and drill holes suggest the presence of a fault or a very sharp flexure, having about 500 feet of downthrow to the south, and running the length of Gold Hill. The Ringold Fault may link with the Level Hill Fault westward in the Equality Quadrangle. Eastward, the Ringold and Ringold South Faults link with faults mapped by Palmer (1976) in the Grove Center, Kentucky Quadrangle.

Level Hill Fault. South of, and subparallel with the front fault in the Equality Quadrangle (sec. B-B', fig. 13; plates 1a, 1b, and 2), this fault is named, in this report, for the Level Hill Cemetery (SE 1/4 NE 1/4 SE 1/4, Sec. 36, T. 9S., R. 8E). This fault can be followed through numerous outcrops westward from its type locality as far as the SE 1/4 SE 1/4, Section 29, where it joins the front fault. The Level Hill Fault may link eastward with the Ringold Fault, beneath the Maumee flood deposits.

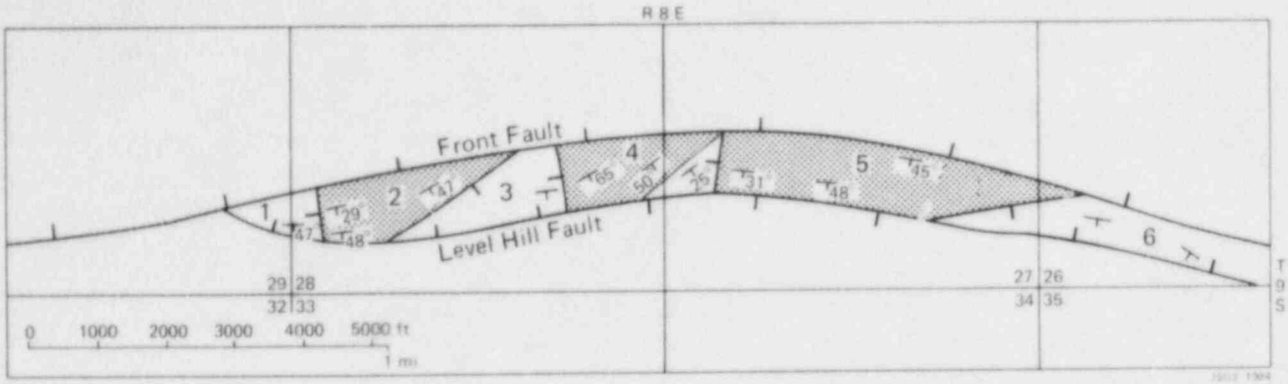


FIGURE 13. Structure of fault slices in Shawneetown Fault Zone, central Equality Quadrangle. Shaded blocks are upthrown, blank blocks downthrown. Numbers in blocks are referred to in text.

Numerous cross-faults connect the front fault with the Level Hill Fault. Some of these are perpendicular with the front fault, and others are oblique. Outlined by the cross-faults are rectangular and triangular slices, inclined southward at 25 to 65 degrees. Upthrown slices bring Mississippian rocks to the surface, juxtaposing them with Caseyville rocks in downthrown blocks. Figure 13 illustrates the relative movements of the blocks. Blocks 1, 3, 6, and the southeastern corner of 4 are downthrown, while 2, 5, and the northwestern part of 4 are upthrown. Note that the positions of the blocks determine whether the north or the south side of the Level Hill Fault is upthrown. This suggests a complex structural history, with the small blocks rising, falling, and rotating between the two large, parallel, east-trending fracture zones.

Negro Spring Fault. This fault, in the eastern part of the Equality Quadrangle, lies north of the front fault and is named, in this report, for the Negro Spring Salt Well in the SW 1/4 of Section 26. The Negro Spring Fault, known from subsurface data only, shows 250 to 300 feet of downthrow to the south. One well penetrated the fault zone; missing intervals of strata on the electric log indicate that the zone includes two normal faults, each with about 80 feet of vertical offset, and possibly several smaller normal faults. The Negro Spring Fault dies out westward and probably links with the front fault eastward.

Jones Fault. Named, in this report, for Glen O. Jones Lake, this fault trends northeastward from the NW 1/4 of Section 11 to the NE 1/4 of Section 1, T. 10S., R. 7E., Rudement Quadrangle, and then turns eastward into the Equality Quadrangle, where it dies out. High-angle fractures and abrupt changes in elevation of coals in abandoned strip mines reveal the Jones Fault on the north side of Wiedeman Hollow (Section 11). Sandstone in the road to the abandoned farm in the SW 1/4 NE 1/4 SE 1/4, Section 2, dips 43^{0} southeast, contrasting with the general dip of 15^{0} to 20^{0} in the vicinity. Drill holes show downthrow of 100 feet or more, to the southeast; the log of one hole showed a jumbled stratigraphic section, with several missing intervals. The Jones Fault apparently is a compound zone of dislocation--a sharp faulted flexure.

Other faults. A fault immediately north of the front fault is mapped on the basis of a single drill hole in the NE 1/4 of Sec. 33 (plates 1a and 2). The well, National Associated Petroleum Co. 1 Max Galt, from bottom of surface casing to a depth of about 400 feet, penetrated red-brown shale and siltstone along with light tan to buff, lithographic, dolomitic limestone. Elwood Atherton (1983, personal communication) examined the cuttings and interpreted them as upper Pennsylvanian--perhaps the West Franklin Limestone Member of the Modesto Formation. The abnormal thickness (about 150 feet) of the limestone suggests steep, possibly near-vertical attitude of the fault slice. Below 400 feet the drill entered a normal section of middle and lower Pennsylvanian and Chesterian (upper Mississippian) rocks. The fact that the well, located less than 500 feet north of the front fault, did not pass through that fault, indicates that its plane either is nearly vertical or dips southward as a reverse fault.

Three secondary faults, which apparently branch away from the front fault, have been mapped on Gold Hill. The north side of each fault is downthrown. The two eastern faults are visible in surface exposures; their planes are steeply dipping, almost vertical. The most accessible exposure is in the narrow east-flowing ravine at the center of the SW 1/4, Section 36, T. 9S., R. 9E., where highly fractured sandstone can be seen. Both are seen to die out westward and increase in throw eastward as they converge with the front fault. The westernmost fault is not exposed, but its presence is indicated by the attitude and elevation of Caseyville sandstone in the NE 1/4 NE 1/4 SW 1/4 and SE 1/4 SW 1/4 NW 1/4, Section 33, T. 9S., R. 9E. Continuation of this fault (to the SW 1/4 SW 1/4 of Sec. 32) is suggested by the hogback form of loess-covered foothills and valleys on the northwest corner of Gold Hill.

A deep cut on a private road at the summit of Gold Hill, NE 1/4 NW 1/4 SE 1/4, Section 32, exposes 9 feet of Peoria Loess overlying 10 feet of reddish-brown Loveland or Roxanna Silt. The loess bank is directly in line with a fault offsetting Caseyville and Chesterian rocks on the north face of the hill. No sign of tectonic disburbance is visible in the loess.

Offset in the outcrop of lower Pennsylvanian sandstones suggests the presence of a north-trending fault beneath the alluvial fill in Horseshoe Gap. The Caseyville-Abbott contact is approximately 700 feet farther south on the east side of the gap than on the west side, although the strata have nearly the same attitude (dip 13^{0} to 18^{0} south) on both sides. Either a right-lateral fault, or a dip-slip fault with the west side downdropped, is indicated.

Fractured, easily eroded rock along a fault may partly explain the existence of the gap.

Faults mapped near Horton Hill (Sec. 21, 20, T. 10S., R. 7E.), may connect with faults shown by Baxter, Desborough and Shaw (1967) in the Herod Quadrangle. The best exposed fault can be seen in the bed of the north-flowing tributary ravine near the center of the SE 1/4, Section 21. It is a normal fault with vertical slickensides; the east side is downthrown a few tens of feet. Accompanying the fault are numerous parallel vertical fractures. Despite excellent exposures, the fault does not appear in the north wall of the east-flowing ravine 1/4 mile north. However, a sharp flexure in Abbott sandstone, a mile to the north in Dennison Hollow, is in line with, and may be related to, the fault seen in the north-flowing gully.

A northwest-striking fault (about 1/2 mile north of Horton Hill) is inferred from locally intense fractures and steep dips observed in outcrops. This fault, if it actually exists, has little displacement. Baxter, Desborough, and Shaw (1967) mapped several faults as projecting from the Herod Quadrangle into the Rudement Quadrangle, but we could not locate evidence for these faults in the Rudement Quadrangle.

Eagle Valley Syncline. The Eagle Valley Syncline (EVS) lies immediately south of the Shawneetown Fault Zone in Illinois (fig. 10). The elongate trough trends east, is about 15 miles long, and is roughly 5 to 8 miles wide (sec. A-A', B-B', C-C', plate 1b). The upturned northern and western limbs are truncated by the Shawneetown Fault Zone. In the Rudement and Quality Quadrangles the gentle southern limb runs parallel with the northern limb, but eastward into the Shawneetown Quadrangle and Kentucky, the southern limb turns east-southeastward and the syncline abruptly deepens and widens. The EVS actually is a narrow extension of the broad Moorman Syncline of Kentucky.

Butts (1925) mapped the EVS as a relatively simple fold that becomes steadily deeper and wider eastward. His map shows a gentle (5^0) south limb and a steeper (20^0) north flank, both with uniform dips, and a broad, flat axial trough, with no significant discontinuities except for the Grindstaff and Saline River Faults. Our map (plate 2), based on thousands of data points not available to Butts, reveals many interesting irregularities in the syncline.

Inclination of the south limb is rather uniform, except where faults are present. (These faults will be discussed in the section on the Fluorspar Area Fault Complex.) Near the southern edge of the Rudement and Equality Quadrangles, the strata dip northward at about 10 feet per 100 (6^0). This dip flattens out gradually toward the synclinal axis. Eastward, in the southeastern Equality and southwestern Shawneetown Quadrangles, the pitch of the beds increases to an average of 8^0 or 9^0. Precise structural attitudes are difficult to obtain because the outcropping Lower Pennsylvanian sandstone tends to be massive or have many local irregularities in the bedding.

The northern limb is, overall, considerably steeper than the southern limb; however, it would be misleading to provide an average pitch figure. Dips measured on outcrops range from horizontal to as high as 68^0 adjacent to faults. As previously noted, even steeper dips occur within fault slices near the front fault. Most readings, however, fall in the range of 10^{o} to 30^{o}. The degree of control is quite good; many exposures of planar-laminated rocks are available, and formational contacts can be identified more reliably here than on the southern flank of the fold.

Flexures. The dip on the north limb of the Eagle Valley Syncline might be expected to increase steadily as it approaches the Shawneetown Fault Zone, but such is not the case. Many local flexures large and small, and one major reversal of dip are present. A flexure is an abrupt fold, usually monoclinal, that may overlie a buried fault. The reversal can be seen in the north-facing hollow immediately south of the Shawneetown Fault Zone, near the northwest corner of Section 32, T. 9S., R. 8E., Equality Quadrangle. Near the mouth of the ravine, Battery Rock Sandstone dips northward at 5°-17°: southward the rocks assume a horizontal position, then gradually take a southward dip. The sandstone is moderately fractured, but no faults are evident. The basic structure appears to be a small, east-trending anticline (plate 2).

One of the most prominent large flexures lies southeast of the summit of Cave Hill, Section 2, T. 10S., R. 7E. (plates 1a and 2), For more than 1/2 mile southeast of the hilltop the beds are inclined regularly about 12^{o} to the southeast, but the dip increases to 20^{o} or more and then flattens out on a narrow bench immediately northwest of the Jones Fault. A similar flexure appears near the west end of Gold Hill (plates I and II), where rocks dip about 10^{o} southward in the S 1/2 of Section 33, T. 9S., R. 9E.; the dip increases to 25^{o} in the N 1/2 of Section 4, T. 10S., R. 9E., approaching the Ringold Fault. Farther east, a horizontal bench interrupts the southward pitch of the strata in the NW 1/4 NW 1/4, Section 2, T. 10S., R. 9E. (plates 1a and 2).

Small, sharp, fractured monoclines have been observed in a number of places. One in the bed of Dennison Hollow (NW 1/4 NW 1/4 SW 1/4, Sec. 15, T. 10S., R. 7E., Rudement Quadrangle) affects uppermost Caseyville or basal Abbott sandstone. Within a distance of less than 10 feet the dip increases from about 8^{o} to as steep as 25^{o}, then flattens out again. Closely-spaced high-angle fractures strike parallel with the trend of the fold, but no slickensides or other evidence of movement are apparent. This flexure is directly in line with a normal fault exposed about a mile to the south. Similar flexures occur in ravines at several places on the south slope of the Wildcat Hills. They strike east-west, range from a few feet to almost 100 feet wide, and show dips as steep as 40^{o}. Steeply-dipping to vertical parallel fractures invariably are present along flexural axes. Some flexures can be followed for 1000 feet or more, but most are seen only in single outcrops.

The distribution of flexures, their parallelism to faults, and the fracturing along them indicates that they probably overlie buried faults: rocks near the surface failed by folding rather than by shearing. They appear comparable (in small scale) to the great monoclines that overlap basement faults at the edges of uplifted blocks in the Wyoming Rockies and on the Colorado Plateau. Stearns (1978) uses the term "forced folds" for such flexures that develop above high-angle faults; he distinguishes them from the "free folds" that result from horizontal compression, where the position of the fold is not predetermined by underlying structure. Stearns argues that the basin and mountain ranges of the central Rockies are the product of direct vertical uplift.

Axial region. A series of depressions, anticlines, and saddles interrupts the central trough of the Eagle Valley Syncline. The axis of the syncline, if traced along the lowest contours of the fold, is sinuous and not parallel with the limbs of the syncline.

The western end of the EVS is a roughly oval basin whose long axis trends southeastward, southeast of the Jones Fault. The enclosed area is about a square mile and the maximum depth is at least 125 feet. Eastward from this depression extends a broad, fairly symmetrical trough (saddle). Several small anticlines, with closures of 10 to 20 feet, occur near the eastern end of the saddle in Sections 3, 4, and 10, T. 10S., R. 8E. (plate 2).

A deep and irregular depression, named, in this report, the Pisgah Syncline for the Pisgah Church (NW 1/4 SW 1/4 SE 1/4, Sec. 12, T. 10S., R. 8E.), is found in the eastern part of the Equality Quadrangle. The Pisgah Syncline is bisected by the Grindstaff Fault Zone (plate II). The axis of the western segment strikes east-west, that of the eastern segment trends east-southeast. The deepest point of the syncline is at least 300 feet below the rim (as contoured on the Springfield Coal). The Pisgah Syncline is asymmetrical, its northeastern flank steepest. The Springfield Coal rises more than 500 feet within a distance of 4000 feet (average dip 7 1/2 ^{o}) in Section 7, T. 10S., R. 9E. Butts (1925) noted this abrupt change of elevation, and attributed it to faulting. His "Saline River Fault" was mapped as extending southeastward from the Shawneetown Fault Zone across the entire EVS. Recent closely spaced coal-test drilling indicates that the Saline River Fault does not exist. The change in altitude of the coal is evenly distributed among the datum points, without any abrupt breaks. To the southeast, in Section 17, T. 10S., R. 9E., the structure becomes almost level. The Saline River Fault, with its anomalous southeasterly trend, never did fit the regional structural pattern.

The Kuykendall Anticline, named, in this publication, for Kuykendall Valley, is immediately east of the Pisgah Syncline in Sections 4, 8, and 9, T. 10S., R. 9E., Equality Quadrangle. Its axis trends eastward from the SW 1/4 NW 1/4, Section 8 to the NW 1/4 Section 9, where it curves northeastward. Maximum closure is at least 160 feet on the Springfield Coal. The crest of the anticline is irregular; the northern and northwestern flanks are steeper than the southern and southeastern flanks.

A broad saddle separates the Pisgah Syncline from the deep easternmost trough of the EVS. In this broad eastern trough, the elevation of the Springfield Coal drops as low as -700 feet. Average dips are approximately 5^{o}, but considerable local variation is seen, with sharp flexures (as in NW 1/4 SE 1/4, Sec. 10) and flat areas (NE 1/4, Sec. 22).

Rough Creek Fault System

As the eastward continuation of the Shawneetown Fault zone, the Rough Creek Fault System (RCFS) in Kentucky exhibits structure essentially the same as that of the Shawneetown Fault Zone in Illinois.

From the Ohio River, the RCFS runs eastward about 100 miles across Kentucky into Grayson County, where it dies out (fig. 10). The fault system makes numerous bends and curves along strike. The zone widens from approximately 1 mile in western Union County to about 5 miles in McLean County; eastward, the zone gradually narrows, and the displacements of the faults gradually diminish. The zone is composed of a multitude of faults that characteristically form a braided pattern on the map. This anastomosing network is similar to that seen in Illinois around the north end of Cave Hill in the Rudement Quadrangle.

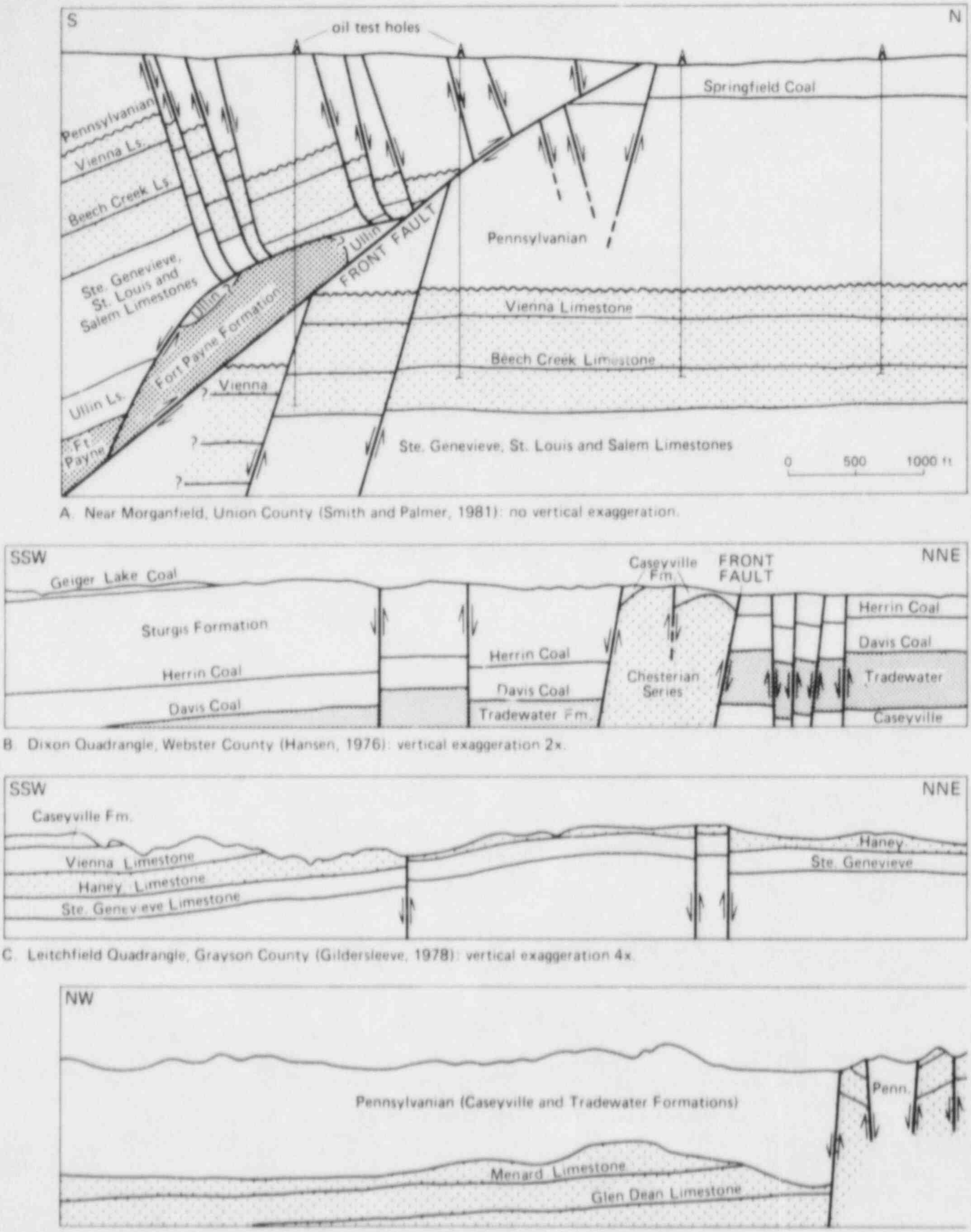
Geologic mapping and drilling show that the RCFS is composed mostly of high-angle to vertical faults. As in Illinois, there is little relative uplift of strata on either side of the system, but within the fault zone very large displacements have taken place. Cross-sections (fig. 14) show that the basic structure is either a broken arch or anticline, or a series of tilted, upthrown blocks or horsts. The zone is generally asymmetrical, with the greatest uplifts near the northern edge of the fault zone. North of the RCFS the strata generally lie flat or dip gently northward and westward toward the center of the Illinois Basin. To the south the rock layers dip southward, away from the fault system into the trough of the Moorman Syncline.

Grabens also occur in the RCFS but are less common than horsts. The most notable graben is the one containing Permian rocks in eastern Union County (Kehn, Beard, and Williamson, 1982). The existence of this graben proves that faulting took place in post-early Permian time, preserving a small remnant of the Permian rocks that elsewhere have been eroded.

From the Illinois state line at least as far east as the Calhoun Quadrangle (Johnson and Smith, 1975) in McLean County, the largest fault in the RCFS is a reverse fault (its south side upthrown) that lies near the northern boundary of the fault system. This reverse fault is equivalent to, and very likely continuous with, the front fault of the Shawneetown Fault Zone in Illinois. In most places where the inclination of this fault has been measured by drilling or other means, it is steep (65° or greater), except in the Morganfield Quadrangle, eastern Union County, where extensive oil-test drilling shows the dip of the fault to vary from 70° to as low as 25° (Smith and Palmer, 1974 and 1981). The fault strikes eastward in the western half of the quadrangle, and curves abruptly to S 50° E in the eastern half; vertical separation along the fault ranges from 660 to more than 1500 feet.

A large slice of the Ft. Payne Formation was penetrated by five separate wells along the reverse fault (fig. 14A). This slice, up to 450 feet thick, is found far above the normal position of the Ft. Payne on either side of the fault zone. The structure is reminiscent of that at the Horseshoe Quarry in Illinois, where a narrow block of Ft. Payne is found between much younger rocks in the fault zone. No single episode of reverse movement could account for the position of the slice. Smith and Palmer concluded that the overriding block must have originally moved farther north than its present position; the slice of Ft. Payne was caught in the fault zone when the overthrust block later moved back down-dip to the south.

The cross-section also indicates that the reverse fault (front fault) served as a master fault to the RCFS. The hanging-wall block is broken by numerous north-dipping normal faults that do not penetrate the reverse fault; other normal faults, most of which dip southward, offset the footwall block. Many of these fractures displace Pennsylvanian rocks but do not extend into the



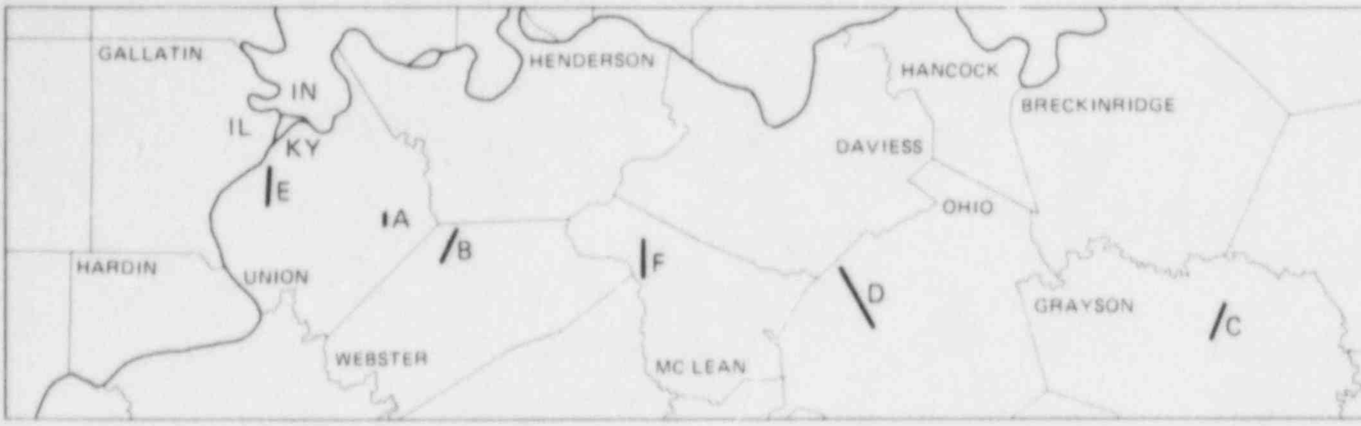
A. Near Morganfield, Union County (Smith and Palmer, 1981): no vertical exaggeration.

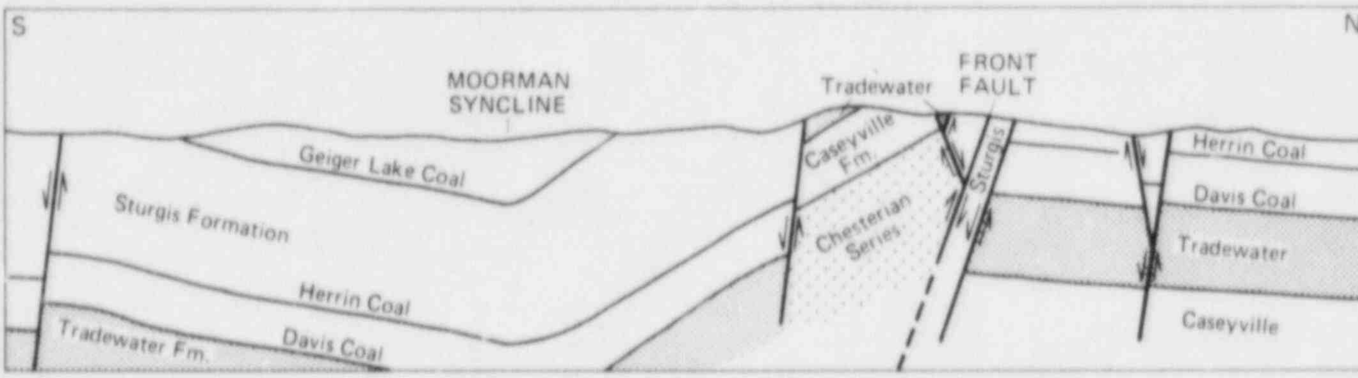
B. Dixon Quadrangle, Webster County (Hansen, 1976): vertical exaggeration 2x.

C. Leitchfield Quadrangle, Grayson County (Gildersleeve, 1978): vertical exaggeration 4x.

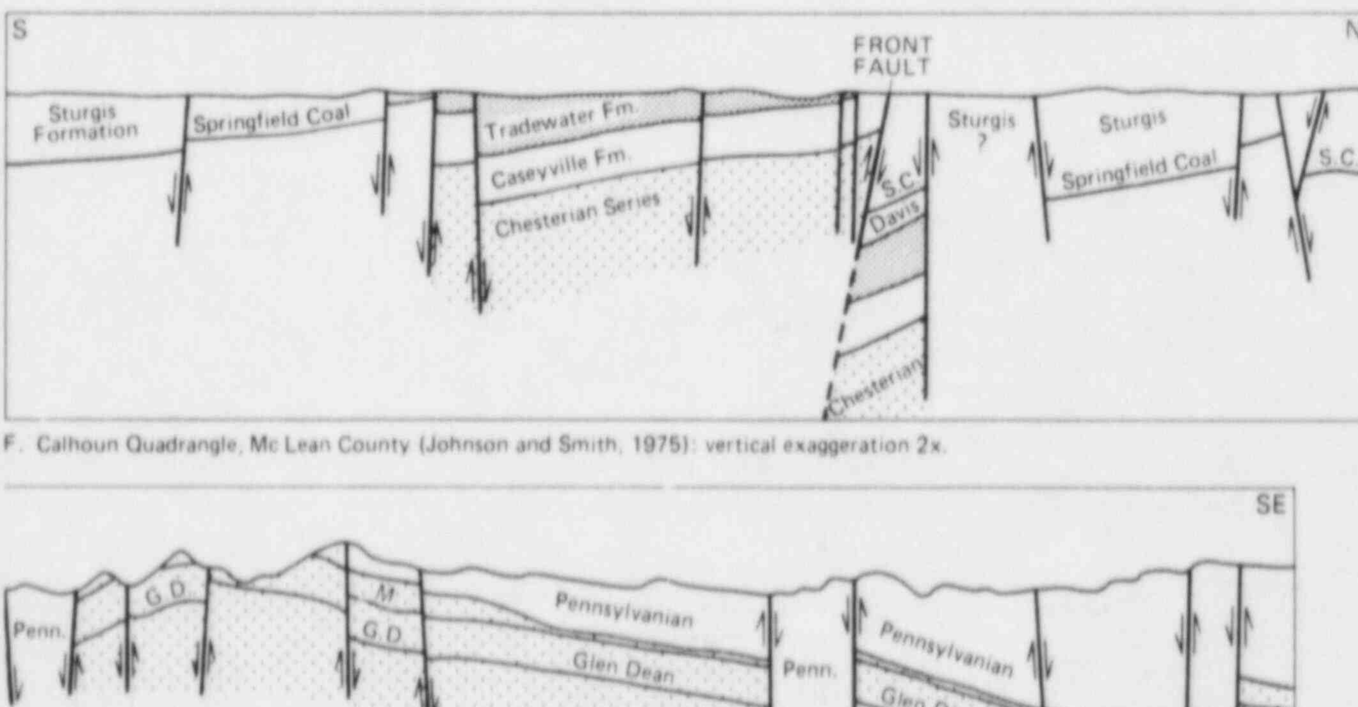
D. Pleasant Ridge Quadrangle, Ohio County (Goudarzi and Smith, 1968): vertical exaggeration 4x.

FIGURE 14. Cross sections of Rough Creek Fault System in western Kentucky.

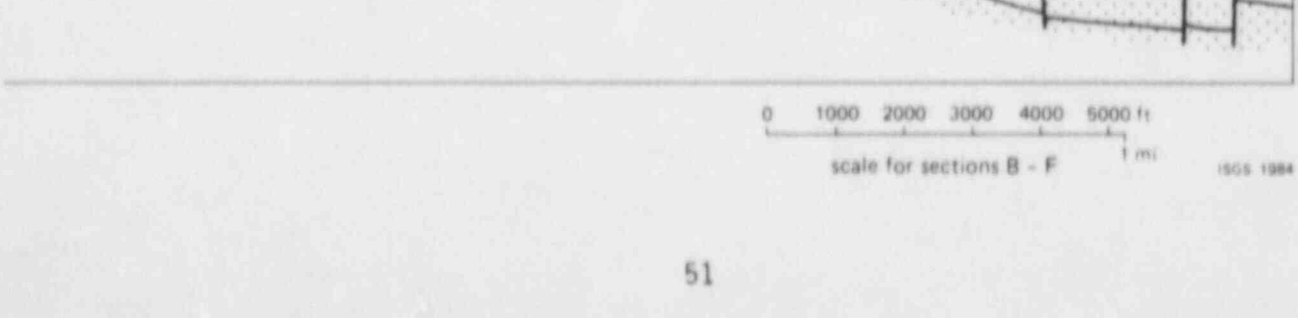




E. Grove Center Quadrangle, Union County (Palmer, 1976): vertical exaggeration 2x.



F. Calhoun Quadrangle, Mc Lean County (Johnson and Smith, 1975): vertical exaggeration 2x.



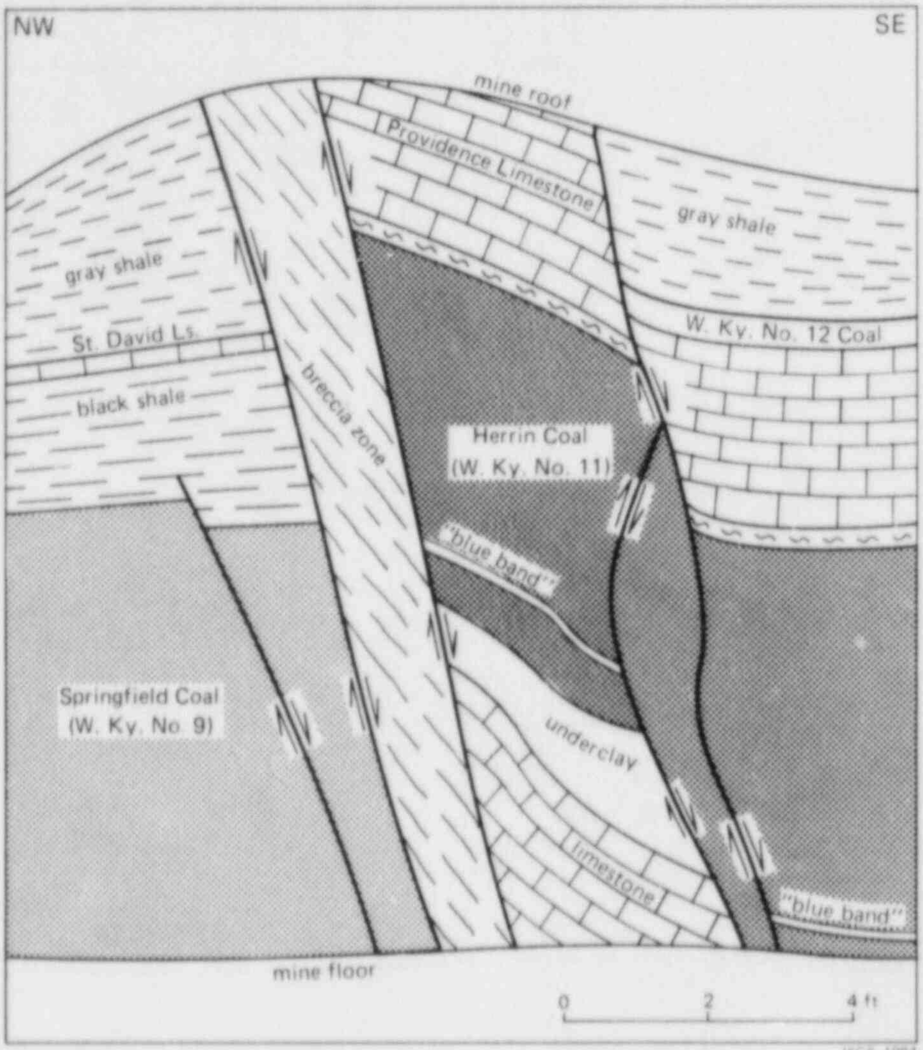


FIGURE 15. Fault exposed underground in Peabody Coal Company's Camp 1 Mine near northern edge of Rough Creek Fault System in Union County, Kentucky. An apparently simple high-angle normal fault has 120 feet of throw (the southeast side is downthrown). The fault conveniently juxtaposed two minable coal seams, allowing the company to mine directly from one to the other without having to excavate rock.

Mississippian. Smith and Palmer theorized that this "thin-skinned" faulting took place both before and during the overthrusting, as the beds near the surface were arched in response to compressional stresses.

Extensive coal-test drilling and underground mining north of the reverse fault near Morganfield bring to light many interesting structural details. Most faults apparently are simple high-angle normal faults; however, complications are evident in some cases. Figures 15 and 16 are sketches of a fault exposed in underground workings of Peabody Coal Company's Camp 1 Mine. This fault forms the northwest side of a broad graben which strikes east-northeast and branches off the north side of the front fault of the RCFS. The fault in the mine has about 120 feet of throw and juxtaposes the Herrin (West Kentucky No. 11) Coal with the Springfield (West Kentucky No. 9) Coal. Figure 15 shows an apparently simple normal fault with a thin breccia zone, narrow tilted fault slices and a slight amount of drag. Slickensides along the fault planes indicate dip-slip movement. However, another view of the same fault (fig. 16) contains contradictory indications of displacement. In the central, strongly folded fault slice, the Herrin Coal is found below its elevation on either side of the fault. Also, although the main fault is normal, there is a small, sharp reverse flexure in the Springfield Coal and its roof shale on the northwest side of the fault. Evidence for strike-slip movement is absent; the most likely explanation is that this fault experienced one or more reversals of movement during its formation.

A cross-section (fig. 17) based on drilling south of the Camp 2 Mine shows a peculiar structure. The section crosses several east-trending faults in the northern part of the RCFS. Between holes 3 and 5 in the section the Madisonville Limestone is displaced more than 100 feet down to the south along two separate faults, while the underlying coals maintain constant elevation. Farther southwest, between holes 7 and 8, the limestone remains level, but the coals are faulted. Apparently, the fault zone becomes horizontal and follows bedding planes through holes 5, 6, and 7. This pattern is reminiscent of large-scale slump features and suggests that the Madisonville Limestone was displaced by earth movements that were triggered by tectonic movements during sedimentation. The same cross-section also illustrates a peculiar situation in borehole 6. In this hole the Herrin Coal was found at nearly the same elevation as in adjacent holes, but the Springfield and West Kentucky No. 10 Coals, highly persistent in this area, were replaced by a jumbled stratigraphic section in which no marker beds could be recognized. This may represent additional faulting or paleoslumping that occurred before the Herrin Coal was deposited.

The best exposure of the Rough Creek Fault System is in a roadcut at milepost 53 on the Green River Parkway, about 15 miles southeast of Owensboro, Ohio County, Kentucky. The roadcut reveals only part of the fault zone, which is roughly 3 miles wide and composed of high-angle faults forming a braided pattern in map view (Goudarzi and Smith, 1968). Pennsylvanian rocks of the Caseyville and Tradewater (Abbott) Formations flank the RCFS to north and south, and they dip gently away from the zone (fig. 14, sec. E). Within the RCFS, blocks of Pennsylvanian and Chesterian rocks define a complexly faulted anticline or series of tilted horsts. Krausse, Nelson, and Schwalb (1979) applied the name Clear Run Horst to the uplifted block visible in the roadcut.

Figure 18, the east wall of the roadcut, is a simplified version of a detailed series of drawings by Krausse, Nelson, and Schwalb (1979). At the core of the

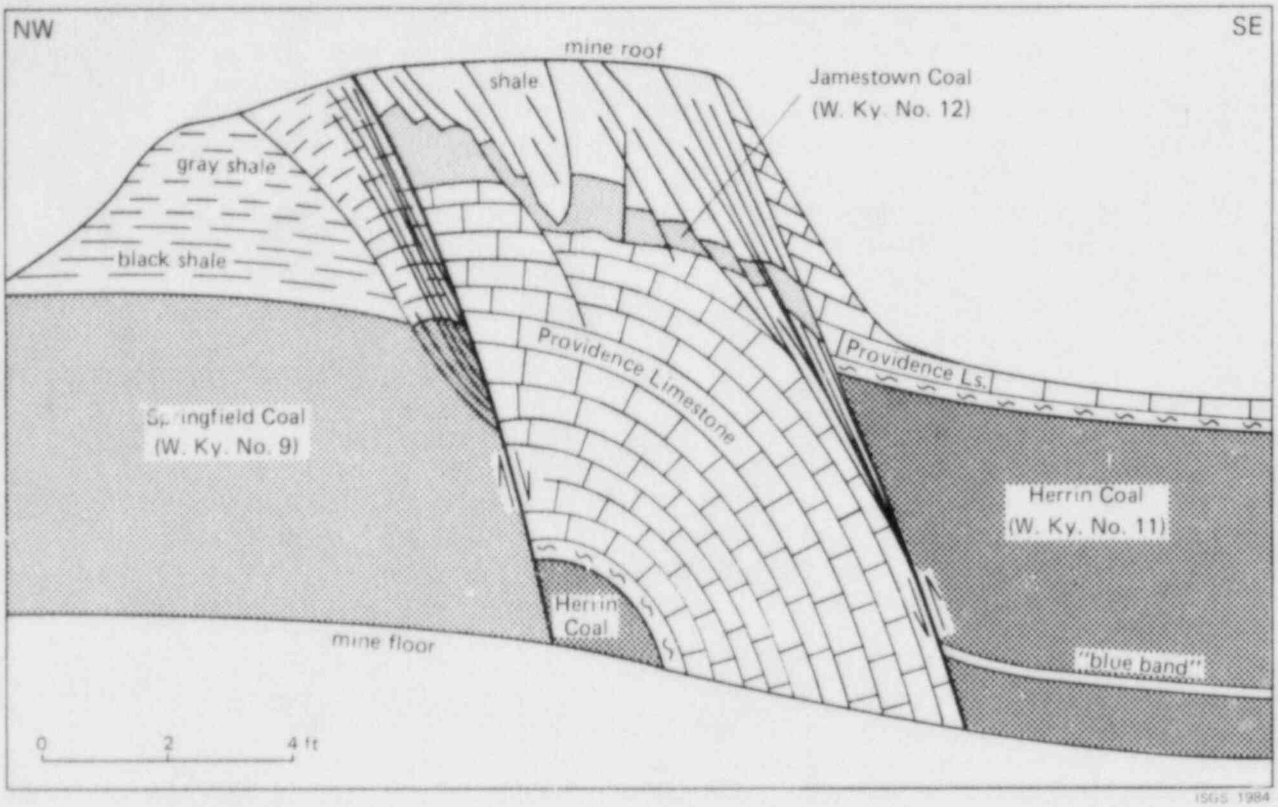


FIGURE 16. View of same fault as in figure 15, on an adjacent heading in the mine; here the structural situation is more complicated. Although the overall displacement is normal, the central slice of the fault zone is dropped below its level on either side of the zone, indicating reverse movement on the right-hand fault. Note the small reverse flexure in the Springfield Coal and overlying shales, left of center.

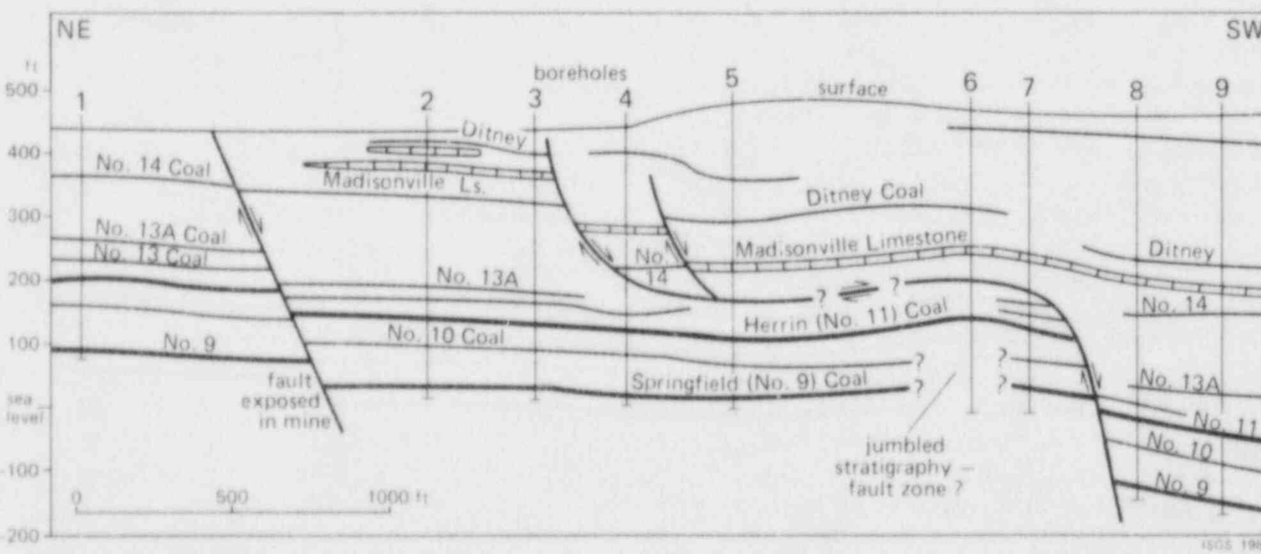


FIGURE 17. Cross section prepared from coal-test boreholes in northern part of Rough Creek Fault System southeast of Morganfield, Kentucky. The indicated horizontal fault in boreholes 5, 6, and 7 apparently links normal faults near borehole 4 with large high-angle fault between boreholes 7 and 8. Listric faulting (perhaps a paleoslump triggered by tectonic movement) is suggested. The indication of faulting in borehole 6 below the No. 11 Coal may represent more slumping or tectonic movement during Pennsylvanian time before deposition of No. 11 Coal.

structure, just south of the center of the roadcut, is a faulted asymmetrical anticline in interbedded limestone and shale of the Menard Formation. This fold is exposed on both sides of the highway and appears much the same in both exposures. The axial plane, as sighted across the roadway, strikes N 75^{o} W and dips 70-75^{o} NE; the axis of the fold is essentially horizontal. Numerous faults, with a wide variety of attitudes, break the anticline. Faults strike subparallel to the axis of the fold and dip vertically to horizontally; most of them are normal faults.

The largest faults in the roadcut border the anticline and juxtapose the Menard Formation with Caseyville strata. South of the anticline faults dip steeply and show both normal and reverse displacements. North of the fold most faults dip steeply, but one break is sharply folded from a N 70^{o} dip to a S 20^{o} inclination over the north limb of the anticline. This fault, which closely follows the bedding of a thin coal near the base of the Caseyville Formation, apparently was one of the first fractures to develop; it has been folded and also offset by later tectonic movement. Many other examples of one fault offsetting another are found in the roadcut, demonstrating that more than one episode of movement took place here.

The shales between the Menard and Caseyville Formations responded primarily in a ductile manner to faulting, as did shales and thin limestones within the Menard. Incompetent shales are greatly squeezed and contorted, and in places appear to have flowed along faults. The coal beds and coaly shales in the basal Pennsylvanian appear particularly susceptible to ductile failure; these materials are pervasively sheared and, in several cases, faults run parallel to the bedding. The three steeply-dipping coals south of the anticline in figure 18 apparently are the same seam repeated by faulting. Magnitude of faulting is difficult to estimate, because many faults apparently follow bedding, and because the missing stratigraphic interval between the Caseyville and Menard is unknown in this vicinity.

Intense deformation is displayed on the north flank of the anticline on the west wall of the roadcut (fig. 19). Here, in a broad zone 10 to 20 feet across, large blocks of sandstone and limestone "float" in a matrix of crushed shale. The bedding of the detached blocks strike more or less parallel with the adjacent faults. Note that the block of limestone at the south margin of the fault zone is tilted so that its upper end is above the same bed in the unfaulted section to the south.

Evidence is overwhelming that the major movements in the roadcut were vertical or nearly so. Slickensides and mullion are prominent on many faults and indicate steeply oblique to dip-slip movement. Axes of small folds and flexures, like the axis of the large central anticline, are horizontal. Faults are subparallel with the bedding of tilted and folded rocks. Although low-angle to horizontal faults are present, they are local features and are subordinate to the major offsets, which are steeply dipping to vertical.

The Clear Run Horst, therefore, is the product of essentially vertical movements along a number of faults. Multiple and reversed movements are required to account for the complex structure, particularly the central core of Mississippian rocks that is sharply upthrust between Pennsylvanian strata on either side.

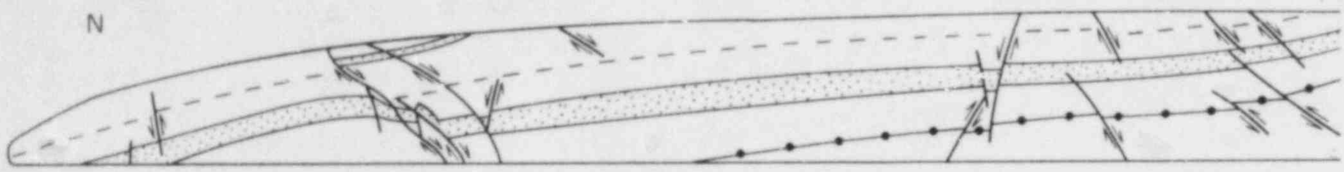


FIGURE 18. Simplified sketch of part of Rough Creek Fault System exposed on east wall of roadcut at Milepost 53, Green River Parkway, Ohio County, Kentucky (Krausse, Nelson, and Schwalb, 1979).

From Ohio County eastward into Grayson County, the Rough Creek Fault System gradually becomes narrower and less complex as it loses displacement. All the way to its eastern terminus the system maintains its overall structure as a broken anticline or a series of relatively uplifted and downdropped (mainly uplifted) blocks (fig. 14, sec. F). Reverse faults have not been mapped, but evidence that would prove their presence or absence is scanty. Little drilling has been done in this part of Kentucky and, as elsewhere in the state, surface exposures of actual fault surfaces are rare.

Near Leitchfield the Rough Creek Fault System curves sharply to the southeast, and the faults die out near the Grayson-Edmonson county line (fig. 10). Heyl (1972) and others have suggested that the Rough Creek Fault System continues farther east and links with other faults, but this idea cannot be substantiated by surface mapping or by data from drilling.

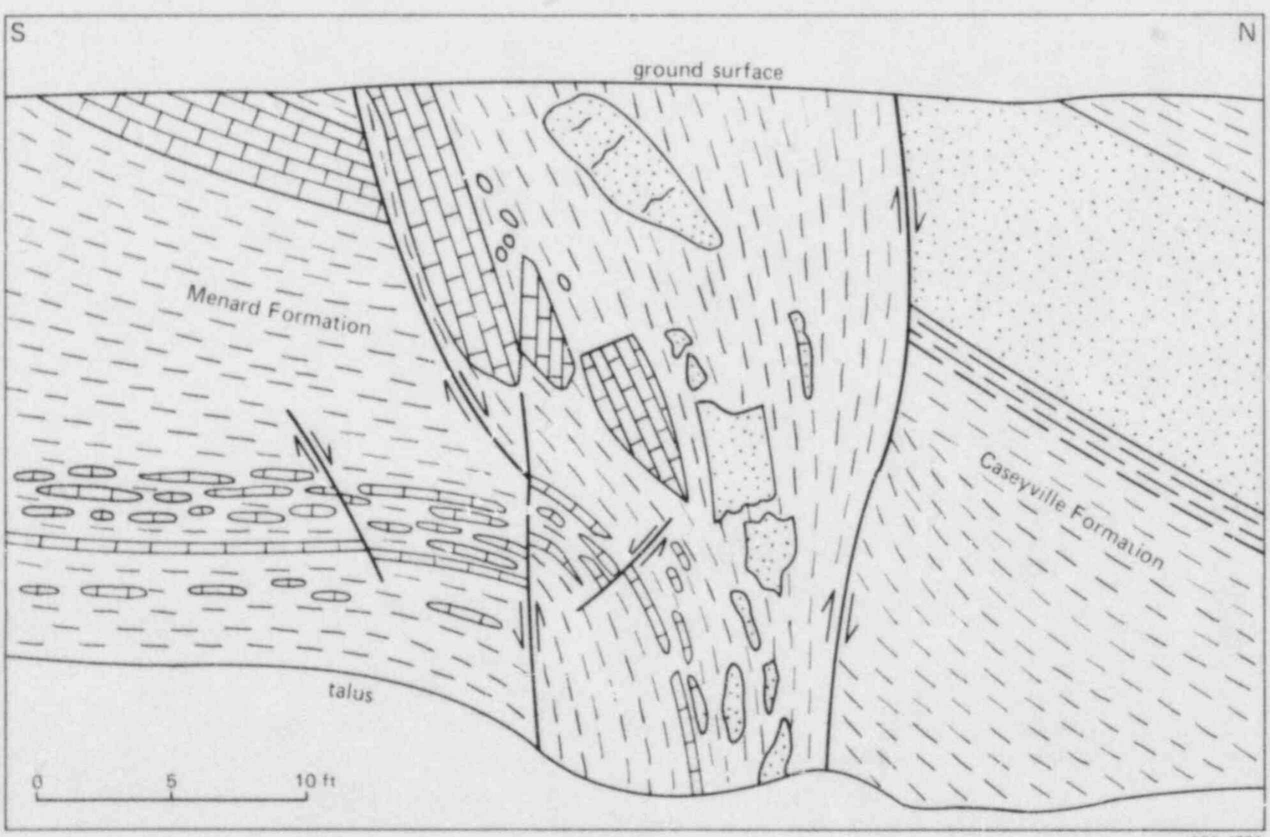
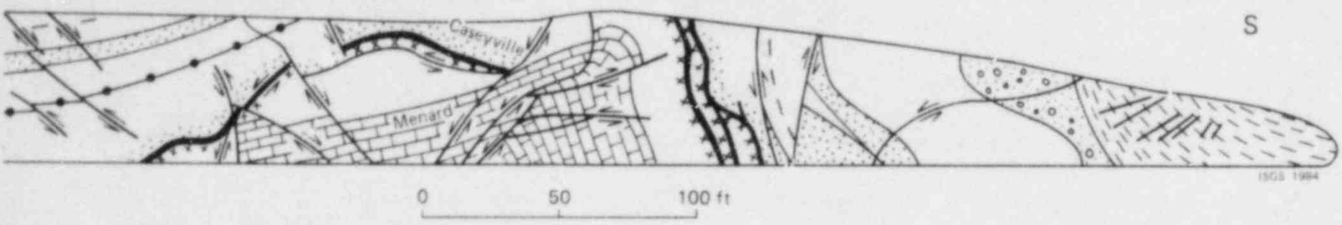


FIGURE 19. Fault zone on west side of Green River Parkway; blocks of Menard Limestone and Caseyville sandstone floating in a matrix of highly sheared shale.



Origin of the Rough Creek-Shawneetown Fault System

Three major theories have been advanced to explain the origin of the Rough Creek-Shawneetown Fault System: (1) horizontal compression; (2) strike-slip faulting; or (3) recurrent vertical movement.

Horizontal compression. Weller (1940) apparently was the first to advocate horizontal compression as the cause of the Rough Creek-Shawneetown Fault System (RC-SFS). He proposed that a push from the south or southeast first formed an anticline, and then broke it, to produce the fault system. He pointed to the New Burnside and McCormick "anticlines" (fig. 9), northwest of, and roughly parallel to, the southwest-trending portion of the Shawneetown Fault Zone as further products of the same stresses. Weller suggested that the thrusting forces from the Appalachian orogeny were transmitted far inland to the pre-existing zone of weakness along the Rough Creek-Shawneetown Fault System.

Smith and Palmer (1974 and 1981) likewise argue that post-Pennsylvanian faults of the the RC-SFS were produced by compression from the south, but they do not speculate on the origin of the compressive forces. As previously mentioned, Smith and Palmer theorized that a late relaxation of compression allowed the overthrust block to slide back down to the south; slices of Ft. Payne and older rocks were sheared off the hanging wall and caught along the fault zone during this action. Smith and Palmer allow for the possibility that pre-Pennsylvanian movements in the RC-SFS may have been strike-slip or vertical.

Surface exposures and available subsurface data lend little support to the horizontal compression theory. The front fault is a high-angle reverse fault, except near Morganfield, and most other faults in the system are normal or vertical. No parallel folds, thrust faults, or other structures indicative of horizontal compression have been mapped in the vicinity of the RC-SFS. The McCormick and New Burnside structures, which Weller (1940) described as anticlines, actually are zones of high-angle faulting (Jacobson and Trask, 1983).

This lack of surface evidence for horizontal compression does not rule out the possibility that the front fault may flatten with depth and merge with a low-angle thrust fault or décollement. Conceivably the RC-SFS may be similar to

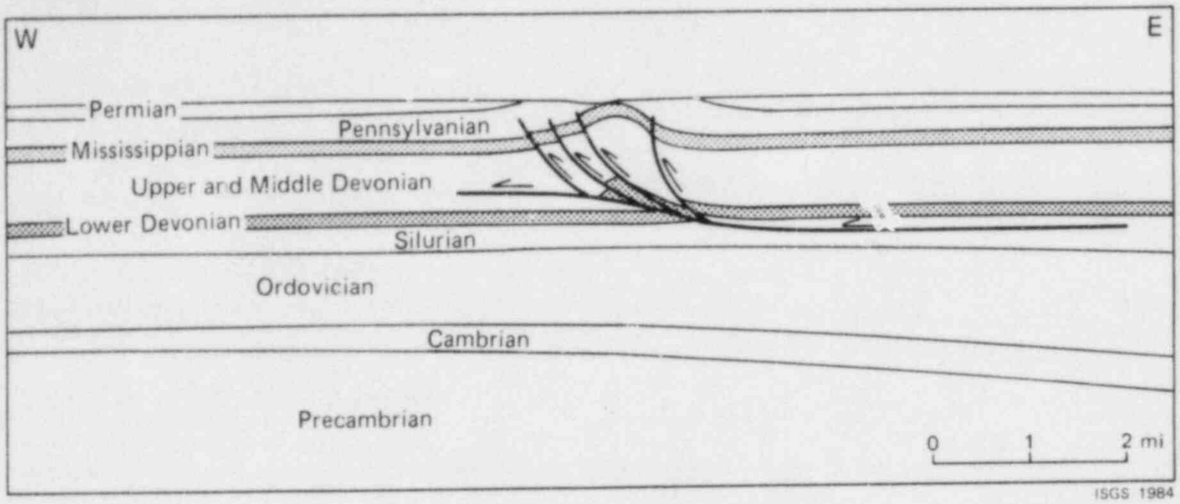


FIGURE 20. Burning Springs Anticline, Wood and Ritchie Counties, West Virginia, interpreted as the westward termination of decollement that was developed in Silurian evaporites during the Appalachian Orogeny (Cardwell et al., 1968).

the Burning Springs Anticline of West Virginia (fig. 20). The Burning Springs Anticline is a sharp, north-trending faulted anticline, having up to 1650 feet of closure at the surface, that lies approximately 75 miles west of the Allegheny Front. Only rocks of Devonian and younger age are deformed. Drilling and regional studies strongly indicate that the Burning Springs Anticline marks the western terminus of an enormous thrust fault that originated in the folded Valley and Ridge Province and followed incompetent evaporites of the upper Silurian Salina Group westward. Westward pinch-out of the salt apparently forced the leading edge of the décollement to "pile up" as a series of overlapping thrust blocks, which in turn arched the overlying strata (Woodward, 1959; Rodgers, 1963; and Gwinn, 1964).

What little information is available on deep structure of the RC-SFS rules against the possibility that the fault zone becomes a low-angle thrust or décollement at depth. Drilling and seismic sections indicate that surface faults extend downward at least to the Eau Claire and probably into the Mt. Simon. The seismic sections are not entirely conclusive--reflectors tend to break up in the fault zone--but they generally show that the RC-SFS is steeply inclined. The seismic section in Illinois (running southward from Equality across the Shawneetown Fault Zone and Eagle Valley Syncline), shows a steep fault zone from surface down to Cambrian. One of the sections in Kentucky having a prominent reflector of probable basement at 25,000 feet showed no trace of structural discontinuities along or south of the axis of the Moorman syncline.

The Appalachian-Ouachita foldbelt is 120 miles from the eastern end of the Rough Creek Fault System and more than 200 miles from the Shawneetown Fault Zone. A décollement connecting the foldbelt with the RC-SFS would have to cover nearly the entire state of Tennessee plus southern Kentucky and northern Alabama and Mississippi. The numerous drill holes in those states--many of them reaching basement--have revealed no sign of such a vast feature. In contrast, there are plenty of surface indications--such as fracture patterns and lineaments indicating tear faults--for the Burning Springs décollement and other sole faults in the Appalachian Plateau of West Virginia and Pennsylvania (Gwinn, 1964; Wing et al., 1970).

The idea that horizontal compression originated more locally, within the Rough Creek Graben itself, has been suggested, but falls into the realm of pure speculation.

In conclusion, barring new evidence from deep drilling or seismic surveys, we find that a horizontal compressive origin for the Rough Creek-Shawneetown Fault System is unlikely.

Strike-slip Faulting. Many geologists have noted a basic similarity between the Rough Creek-Shawneetown Fault System and large strike-slip faults. Clark and Royds (1948) were the first to suggest wrench-faulting as the origin of the RC-SFS. Heyl and Brock (1961), Heyl et al. (1965), Heyl (1972), McGinnis et al. (1976), and Viele (1983), among others, also advocated a strike-slip origin for the system. Heyl regards the RC-SFS as a major link in his 38th Parallel Lineament, and claims that geophysical evidence suggests 50 km of right-lateral slip in the basement.

The absence of consistent vertical offset across the RC-SFS does suggest wrench faulting. So does the braided pattern of high-angle fractures, with numerous narrow upthrown and downthrown slices. When a wrench fault moves, wedges of rocks may be literally squeezed, like a watermelon seed, toward the surface. This is especially apparent when the wrench fault has a component of convergence, or horizontal compression. A characteristic upthrust structural style, recognized in many large strike-slip faults and often producing petroleum traps, has been termed a "flower structure" (Harding and Lowell, 1979). In a flower structure, reverse faults diverge upward away from the vertical "stem" fault at depth, and flatten toward the surface (fig. 21). Flower structures are well-developed along California's San Andreas Fault and along large wrench faults in the Ardmore Basin of Oklahoma (Harding and Lowell, 1979). They also occur in the right-lateral Cottage Grove Fault System of Illinois (Nelson and Krausse, 1981; fig. 38, p. 43). Our interpretive cross-sections of the Shawneetown Fault Zone resemble these and other "flower structures" associated with known strike-slip faults and described in the literature.

Be that as it may, other evidence rules against the idea that the RC-SFS is a wrench fault. First, we have the field observations. With very few exceptions, slickensides and mullion on fault surfaces indicate vertical or nearly vertical dip-slip, and the orientation of drag folds shows the same. The only indications of horizontal or oblique slip are found in complexly faulted zones, and there only on minor fractures. Such indications probably can be found in any large fault zone, and represent rotation or differential uplift of slices, rather than a dominant strike-slip action. The large faults, as far as can be determined, are consistently dip-slip fractures: the front fault is a south-dipping reverse fault, and the other faults normal.

Anticlinal and monoclinal flexures along the RC-SFS strike essentially parallel with the major faults and with the zone as a whole. They do not show the oblique, en echelon relation to the master fault that is diagnostic of strike-slip. En echelon folds result from the compressional component of the horizontal shearing stress, and their orientation indicates the directon of wrenching. The Cottage Grove Fault System has a well-developed belt of en echelon folds. So do many other known wrench faults around the world (Moody

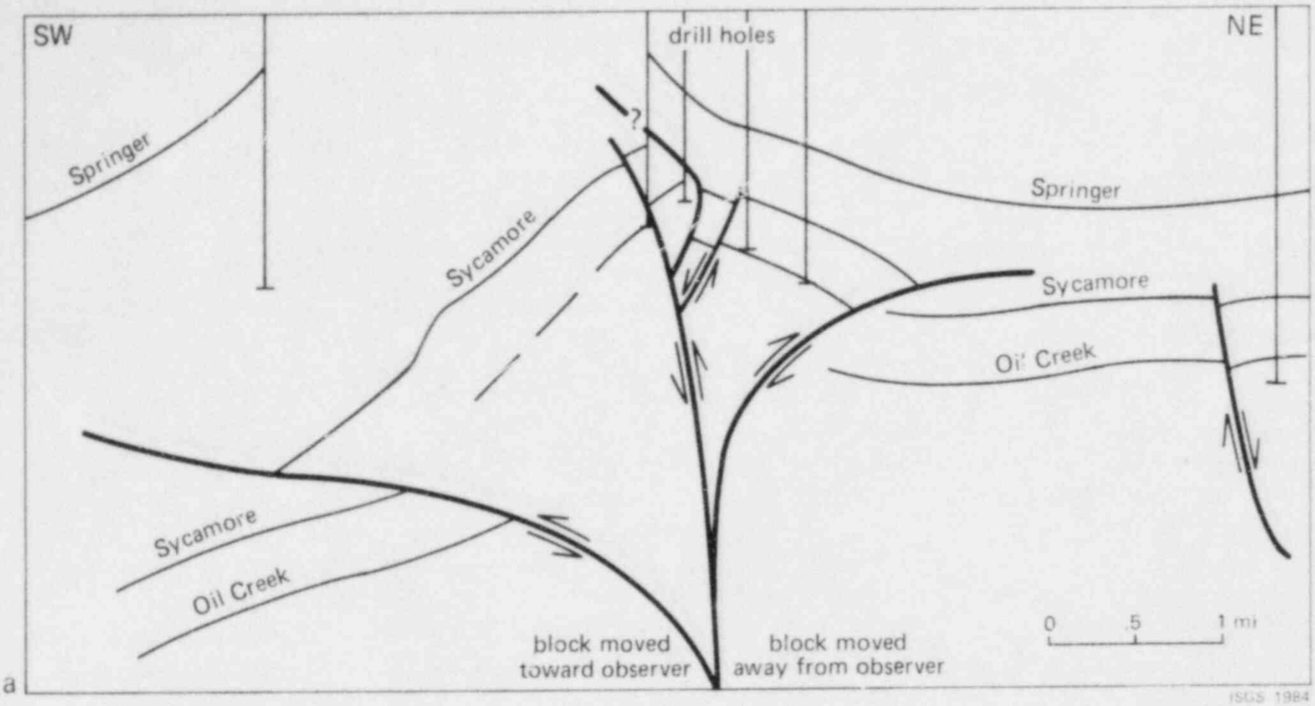
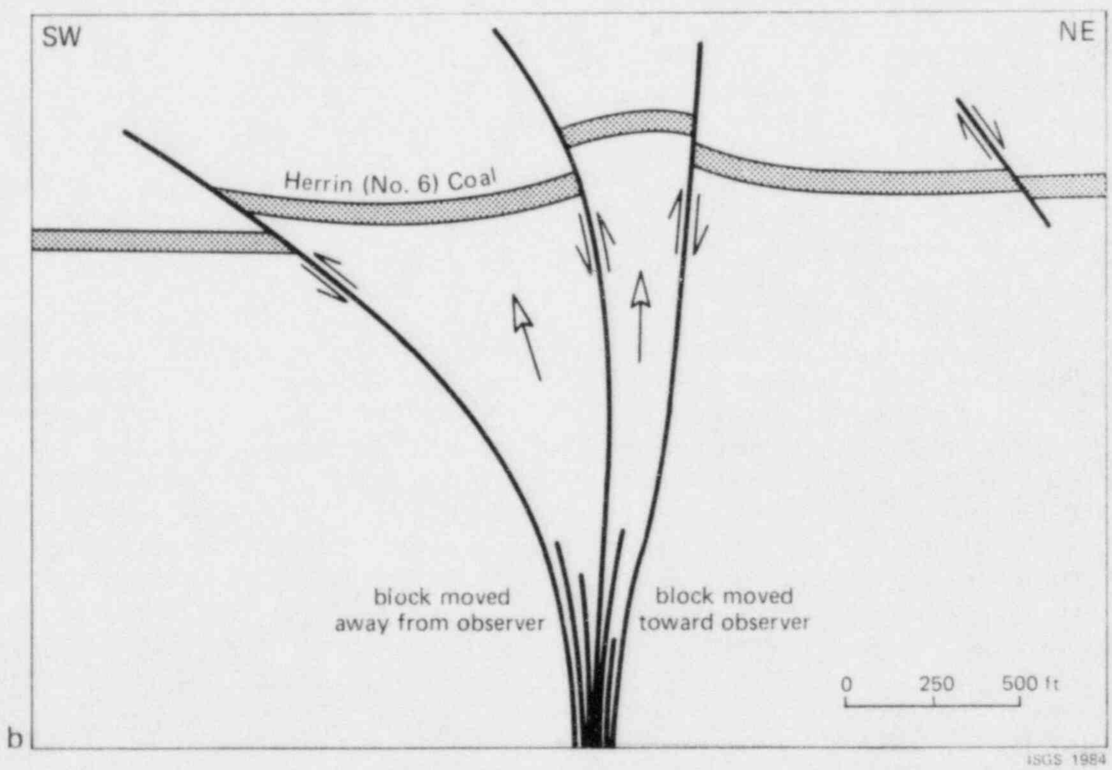


FIGURE 21. "Flower structures" produced by upthrust faulting in wrench-fault zones. Above: Ardmore Basin of Oklahoma, based on seismic profile and drill-hole data from Harding and Lowell (1979); below: Cottage Grove Fault System, Williamson County, Illinois, from Nelson and Krausse, 1981.



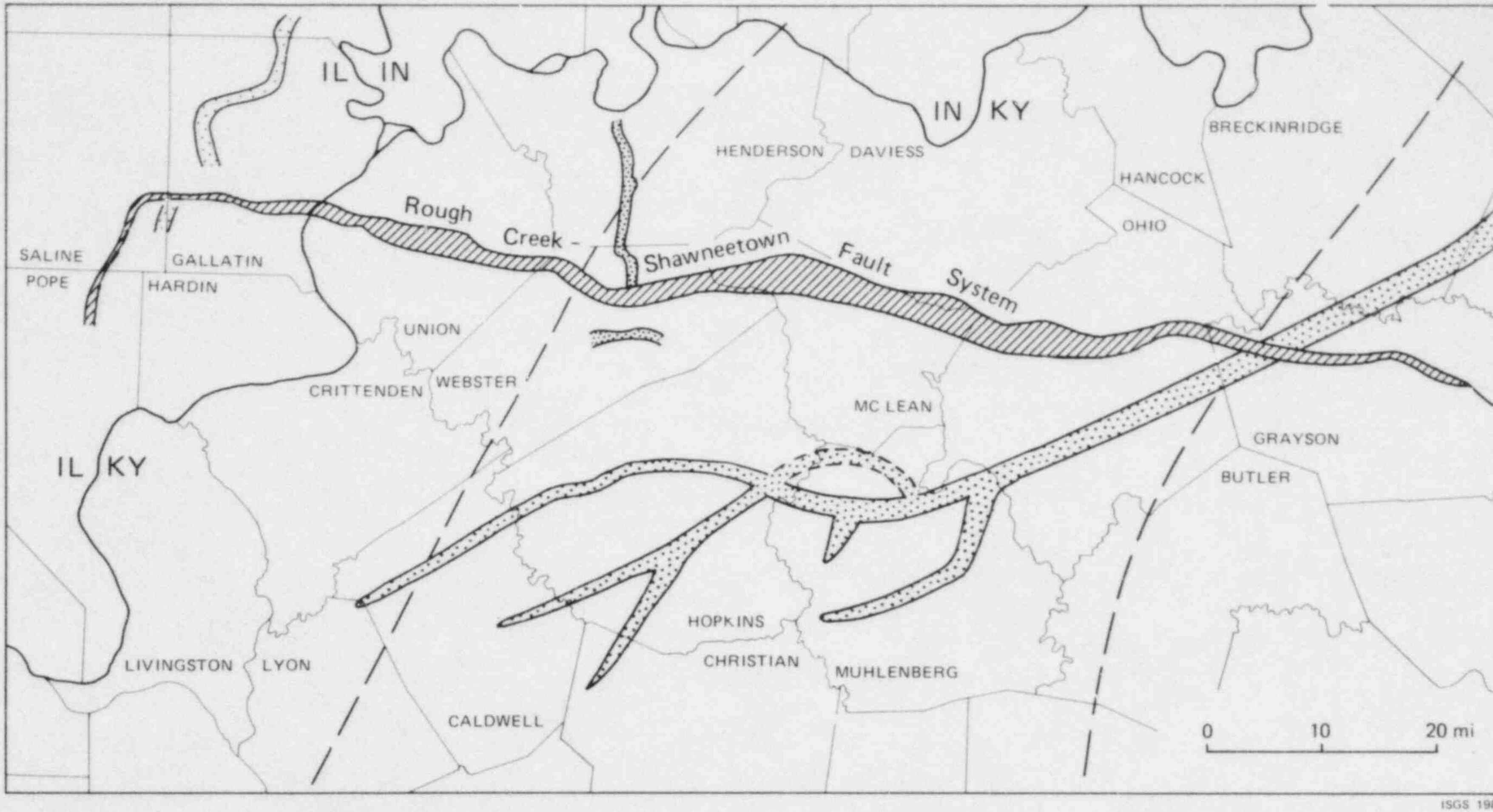
and Hill, 1956; Wilcox, Harding, and Seely, 1973; and Thomas, 1974). These fold belts are eagerly sought by petroleum explorationists because of their obvious trapping potential.

Another feature of strike-slip, lacking in the RC-SFS, is the complementary system of en echelon or pinnate normal faults created by the tensional component of wrenching stress. At first glance, the Wabash Valley and Fluorspar Complex faults, and other northeast-trending fractures along the RC-SFS, suggest that the RC-SFS is a left-lateral shear zone. However, the detailed structure of those faults and their relationship to the RC-SFS preclude such an interpretation--as will be discussed later in this report.

As we have noted, cross-sections of the RC-SFS are reminiscent of flower structures. However, some characteristics of true flower structures are lacking. In a wrench-fault flower the upthrust faults curve off both sides of the master strike-slip fault in the basement. The RC-SFS, in contrast, has an upthrust (the front fault) only on the north side; no northward-dipping reverse faults have been recognized. Also, the rollover anticlines associated with most true flower faults are not present in the RC-SFS. Instead, the fault blocks are either tilted southward toward the Moorman Syncline, or segmented into an asymmetrical, block-faulted arch.

Strike-slip faults typically are linear along strike. If the fault bends, part of the lateral slip must be transformed to either divergent (extensional) or convergent (compressional) deformation, depending upon the configuration of the bend and the direction of strike-slip. The Shawneetown Fault Zone makes an abrupt 70-degree bend in southeastern Saline County, but the structural style remains the same around the curve. Neither the extension indicative of left-lateral movement on the main fault, nor the compression indicative of right-lateral slip, is apparent.

The most conclusive evidence against a major element of wrench-faulting in the RC-SFS is found in paleochannels that cross the fault zone without being offset laterally. The best examples are found in Davis, Plebuch, and Whitman (1974), which reports on a large area in west-central Kentucky, including a 40-mile segment of the Rough Creek Fault System. Faults and geologic structure compiled from geologic quadrangle maps and other sources are shown in plate 4, Davis et al. (1974); plate 2 of Davis et al. is a map of the pre-Pennsylvanian geology, as mapped from borehole data. This map shows a system of steep-sided anastomosing paleochannels cut into Chesterian strata beneath the basal Pennsylvanian deposits. The dominant direction of these ancient valleys is southwesterly, as it is throughout most of the Illinois Basin (Bristol and Howard, 1971). One of the largest paleochannels, the Madisonville Valley, crosses the Rough Creek Fault System at the common corner of Daviess, McLean, and Ohio Counties. Well control here is adequate to limit the maximum possible horizontal offset of the channel to less than 1000 feet, which is less than the local maximum vertical separation in the fault zone. In Webster County, just west of the town of Sebree, two smaller paleovalleys cross the fault zone without noticeable horizontal offset. Here again, well control limits the possible error in detection to less than 1000 feet. At Sebree the main fault is a high-angle reverse fault with approximately 1500 feet of vertical separation; it lies at the north edge of the fault system.



Border of Sebree Valley (Ordovician), from Schwalb (1982)

Bethel Sandstone (Mississippian), from Reynolds and Vincent (1967)

Anvil Rock Sandstone (Pennsylvanian), from Hopkins (1958) with additions

Henderson Channel (Pennsylvanian), from Beard and Williamson (1979)

FIGURE 22. Paleochannels crossing the Rough Creek-Shawneetown Fault System.

Other paleochannels are mapped as crossing the RC-SFS without lateral offset, but on these the degree of control is either not indicated or not as precise as that of Davis et al. The 30-mile-wide Sebree Valley, (fig. 22) filled with Maquoketa Shale (Ordovician), crosses the fault zone without interruption; datum points at the critical junction are less than a mile apart (Schwalb, 1982). Other channels include one filled with the Chesterian Bethel Sandstone (Reynolds and Vincent, 1967, fig. 1); sub-Pennsylvanian channels mapped by Potter and Desborough (1965), and Bristol and Howard (1971); and Pennsylvanian paleovalleys of Hopkins (1958) and Beard and Williamson (1969) (fig. 22). None of these authors suggests strike-slip, although some attribute local deflections of paleo-stream courses to possible contemporaneous tectonic activity, as will be mentioned later in this report.

In summary, the data show that any strike-slip movements that may have occurred were subordinate to dip-slip movements in the RC-SFS. The later phases of faulting were almost purely vertical and may have erased signs of earlier but minor horizontal slippage. Although post-Pennsylvanian faulting was mostly vertical, we cannot preclude the possibility of major strike-slip motion along an ancestral Rough Creek Fault in Cambrian time or earlier.

Recurrent vertical movements. The foregoing discussion leads us to the third hypothesis: that the Rough Creek-Shawneetown Fault System was produced by vertical movements. Clearly, a single state of uplift cannot account for the complex structure of the RC-SFS, especially the narrow slices of rock upthrown thousands of feet within the fault zone. Therefore, at least two stages of movement must have taken place. That is, one side of the fault zone must have been first uplifted, and then dropped back approximately to its original position.

The front fault is the master break, and its configuration indicates that the southern block was first uplifted. The front fault is a reverse fault, consistently inclined to the south. Faults formed by direct vertical uplift invariably bend outward from the uplifted block (fig. 23). This has been demonstrated repeatedly in laboratory experiments in which layered materials are deformed by raising rigid basement blocks (Sanford, 1959; Couples, 1978; Logan et al., 1978). The faults generated in these experiments are vertical at depth and curve away from the uplifted block upward, becoming reverse faults. In some cases (fig. 23) the fractures break the surface as low-angle overthrusts. The central portion of the upraised block is placed in horizontal tension; high-angle normal faults develop, forming steps or grabens that may intersect the master reverse fault at depth.

These experiments illustrate a mechanism whereby low-angle reverse faults, such as the one at Morganfield, could have been produced without horizontal compression. Vertical uplift also accounts for the secondary normal faults south of the front fault.

Vertically uplifted blocks bounded by outward-bending reverse faults apparently are common in nature. Kerr and Christie (1965) report this style of deformation in the Boothia uplift of arctic Canada (fig. 24), and Gibbons (1974) describes most faults of the eastern Ozarks area, Missouri, as upthrusts. Probably the best examples of vertical uplifts bounded by reverse

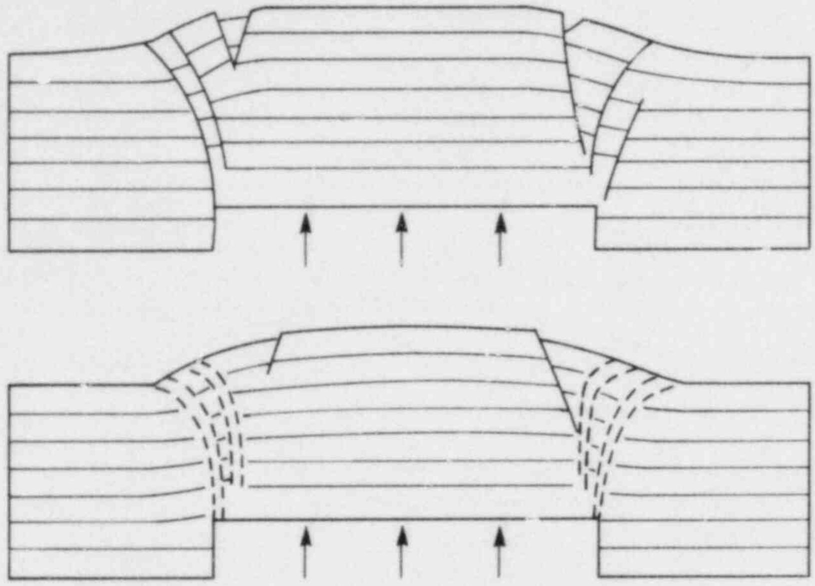


FIGURE 23. Sketches from Sanford (1959) illustrating results of experiments simulating simple vertical uplift of rigid basement block. Layers of sand and clay represent sedimentary strata. Faults, vertical at depth where they begin, curve outward and become thrust faults near the surface. The central part of the uplifted block is under horizontal tension, which produces normal faults.

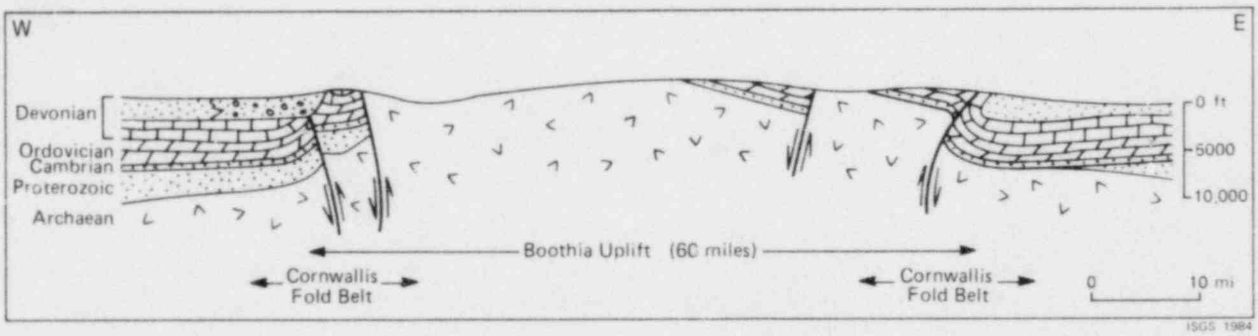


FIGURE 24. Cross section of Boothia Uplift, arctic Canada, from Kerr and Christie (1965). Direct vertical uplift of the basement during Paleozoic time is indicated. Note similarity between this sketch and those of Sanford (fig. 23).

faults are found in the Central Rocky Mountains and on the Colorado Plateau (Stearns, 1978; Matthews, 1978). In all of these, however, as in the laboratory experiments cited above, the uplifted mass remained high and did not settle back, as we postulate for the Rough Creek-Shawneetown Fault System.

Upheaval of the southern block, therefore, was apparently the first step in the development of the RC-SFS (fig. 25). The amount of uplift must have been equal to or greater than the maximum vertical separation of strata as observed today. This means that in the vicinity of Horseshoe, the southern block must have risen at least 3500 feet. The uplift was 2000 feet or more at Morganfield, 1500 feet at Sebree, and less farther east along the fault system. The portion of the Shawneetown Fault Zone running southwestward from Cave Hill shared in the upward movement, which appears to have diminished rapidly toward the southwest. This sharp bend of the fault zone may reflect the areal configuration of the uplifted basement block. (The regional extent and nature of this block will be discussed in a later section, after other fault systems of the area have been described.)

After the initial uplift of the southern block, the southern block dropped back downward, reactivating the front fault and other fractures (fig. 25). As the great mass of rock settled, it became wedged against the front fault. The rocks immediately adjacent to the front fault were held in place by friction and confining pressure as the main mass dropped. This differential movement produced the great drag fold that is the north limb of the Eagle Valley-Moorman Syncline. As the southern block continued to sink, slices of it were sheared off and left stranded high in the fault zone. These blocks, caught in a rotational couple, rotated southward, until in extreme cases (as at Horseshoe Quarry) the bedding became vertical or even overturned. Meanwhile, additional vertical breaks propagated upward from the front fault. Some of these, such as the Jones, Ringold, and Ringold South Faults, broke the surficial strata, but others did not break through to the surface; overlying sedimentary layers draped over these faults as monoclinal flexures.

Therefore, the narrow upthrown slices that characterize the RC-SFS are remnants of the original upthrown southern block that were trapped above the fault and prevented from returning to their original position.

Grabens are rare in comparison to horsts in the RC-SFS, because grabens form only under special conditions. Some grabens, such as the small one immediately north of the front fault in the Shawneetown Quadrangle, may have resulted from extensional shearing of the footwall, perhaps combined with downward friction exerted by the subsiding hanging wall. Such a mechanism may account for the configuration in the Margaret Karsch well, where lower Devonian rock was found in fault contact above lower Pennsylvanian strata. The Pennsylvanian rock at the bottom of the hole may be a slice of the footwall that dropped or was pulled down as the hanging wall sank (fig. 26). A different mechanism is required to account for the Mauzy graben, with its Permian rock. This graben is situated near the southern edge of the RC-SFS, about two miles south of the front fault (fig. 10). This area would have been under north-south extensional stress during the first stage of faulting, as the southern block rose (fig. 23). The Mauzy graben probably developed during uplift, and was preserved when the southern block sank back down.

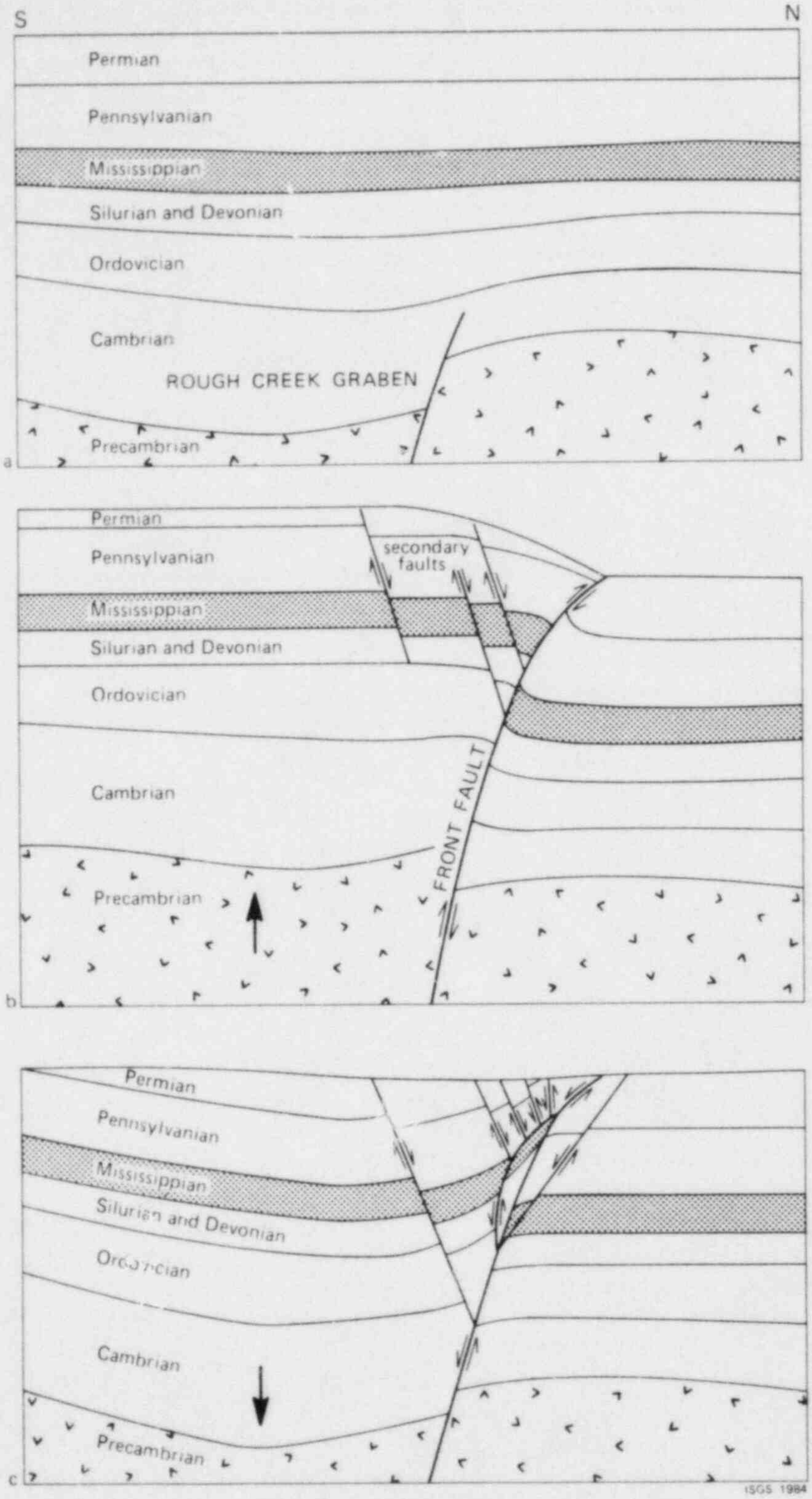


FIGURE 25. Development of the Rough Creek-Shawneetown Fault System. (a) Prior to faulting, in Permian time, the basement is broken by the northern fault of the Rough Creek Graben, which had developed in Cambrian time. (b) The southern block is uplifted, reactivating the Cambrian fault as an upthrust. Secondary faults develop under horizontal tension near the top of the upthrown block. The raised block presumably is subjected to erosion. (c) The southern block drops back to approximately its original elevation. The overhanging portion of the southern block is wedged in position and held up by friction so that it cannot drop. Flexure and tilting of the sedimentary strata produce the steep northern limb of the Eagle Valley-Moorman Syncline, while narrow slices of rock are sheared off within the fault zone and trapped there. Secondary faults undergo renewed movement, and many additional faults are created.

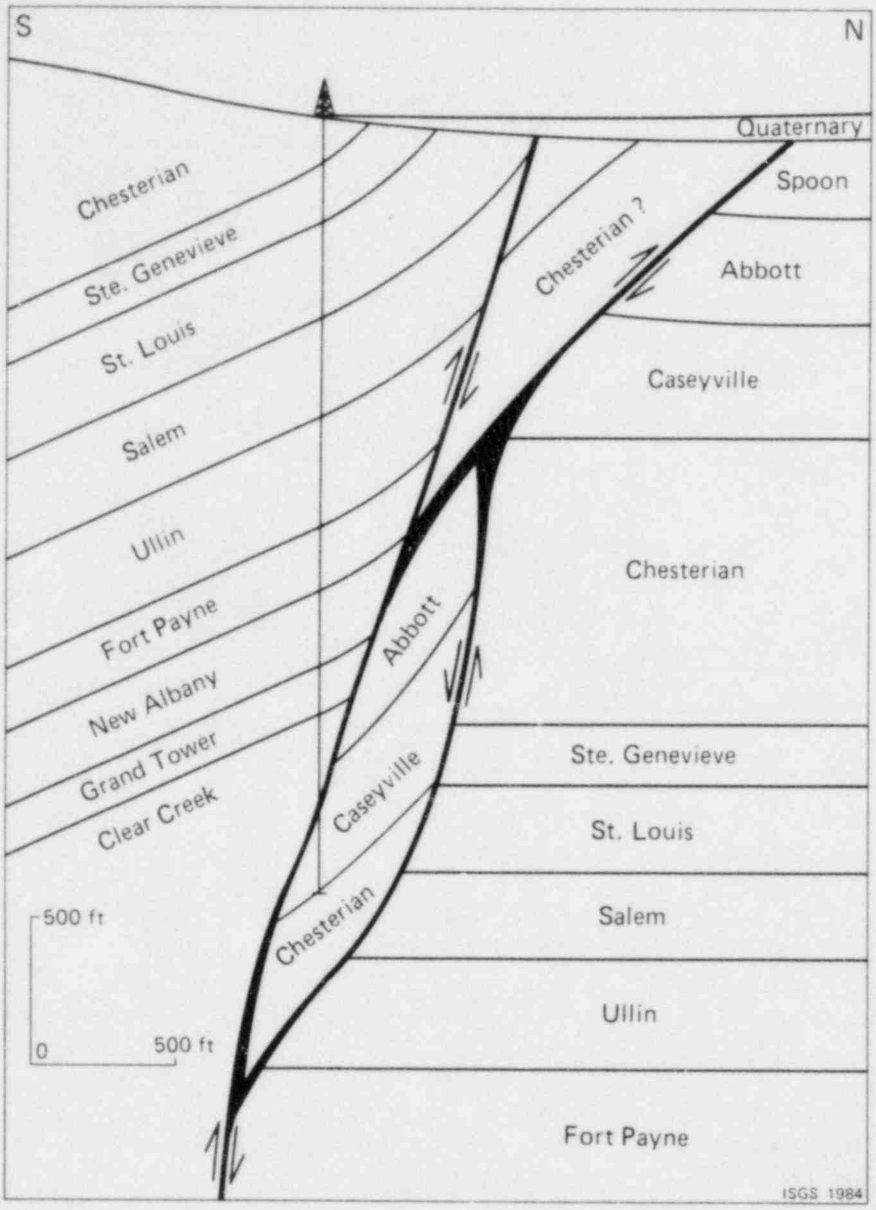


FIGURE 26. Intrepretation of structure in the Margaret Karsch well, about a mile west of Horseshoe. At a depth of 2380 feet, the drill cut the front fault of the Shawneetown Fault Zone and passed from lower Devonian to lower Pennsylvanian strata. The Pennsylvanian rocks occupy a fault slice that presumably was sheared off the northern (footwall) block and dragged downward when the southern (hanging wall) mass moved down.

The irregularly-shaped subordinate anticlines and synclines in the axial region of the Eagle Valley Syncline may reflect differential subsidence of the southern block in the late stages of movement. Perhaps the block is segmented at depth by faults of varying attitudes, over which the surficial strata are draped in forced fields. Additional subsurface information will be needed to confirm this hypothesis.

Although we believe the structural evolution of the RC-SFS can be defined on the basis of surface exposures and shallow subsurface data, we wish to emphasize that very little is known about the deep structure of the fault zone. Very few wells have penetrated the zone, and the few seismic lines we have been privileged to view reveal little about the attitude and continuity of faults at depth. More seismic information and/or drilling is required to reveal the nature and hydrocarbon potential of the Rough Creek-Shawneetown Fault System below the Devonian and Mississippian rocks.

Time of faulting

The present-day Rough Creek-Shawneetown Fault System obviously developed after early Permian time, but an ancestral RC-SFS was active during Cambrian and Devonian, and possibly Mississippian and Pennsylvanian time. Major movements probably are pre-Cretaceous; no evidence for Pleistocene tectonism has been uncovered.

Pre-Pennsylvanian movements. Deep drilling and geological evidence have revealed a buried south-facing escarpment, coinciding with the Cottage Grove Fault System and RC-SFS, in the Precambrian basement (Soderberg and Keller, 1981). Facing this scarp and following the surface trace of the Pennyrile Fault System, just south of the RC-SFS, is another Precambrian scarp. The trough between, more than 6,000 feet deep in places, is the Rough Creek Graben.

Whether the Rough Creek Graben existed in Precambrian time has not been determined, but it definitely came into being by the middle Cambrian. The graben, several thousand feet deep, filled rapidly with detrital sediments shed from adjacent uplands. Faults may have been reactivated from time to time during the Cambrian, but by Champlainian (middle Ordovician) time the graben was filled with sediments (Schwalb, 1982).

The Rough Creek Graben was quiescent during Ordovician time. As mentioned earlier, the Sebree Valley, a submarine channel filled with Cincinnatian (upper Ordovician) shale, crosses the fault zone without apparent interruption (Schwalb, 1982). Local abrupt thickening of Silurian rocks in the graben suggest renewed movement in Silurian time (Schwalb, personal communication, 1983).

Schwalb suggests that the eastern portion of the graben apparently was reactivated during the Devonian Period. The Lower and Middle Devonian section within the graben is considerably thicker than that outside the trough. Outside the graben, Middle and Lower Devonian rocks were uplifted and partially eroded; Upper Devonian New Albany Shale unconformably overlies rocks as old as Silurian. Not only the RC-SFS proper, but also a northeast-trending fault north of the RC-SFS in Breckinridge County, Kentucky, show evidence of Devonian activity (Howard Schwalb, personal communication, 1983).

Mississippian movements on the RC-SFS have been suspected, but evidence is scanty. Wood (1955) attributed local thickening of Chesterian sandstones in the Morganfield area to contemporaneous tectonism. Davis et al. (1974) suggested that local deflections of pre-Pennsylvanian valleys along the central portion of the RC-SFS may be the result of localized contemporaneous uplift in that area.

Pennsylvanian movements. Localized uplift along the RC-SFS may have played a role in the origin of narrow, deeply incised paleochannels and large paleo-slump structures that occur in Carbondale and Modesto strata of Eagle Valley and western Kentucky.

Spectacular paleoslumps formerly were exposed close to the axis of the Eagle Valley Syncline in now-reclaimed pits of Peabody Coal Company's Eagle Surface Mine, in and near Section 14, T. 10S., R. 8E., Equality Quadrangle, Gallatin County. Narrow elongate grabens, generally trending east-west, are the most common type of slump (fig. 27). They are up to 2,000 feet long and 50 to several hundred feet wide, and their faults have as much as 40 feet of throw. The time of faulting can be fixed precisely; the tops of grabens (and other paleoslumps) are erosionally truncated and overlain by the Gimlet Sandstone. In some cases (as in fig. 27), conglomeratic Gimlet Sandstone also is included in downfaulted, tilted blocks. Therefore, the faulting took place slightly before and/or during deposition of the Gimlet Sandstone.

Other slumps show more complicated structure, including thrust faults. In one exposure the Herrin Coal is repeated three times on the highwall as a result of multiple thrusting. Figure 28 illustrates a slump that combines low- and high-angle reverse faulting. The Gimlet Sandstone unconformably overlies the faulted and tilted Carbondale rocks.

Structures such as these are commonly attributed to failure of undercut river-banks. Drilling and exposures in the mine reveal that the Gimlet Sandstone locally fills channels cut into or through the Herrin Coal; however, none of these channels can be related to paleoslumps. Furthermore, most rocks show brittle structural deformation rather than the plastic or ductile deformation normally associated with landsliding and slumping of unconsolidated sediments. Coal near faults is intensely slickensided and shattered; shale is so thoroughly fractured in some places that its bedding is obscured. These materials must have been already fairly brittle at the time of failure: they were not soft, unstable sediments. Tectonic activity--either actual slippage along surface fractures or strong seismic shocks--is thus a likely triggering mechanism for the deformation at Eagle Surface Mine.

Coal-test drilling near Peabody Coal Company's Camp 11 Mine immediately north of the RC-SFS in Union County, Kentucky has revealed a deep, narrow, west-northwest-trending paleochannel. Within the channel the Herrin Coal is eroded and replaced by shale or sandstone probably equivalent to the Gimlet Sand-stone. The cutout is at least 3500 feet long, only 150 feet wide, and more

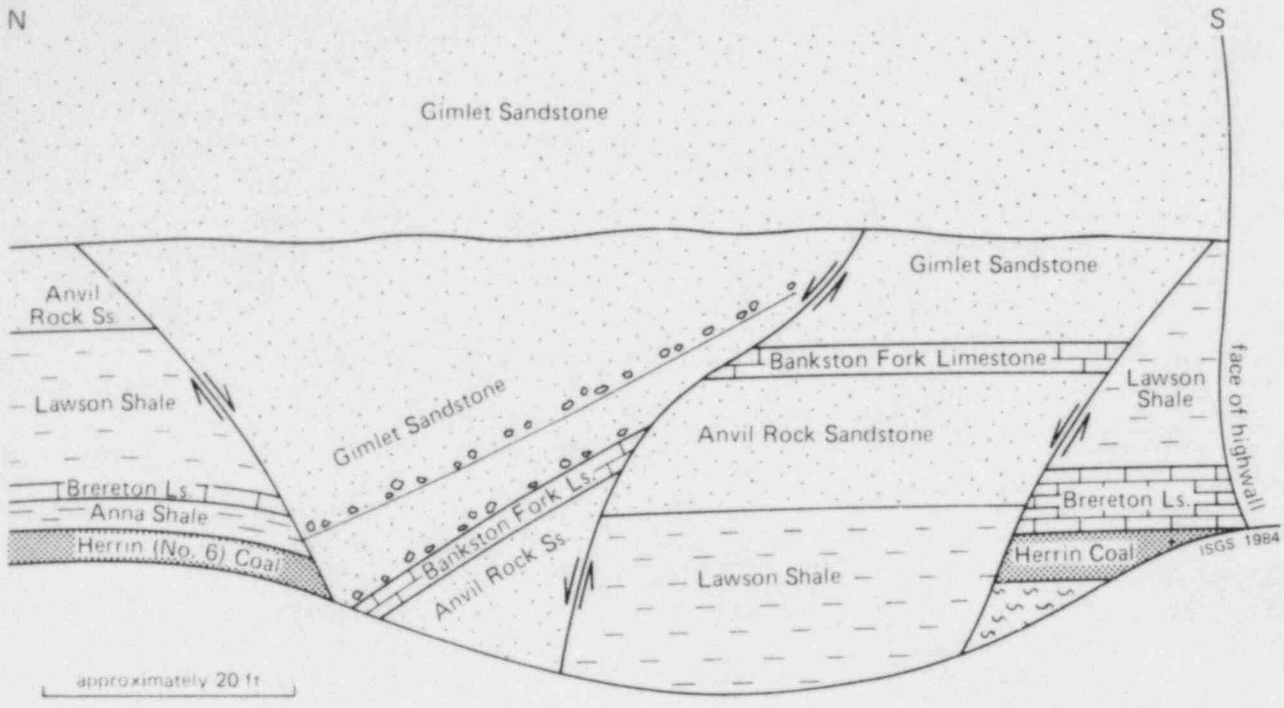


FIGURE 27. Paleoslump in highwall of Peabody Coal Company's Eagle Surface Mine.

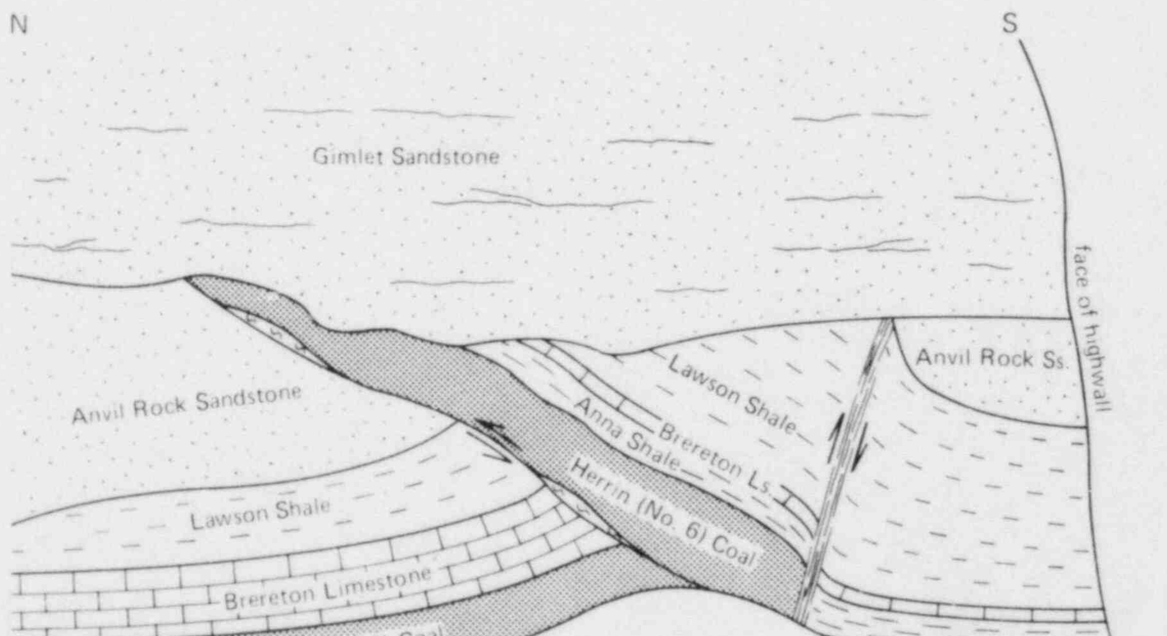


FIGURE 28. Thrust fault exposed on highwall of abandoned Peabody Eagle Surface Mine. Fault is truncated at base of Gimlet Sandstone, so it must have developed before that unit was deposited. The thrust is probably the toe of a paleoslump, but direct tectonic faulting cannot be ruled out.

than 50 feet deep in places. Closely-spaced test holes show that the walls are steep; in several places, slump blocks, probably undercut banks of the stream, lie within the channels.

The slumping seems readily explainable, but the form of the channel arouses suspicion of tectonic control. The Gimlet Sandstone of the southern Illinois is a flood-plain or deltaic deposit; mapped channels are sinuous or meandering and branching, and rarely more than 30 feet thick (Orlopp, 1964). Broad, sluggish, and shallow distributaries, rather than narrow and deeply incised cutouts, would be expected. Perhaps abrupt tectonic uplift of a portion of the delta induced rapid downcutting, as streams sought base level.

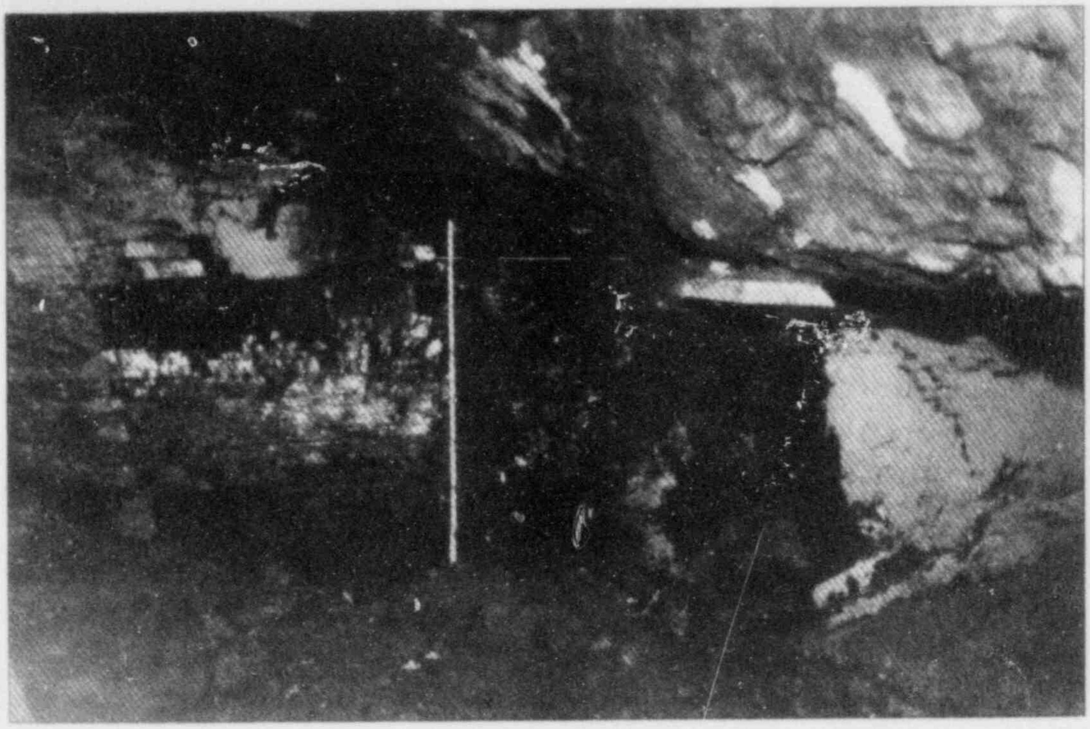
Within the Camp 11 Mine a series of linear structures, known to the miners as "horsebacks," has been mapped. Horsebacks are narrow protrusions of the overlying Providence (Brereton) Limestone into the Herrin (W. Ky. No. 11) Coal. They are straight, or nearly so, and all of them trend N 45° W. Their width varies from a few feet to about 25 feet, and they can be traced for several hundred to more than a thousand feet along strike. In cross-section (fig. 29) a horseback may resemble a graben, bounded by curving, medium to low-angle, normal faults that die out both upward and downward; however, some horsebacks displace the coal without faulting--the coal layers are ruptured or pushed downward.

The horsebacks clearly formed while the peat and enclosing sediments were still soft, not yet lithified. Limy material intricately injected into coal can be seen along margins of some horsebacks. The layers of coal are bent, sometimes contorted; they may be offset by shear planes but never are shattered or brecciated. Claystone bands in the coal seam and in the floor deformed in a totally plastic manner.

Horsebacks at Camp 11 are similar to the clastic dikes found in coal seams in many parts of the Illinois Basin (Krausse et al., 1979-A, 1979-B; Nelson, 1983). Both clastic dikes and horsebacks evidently formed through downward pressure of overlying sediments on layers of peat that were being stretched apart laterally. However, clastic dikes, at least those in the Herrin Coal of central Illinois, are randomly oriented. Detailed mapping reveals that their distribution commonly reflects depositional patterns of the sediments immediately overlying the coal seam (Krausse et al., 1979-A and B). In contrast, horsebacks of Camp 11 all run in the same direction. The extensional stresses that formed them must have been directed stresses (i.e., tectonic).

Another feature that suggests movement contemporaneous with Pennsylvanian sedimentation along the RC-SFS is the curving normal fault shown in figure 17. As already discussed, the form of this structure strongly suggests gravitational slumping, triggered by tectonic faulting, of partly lithified sediments.

Permian and later movements. Although the RC-SFS was active recurrently for much of the Paleozoic era, the faults mapped at the surface are largely, if not entirely, post-early Permian in age. Upper Pennsylvanian and lower Permian rocks are cut by the faults and, with a few possible exceptions (noted in the preceding section), they were fully lithified when they were deformed.



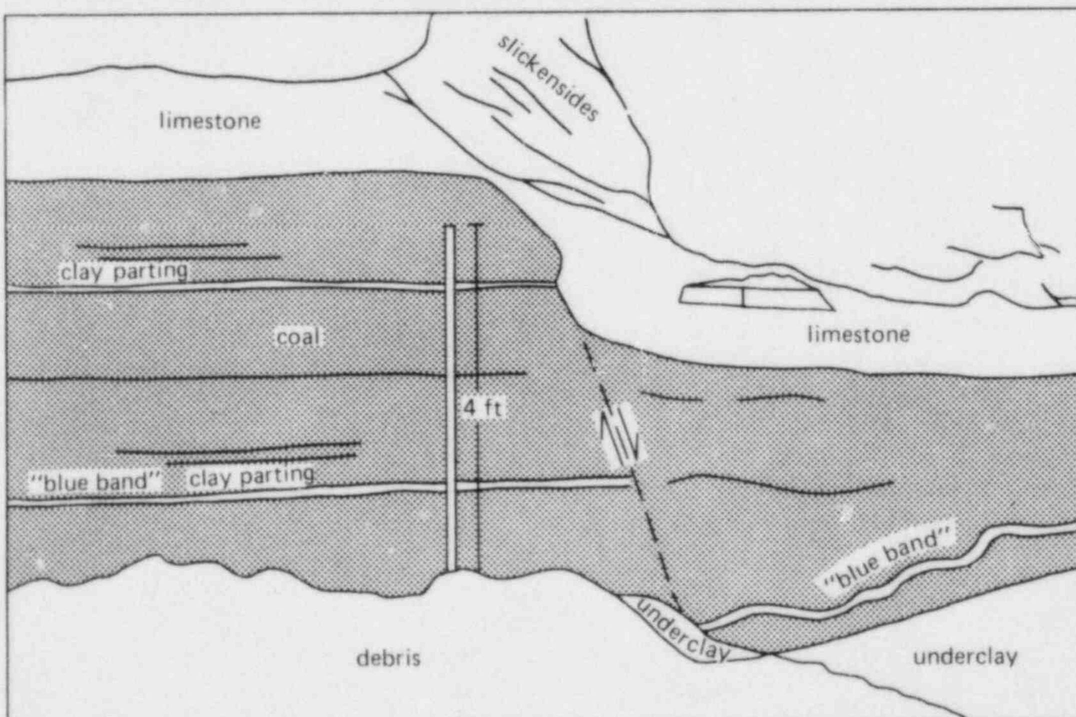


FIGURE 29. Northwest-trending linear protrusion ("horseback") of the overlying limestone into the Herrin Coal at Peabody Coal Company's Camp 11 Mine, Union County, Kentucky. Coal has undergone brittle (shearing) and plastic (tightly contorted folding) deformation beneath the horseback: plastic faulture indicates that the sediments were unlithified when the structure developed.

Permian strata probably covered much of the region when tectonism commenced. These rocks have been removed by later erosion, except in the Mauzy graben.

Rocks of Mesozoic age are totally unknown and only a few scattered outliers of Tertiary deposits have been found near the RC-SFS. Remnants of Mounds Gravel in the Shawneetown Hills are widely removed from their closest counterparts south of the fault zone. The only other Tertiary sediments near the zone are gravels, fragments of terraces, in the Curdsville (Fairer and Norris, 1972) and Calhoun (Johnson and Smith, 1975) Quadrangles, McLean County, Kentucky. These gravels occur at approximately similar elevations on opposite sides of the fault zone; but no conclusions regarding possible Tertiary tectonism can be drawn from such meagre findings.

Definitive Pleistocene outcrops overlying bedrock faults are rare. The best we have found is in the roadcut near the summit of Gold Hill, where Peoria and older loesses show no deformation above a fault cutting Pennsylvanian rocks. Several small exposures in stream beds reveal no offset of the bedrock surface along faults overlain by Quaternary alluvium. These findings are scarcely definitive, but do serve as negative evidence.

We found no traces of fault scarps, offset terraces, or other possible tectonic disturbances in any Quaternary deposits in or near the RC-SFS. To our knowledge, neither have any other geologists.

Heinrich (1982) examined in detail the deposits of glacial Lake Saline, and noted no structural disruptions that could be interpreted as resulting from seismic activity. He also mapped a series of subtle ridges, apparently longitudinal bars, in the Maumee flood deposits above the Shawneetown Fault Zone. No sign of offset can be detected in these features.

In contrast, Quaternary alluvium in the Reelfoot Rift area displays obvious deformation resulting from seismic events. Such features as sand blows, fault scarps, fissures, and sunken and uplifted areas were evident to the earlier observers and can be seen today (Fuller, 1912; Nuttli, 1973). Many disturbances date from the 1811-1812 earthquakes, but others are older. Faults displacing Tertiary sediments also have been documented (Stearns, 1980; Hamilton and Zoback, 1982). The fact that no such items have been identified or even suspected along the RC-SFS leads to a strong presumption that they do not exist.

To summarize, field evidence indicates that near-surface faults in bedrock of the RC-SFS developed after the early Permian Period and before the Pleistocene Epoch. Regional considerations, to be discussed later in this report, indicate that major movements were pre-Cretaceous.

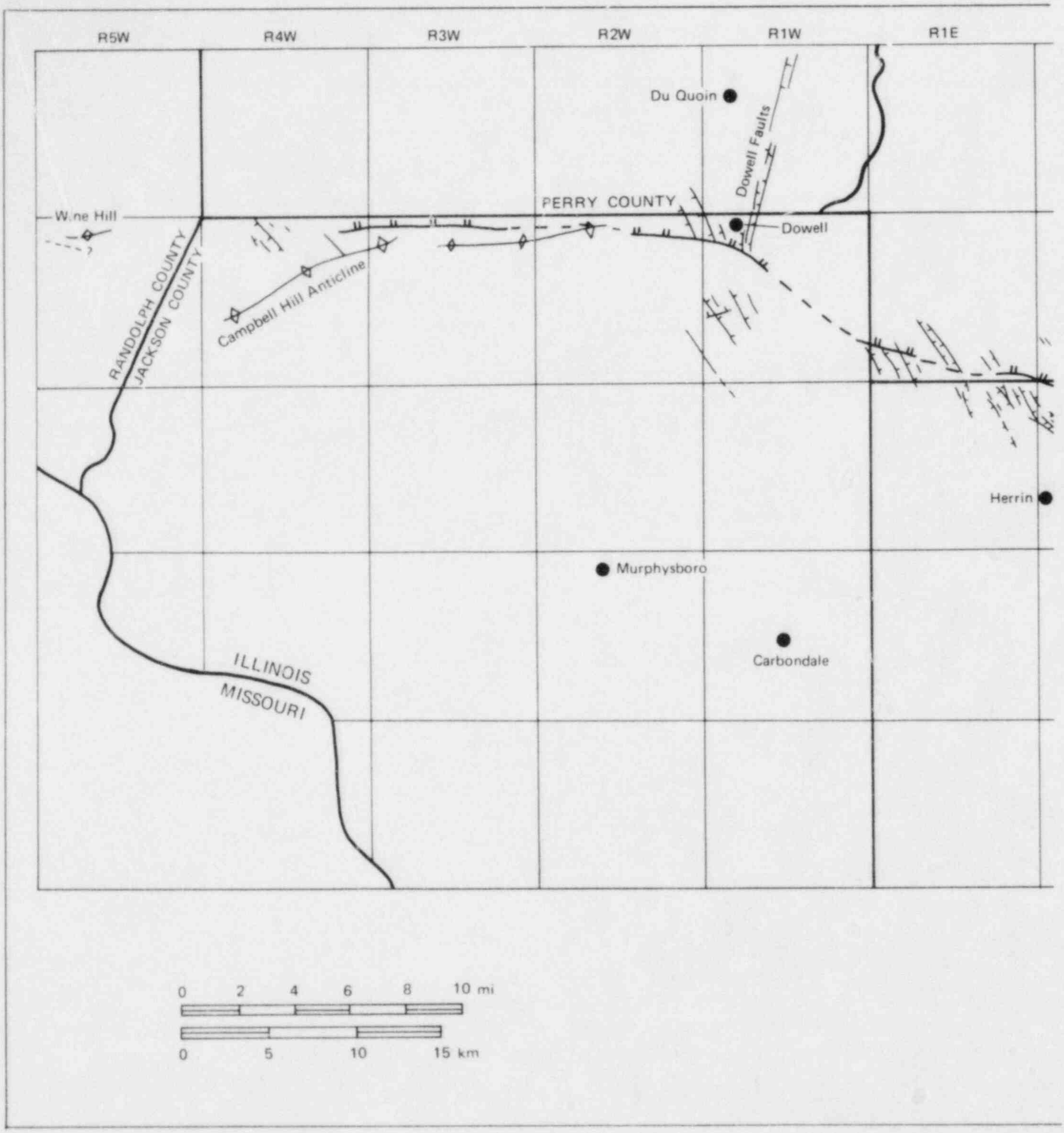
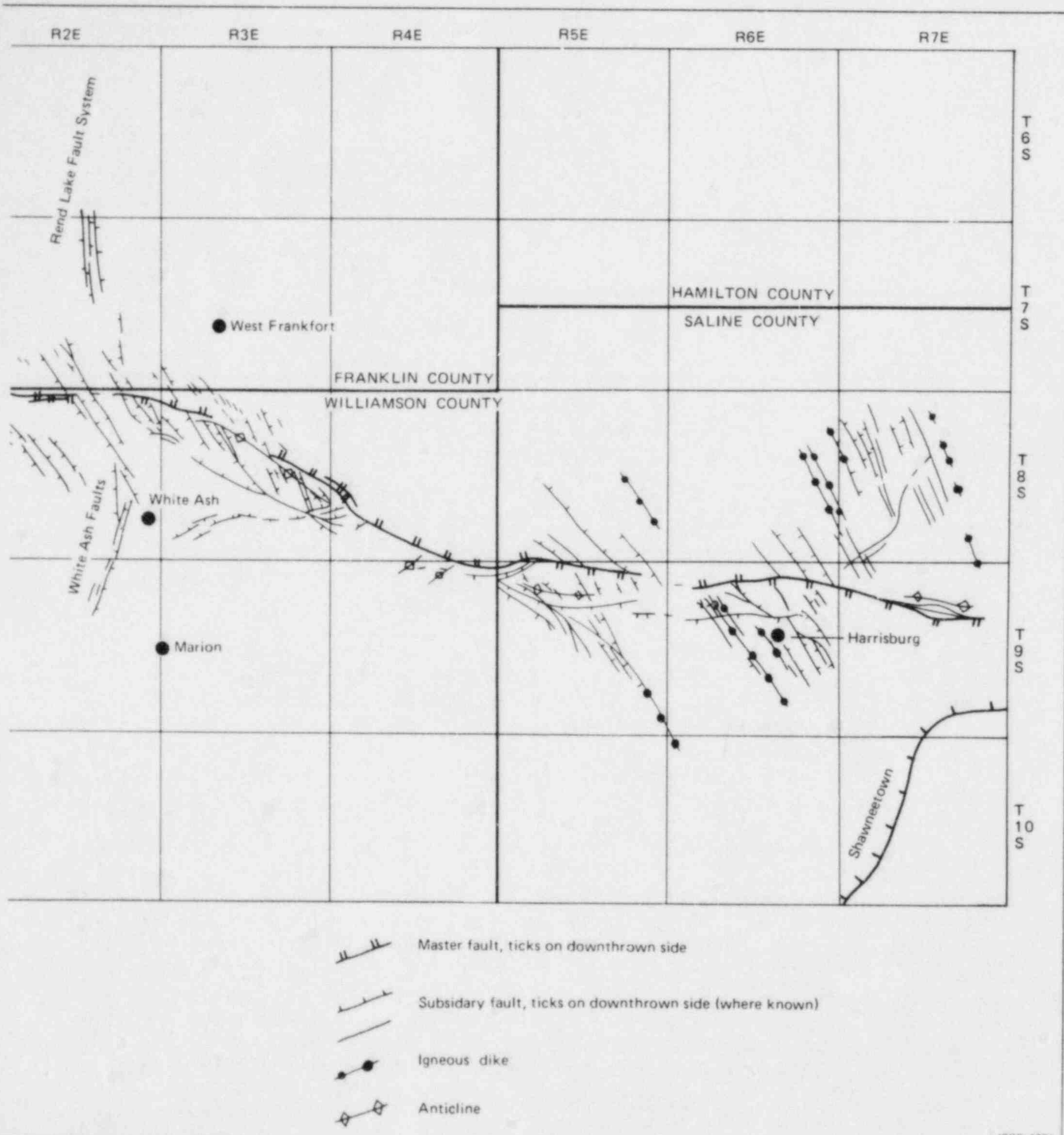


FIGURE 30. The Cottage Grove Fault System (from Nelson, 1981).


R2E
R3E
R4E
R5E
R6E
R7E
T 6 S
T 7 S
T 8 S
T 9 S
T 10 S
Rend Lake Fault System
HAMILTON COUNTY
SALINE COUNTY
West Frankfort
FRANKLIN COUNTY
WILLIAMSON COUNTY
White Ash
White Ash Faults
Marion
Harrisburg
Shawneetown
Master fault, ticks on downthrown side
Subsidary fault, ticks on downthrown side (where known)
Igneous dike
Anticline
ISGS 1981

COTTAGE GROVE FAULT SYSTEM

Extent and nature of faulting

The Cottage Grove Fault System (CGFS) extends westward across southern Illinois from west-central Gallatin County at least as far as northwestern Jackson County, a distance of roughly 70 miles (fig. 30). The system contains three structural elements (Nelson and Krausse, 1981).

- The "master fault", a single west-trending fault or zone of subparallel high-angle faults forming a braided pattern. A right-lateral strike-slip fault, it has a maximum vertical offset of about 200 feet.
- Subsidiary faults, mostly northwest-trending high-angle normal and oblique-slip faults, diverging from the master fault. Displacements range from inches to several tens of feet. In Saline and Gallatin County some contain igneous intrusions.
- Subsidiary anticlines, adjacent to the master fault, subparallel with it, or obliquely oriented in right-handed en echelon sets.

The CGFS is known largely from exposures in underground coal mines and, to some degree, from drilling. Many faults are too small to be detected by drilling. Surface exposures are rare: most of the area is covered by Pleistocene glacial till, lacustrine and alluvial deposits, loess, and soil. The fault system has limited topographic expression.

The western extent of the CGFS is poorly known because of the scarcity of data. Faulting is known no farther west than the Campbell Hill Anticline in northwestern Jackson County. The Wine Hill Dome and Bremen Anticline in eastern Randolph County lie roughly in line with the CGFS; their orientation is similar to that of typical subsidiary anticlines of the CGFC, but any link to the Ste. Genevieve Fault Zone, as Heyl et al. (1965) proposed, is purely speculative.

The eastern end of the CGFS lies within our area of detailed study (plates 1a and 2). The master fault can be traced across the Rudement Quadrangle on the basis of dense coal-exploratory drilling and scattered oil test holes. A well in the SW 1/4 NW 1/4 NE 1/4 Section 13, T. 9S., R. 7E, penetrated the master fault, which at this location is geometrically a normal fault: approximately 90 feet of section, including part of Clore Formation and Palestine Sandstone, are missing on the log. From this well the fault strikes due east and the amount of vertical offset rapidly diminishes. The fault crossed the workings of the Gallatin Coal and Coke Company "West Side Mine" (abandoned in 1925), on the west side of the village of Equality. According to Newt Glover (personal communication, 1983), a retired miner who worked in the West Side Mine and still resides in Equality, the fault was a sharp, nearly vertical break along which the Springfield Coal dropped about 5 feet to the north. Immediately east of the West Side Mine is the Pekin Coal Co. Pekin Mine, abandoned in 1957; the map of the mine shows an area of abnormally large pillars, indicative of difficult mining conditions, directly in line with the master fault and south of the hoisting shaft of the mine. Ira Adams of Equality, who owned and operated the mine from 1946 until 1957, told us (1983) that there were no actual offsets in the coal in that part of the mine, but that the limestone roof was "rolly" and the workings abnormally wet. We can speculate that the roof may have been fractured, or cut by a strike-slip fault that had no vertical component of displacement. East of the Pekin Mine, however, there is no evidence for an east-trending fault, although the area has been thoroughly drilled. Accordingly, we believe that the eastern terminus of the Cottage Grove master fault lies in or near the Pekin Mine, NW 1/4 Section 16, T. 9S., R. 8E., Gallatin County (plates 1a and 2).

Several northwest-trending subsidiary faults are present in the northeastern part of the Rudement Quadrangle (plates 1a and 2). The largest one strikes N 25° W and extends more than 2 miles south of the master fault. It is exposed on the highwall of an abandoned strip mine in the NE 1/4 SE 1/4 SW 1/4, Section 23, T. 9S., R. 7E., where it is a high-angle normal fault; its southwest side is downthrown about 61 feet. An oil well drilled about 1/4 mile from this location did not noticeably penetrate the fault but did encounter a 60-foot-thick sill of peridotite between the Beech Creek Limestone and the Fraileys Shale (Chesterian). No indications of igneous intrusion are visible at the surface. Farther northwest the fault is delineated by densely spaced coal test drilling; near the master fault the N 25° W-trending fault reverses its direction of throw so that the northeast side is downthrown. The reversal possibly reflects a component of strike-slip motion, as is common for many subsidiary faults in the CGFS (Nelson and Krausse, 1981). Other subsidiary faults include two high-angle normal faults with 3 and 5 feet of throw, observed in the highwall in W 1/2 NE 1/4 Section 23, and a fault in SW 1/4 Section 10 and NW 1/4 Section 15, indcated by drilling.

Origin

Clark and Royds (1948) were the first to speculate publicly that the Cottage Grove Fault System is a wrench fault. Heyl and Brock (1961) presented evidence that the movement was right-lateral. Subsequent researchers--Heyl and Brock (1961), Heyl (1972), Wilcox, Harding, and Seely (1973), and Nelson and Krausse (1981)--concur, as do we. The CGFS presents a classical example of dextral shearing.

Some amplifying evidence should be cited. Recently we observed a portion of the master fault zone in a surface coal mine in west-central Saline County. Fault surfaces showed prominent horizontal to subhorizontal slickensides and mullion; although the degree of shearing was intense, vertical offsets were small and inconsistent. At the Orient No. 4 Mine, in eastern Williamson County, we examined a fault having roughly 50 feet of left-lateral offset, shown by displacement of lithologic contacts between shales above the coal. The fault plane is nearly vertical, with horizontal slickensides; vertical offsets range up to about 10 feet. The fault trends N 45° E, intersecting the master fault at an angle of about 65°. The left-lateral fault thus is an excellent example of a conjugate or second-order strike-slip fault (Moody and Hill, 1956; Tchalenko and Ambraseys, 1970), fitting the overall pattern of right-lateral shearing in the CGFS (fig. 31).

Therefore, the CGFS and Rough Creek-Shawneetown Fault System are not physically connected, and formed in different ways: the first by horizontal movement, the second by vertical movement. The two systems may be related to a common ancestral zone of weakness in the basement, but the faults in Paleozoic rocks are

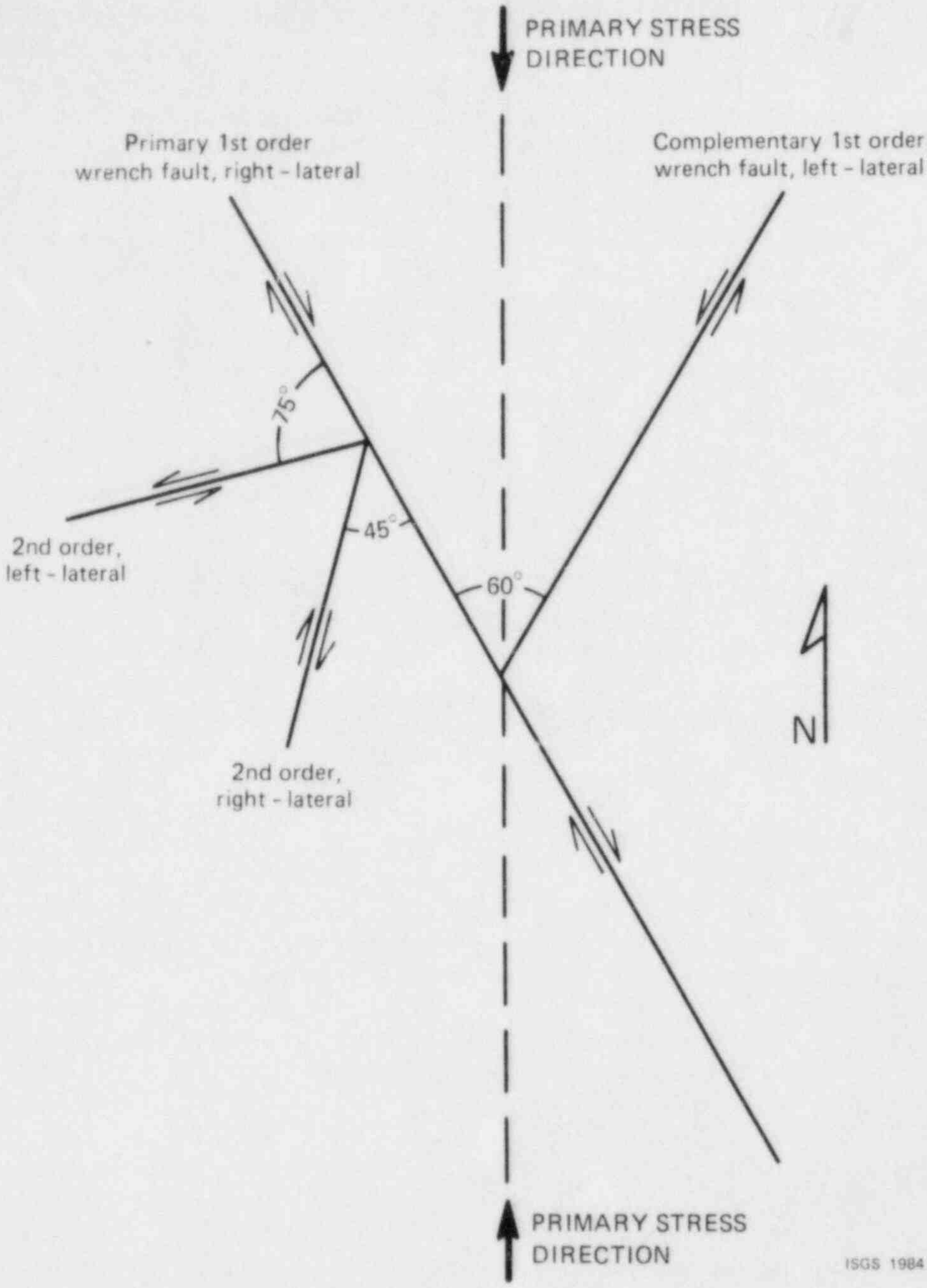


FIGURE 31. Plan of wrench faulting illustrating second-order (conjugate) faulting (modified from Moody and Hill, 1956). If the primary fault is right lateral, as in the CGFC, the second-order wrench makes an angle of 45 to 75 degrees to the primary fault.

separate and genetically unique--contrary to the assumptions of Heyl (1972) and many others.

Time of faulting

The time of formation of the Cottage Grove Fault System can be fixed quite precisely through radiometric age determinations of associated igneous rocks.

Many of the northwest-trending subsidiary faults in Gallatin, Saline, and eastern Williamson Counties are intruded by igneous rocks. Intrusions have been observed in numerous underground coal mines and have been defined by coal-test drilling. The rock, described as lamprophyre or mica peridotite (Clegg, 1955), typically forms dikes, although locally it has been squeezed laterally between rock layers or has burned out and replaced coal seams to produce sills. Dikes range from a few hundred feet to several miles long and are a few feet to 300 feet wide. Like the faults they follow, they are vertical or steeply inclined. Coal adjacent to intrusives is coked and mineralized; shale has been baked (Clegg and Bradbury, 1956).

Clearly, the faults already existed when the dikes formed. The fractures acted as pathways for the magma. The fact that the intrusions are of ultramafic character suggests that the fractures extended clear into the earth's mantle.

Unpublished ISGS field notes report that, in a few cases, igneous rocks have been offset by later movements along the host faults. Most such displacements are vertical, but in one case horizontal slickensides were observed on a fracture in peridotite. Offsets in igneous rocks are slight; most of the faulting took place before intrusion, but minor movements continued in places after magma had hardened.

Geochron Laboratories of Cambridge, Massachusetts obtained potassium-argon dates on three samples of peridotite from dikes in the Cottage Grove Fault System. As previously mentioned, an age of 261 ± 9 million years was determined for the dike at Cottage Grove, and an age of 262 ± 9 million years for a core sample from a second intrusion immediately west of the Rudement Quadrangle, in Section 11, T. 10S., R 5E., Saline County. A third peridotite, from the "Absher Dike," exposed in an abandoned strip mine in Section 34, T. 9S., R. 4E., Williamson County, was found to be 246 ± 9 million years old. These results agree closely with those of Zartman et al. (1967) for igneous rocks in the fluorspar district, and indicate early Permian intrusion.

The youngest rocks observed to be faulted in the CGFS belong to the upper part of the Modesto Formation, or early Missourian age. Since all field evidence indicates that these rocks were well lithified at the time of faulting, the movements probably did not commence until latest Pennsylvanian (Virgilian) or early Permian (Wolfcampian) time.

There is considerable evidence to suggest that an ancestral Cottage Grove fault of large displacement was continuous with the ancestral Rough Creek-Shawneetown fault; that is, the northern boundary of the Rough Creek graben, dating to Cambrian time. The deep wells in Johnson and Pope Counties penetrated slightly thickened Croixan (upper Cambrian) strata; the Johnson County

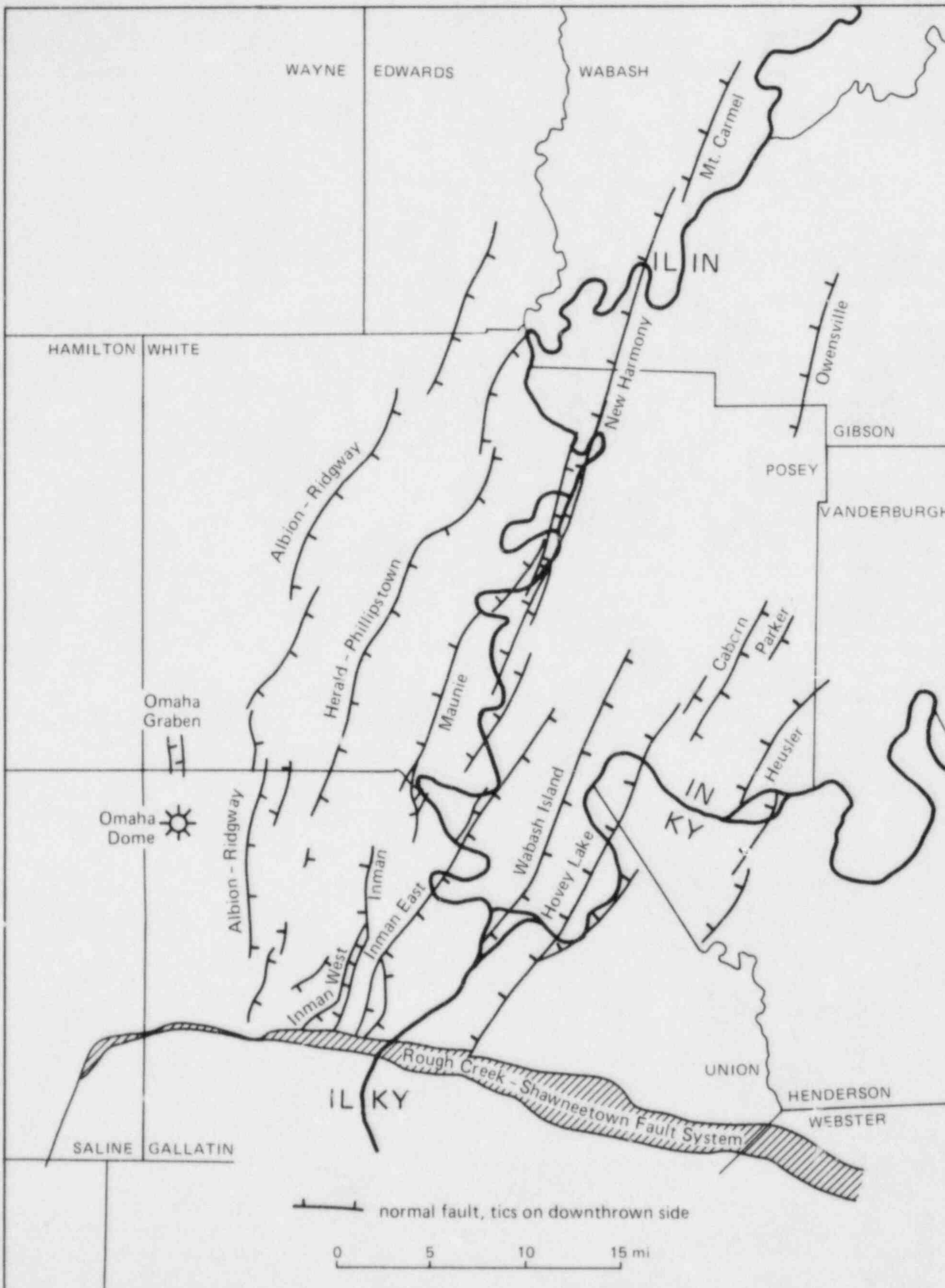


FIGURE 32. Wabash Valley Fault System, modified from Ault, Sullivan, and Tanner (1980), Bristol and Treworgy (1979), and Schwalb and Potter (1978).

well reached pre-Mt. Simon Sandstone south of the CGFS. Seismic sections indicate large and complex faults in lower Paleozoic and Precambrian rocks along the CGFS (Howard Schwalb, personal communication, 1983). Furthermore, Strunk's (1984) gravity data suggest continuation at depth of the Cottage Grove and Rough Creek-Shawneetown zones. The soutnern block may have been downthrown by thousands of feet on this precursor to the modern CGFS.

WABASH VALLEY FAULT SYSTEM

Extent and nature of faulting

The Wabash Valley Fault System (WVFS) extends northward from the Rough Creek-Shawneetown Fault System (RC-SFS) along the Wabash River valley in southeastern Illinois, southwestern Indiana, and Union and Henderson Counties, Kentucky (fig. 32). The system is about 55 miles long and up to 30 miles wide: it is composed of north-northeast striking high-angle normal faults with vertical offsets as great as 480 feet. The faults are known from subsurface information and exposures in underground coal mines; surface expression is lacking because of the cover of glacial and alluvial sediments. Because many areas along the faults have been densely drilled for oil, gas, and coal, detailed information is available on structure.

Several Wabash Valley faults reach, but do not cross, the RC-SFS. In the Shawneetown Quadrangle (plates 1a and 2), the Inman and Inman West Faults definitely intersect the Shawneetown front fault. Drilling in Sections 26 and 35, T. 9S., R. 9E., reveals nearly 200 feet of vertical offset on the Inman Fault 1/4 mile north of the front fault. This displacement increases to 300 feet northward in Section 13. The Inman West Fault has a similar amount of throw; together with the Inman Fault it forms a graben. The Inman Graben does not cross the front fault. No faults with the proper orientation and throw can be seen in the lower Pennsylvanian sandstones that are almost continuously exposed on the north face of Gold Hill immediately south of the Inman Graben. The Inman East Fault may also connect with the front fault, but its displacement is 50 feet or less at the junction point. About 8 miles eastward, in Union County, Kentucky, the Hovey Lake Fault reaches the northern edge of the RC-SFS. The Hovey Lake Fault is a compound fracture zone, with displacements as large as 350 feet on individual breaks near the junction with the RC-SFS; it does not continue south of the RC-SFS.

Other faults of the WVFS lose displacement southward and die out before they reach the RC-SFS.

Exposures in underground coal mines show that Wabash Valley faults are typical dip-slip normal faults. Inclinations of fractures range from 60^{0} to vertical; slickensides are vertical or nearly so, and drag is normal. Minor reverse flexures, apparently resulting from compressive wedging of narrow slices of rock along large faults, are seen locally. Brittle failure of coal and shale indicates that rocks were completely lithified when faulted. Many fractures, up to several inches wide, are filled with calcite or other minerals--clear evidence of horizontal extension at right angles to the fault surfaces.

Faults of the WVFS tend to merge and die out at depth. Bristol and Treworgy (1979) and Ault, Sullivan, and Tanner (1980), reported several instances of fault zones that are more complex in Pennsylvanian than in Mississippian rocks, and noted that some small faults die out downward; however, large faults appear to maintain displacement at least through the Mississippian section. Evidence on deeper structure, which comes from seismic profiling (Braile, Sexton and Hinze, 1983) shows that the Albion-Ridgway and New Harmony Faults lose displacement at depth. Near-surface offsets of 200 to 300 feet diminish to less than the resolution of the profile (about 100 feet) below the Croixan (upper Cambrian) Eau Claire Formation. Prominent Precambrian reflectors exhibit large offsets--apparently due to faulting--but these do not connect with Wabash Valley faults in the Paleozoic strata.

One igneous intrusion has been reported in the WVFS: a dike trending N 10^{o} E, encountered in the easternmost workings of the now-abandoned B. and W. Coal Company Mine (E 1/2 SE 1/4 NW 1/4, Sec. 18, T. 9S., R. 9E., Equality Quadrangle, Gallatin County). Associated with the intrusion was a fault with 4 feet of throw. Immediately to the east is the Ridgway Fault, a major normal fault with the east side downthrown approximately 150 feet. As is the case with dikes in the CGFS, the coal was metamorphosed and mineralized along the igneous body in the B. and W. Mine.

Injection of magma evidently is responsible for Omaha Dome, a nearly circular uplift centered 4 miles west of the Ridgway Fault in Section 4, T. 8S., R. 8E., Gallatin County (fig. 32). Closure on the Omaha Dome decreases from more than 200 feet on the Herrin (No. 6) Coal to zero in Devonian and older strata. Igneous rocks have been struck in many wells: dikes in near-surface Pennsylvanian rocks, and sills or laccoliths at greater depth (Pullen, 1951). According to Howard Schwalb (personal communication, 1983), the sedimentary strata are progressively arched above a series of horizontal tabular intrusions in Devonian and Mississippian rocks. The igneous bodies may resemble a Christmas tree in cross-section, with sills and laccoliths spreading away from a vertical central feeder.

Radiometric dating of samples of igneous rock from the Omaha Dome yielded two different ages--290 and 408 million years (Bikerman and Lidiak, 1982). The former age, regarded as a maximum age by Bikerman and Lidiak, is about 30 million years older than that we obtained on peridotites from the CGFS, while the latter age, older than the country rock, clearly is anomalous.

Origin

The WVFS clearly is the product of horizontal extension of the earth's crust at right angles to the trends of the faults: that is, the region was pulled apart laterally from the west-northwest and east-southeast. As the strata ruptured, blocks subsided to varying degrees, producing grabens, horsts, and step-faults. These are classic gravity faults; they show no evidence of significant reverse, strike-slip, or differential uplifting movement.

The faults die out downward. Some of them may reach the basement, but do not necessarily penetrate it. In contrast, the CGFS, with its ultrabasic intrusions, probably extends all the way to the mantle. The RC-SFS also probably cuts the entire crust; it is difficult to conceive that faults of this magnitude do not.

The fact that the WVFS joins, but does not cross the RC-SFS admits more than one interpretation. One is that the RC-SFS is older; the WVFS extended itself southward until it met the RC-SFS but did not bridge the latter because tensional stresses were relieved by slippage along pre-existing west-trending faults. A second possibility is that both fault systems developed at the same time. Yet another hypothesis is that the WVFS is older, and originally terminated north of the line where the RC-SFS appeared. As the latter system developed, new shearing stresses were applied to the WVFS, causing several of the fractures to propagate themselves southward to the RC-SFS. Little force is required to expand a crack once it has formed.

Because we have not been able to examine the intersection of the two fault systems, we cannot say, on the basis of direct evidence alone, which is older, but must apply other considerations to determine relative ages of the faults.

Heyl (1972), Braile, Sexton and Hinze (1983), and others have postulated that the WVFS is a northeastward extension of the Reelfoot Rift and thus is a major, recurrently active zone of extension that penetrates the crust of the earth. However, Braile, Sexton, and Hinze's seismic data do not suggest such a conclusion. They ran only two east-west lines, only one of which crosses the entire WVFS. The profiles show apparent faults in the basement, but the orientation and regional distribution of these buried faults cannot be determined on the basis of only two lines. None of the faults in the basement connects with or directly underlies the Paleozoic faults. More evidence will be needed before anyone can speak authoritatively on ancestral structure of the Wabash Valley region.

Examination of a regional map of faults in southeastern Illinois and vicinity discloses an interesting pattern (fig. 33). North of the RC-SFS and the

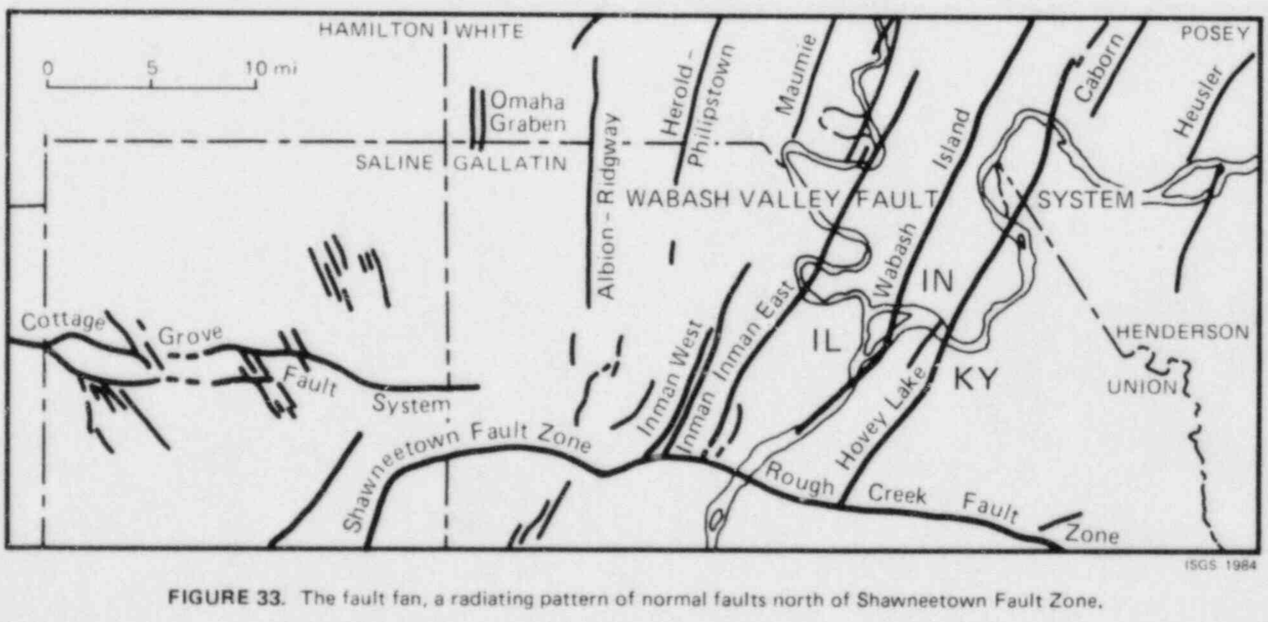


FIGURE 33. The fault fan, a radiating pattern of normal faults north of Shawneetown Fault Zone.

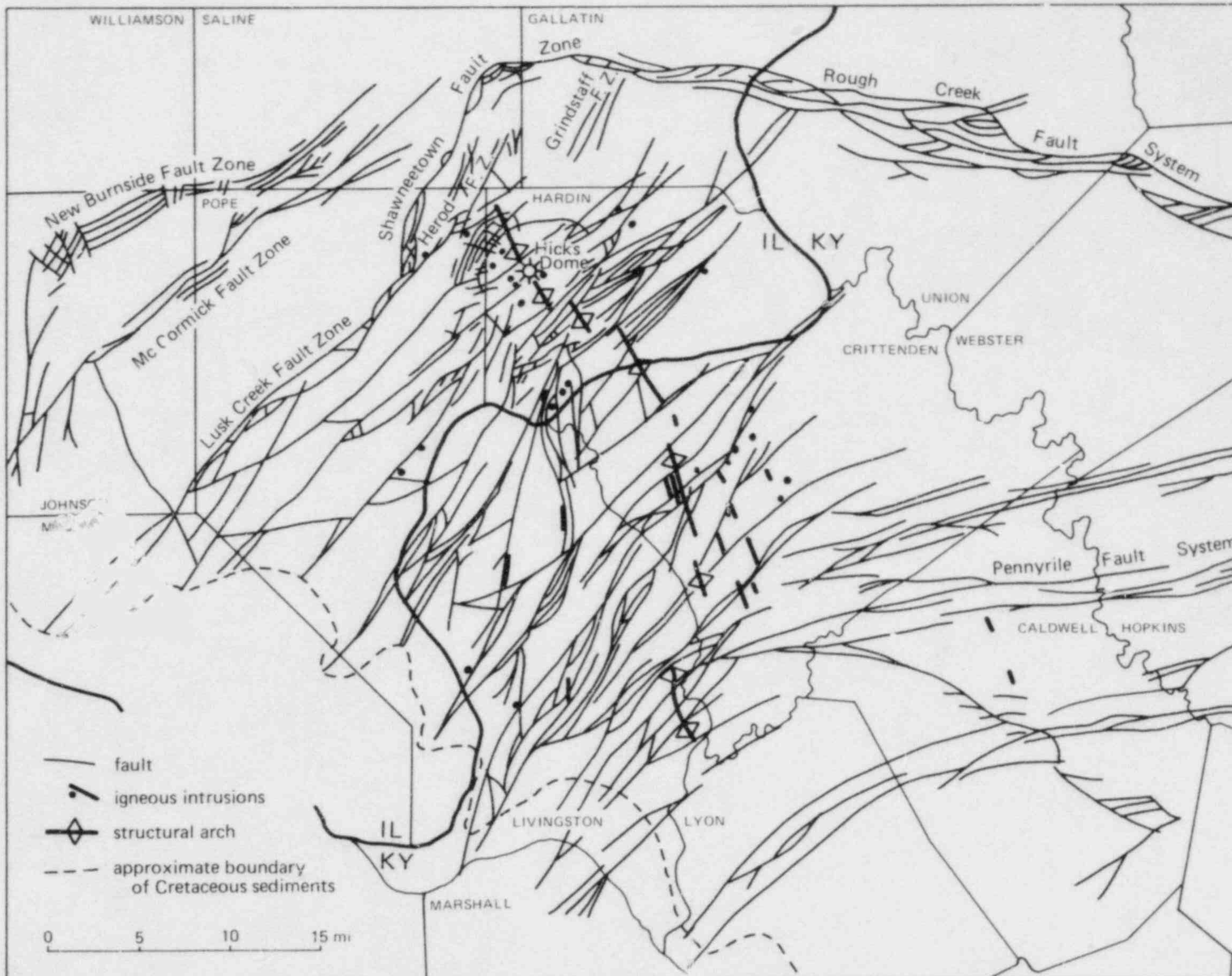


FIGURE 34. Fluorspar Area Fault Complex and associated structures (adapted from Trace, 1974; Schwalb and Potter, 1978; Treworgy, 1981; and Jacobson and Trask, 1983).

Cottage Grove master fault, the faults are arranged like the fingers of a hand or an outstretched fan. If projected southward, all of these faults would intersect in the vicinity of Hicks Dome, south of the Shawneetown Fault Zone. The "fault fan" includes the following features, from west to east:

- Subsidiary faults in the CGFS in western Saline County strike N 45° W.
- Subsidiary faults and peridotite dikes in eastern Saline County strike about N 25° W.
- The igneous dike near Cottage Grove strikes N 20° W.
- Two dikes north of Equality trend N 10° W.
- The Ridgway Fault runs due north.
- Inman Faults trend about N 20° E in their southern extent.
- Wabash Island Fault and others farther east strike about N 30° E.

All of the faults in the "fan" are normal or gravity faults, produced by horizontal extension at right angles to the traces of the faults.

The smooth transition in directional trend of faults in the "fan", from northwesterly to east-northeasterly, suggests that all these faults were formed in a common stress field centered near Hicks Dome.

This, in turn, suggests that the Wabash Valley and Cottage Grove Fault Systems formed in the same tectonic action.

Time of faulting

Data that would confirm the last statement are difficult to obtain. No materials between late Pennsylvanian and Pliocene-Pleistocene age (Mounds Gravel) are known in the vicinity of the Wabash Valley Fault System. Direct evidence allows us only to say that the faults are post-late Pennsylvanian and pre-Pleistocene.

The igneous intrusion at the B. and W. Mine along the Ridgway Fault probably is the same age as the peridotite in the Cottage Grove Fault System. This assumption points to an early Permian age for at least the Ridgway Fault, if not the entire system.

Radiometric ages of igneous rocks from Omaha Dome reveal little about the time of faulting. In the first plce, the dates themselves are questionable. In the second place, Omaha Dome may not be genetically related to the WVFS, and dome and faults may have formed at different times.

To summarize, the age of the WVFS cannot be definitely determined, but probably is early Permian, the same age as the Cottage Grove Fault System.

FLUORSPAR AREA FAULT COMPLEX

As the name implies, the Fluorspar Area Fault Complex (FAFC) is a complicated system of structures centered in the Illinois-Kentucky fluorspar-mining district (fig. 34). The FAFC lies immediately south of the Eagle Valley Syncline, mostly in Hardin and Pope Counties, Illinois and Crittenden and Livingston Counties, Kentucky. Its northernmost extremities reach the quadrangles we mapped in detail (plates I and II).

Nature of deformation

Unlike fault systems discussed previously, the FAFC is not unified tectonically; rather, it comprises several tectonic elements of different ages and origins:

- northwest-trending arch associated with Hicks Dome
- faults concentric and radial to Hicks Dome
- northwest-trending ultrabasic intrusions
- northeast-trending block faults

Northwest-trending arch and Hicks Dome. The Illinois-Kentucky fluorspar district is situated on a broad northwest-trending structural arch that is flanked by the Mississippi Embayment on the southwest and the Illinois Basin on the northeast. This arch has been greatly broken by later northeast-trending block faults, but its overall form is apparent on geologic maps (fig. 34). The arch culminates in Hicks Dome, a nearly circular uplift 10 miles across having 4,000 feet of uplift, in Hardin and eastern Pope Counties, Illinois. Middle Devonian limestone crops out at the domal apex and is surrounded by Upper Devonian, Mississippian, and Lower Pennsylvanian strata on the flanks. Dips decrease gradually outward from 20^{0} or more near the center to about 5^{0} on the outer edges of the structure.

Many diatremes (explosion breccias) occur in the vicinity of Hicks Dome. They take the form of vertical or steeply dipping pipes, dikelike bodies and small stocks up to about 1,000 feet in diameter; they are composed of fragments of sedimentary and igneous rocks, and sometimes crystals of hornblende and biotite, in a groundmass of pulverized rock that may be replaced by carbonate or mineralized with fluorite and metal sulphides or sulphates (Grogan and Bradbury, 1967). One of the largest diatremes was encountered in a well drilled in 1952 at the apex of Hicks Dome. Sidewall cores of breccia were obtained from depths around 2,000 feet, at the expected position of the St. Peter Sandstone. Core samples emitted unusually high radioactivity and were heavily mineralized with fluorite, apatite, metal sulphides, and other minerals (Brown, Emery and Meyer, 1954).

The presence of these diatremes has led most researchers to attribute Hicks Dome and the larger arch to various forms of igneous activity. Weller et al. (1920) believed that intrusion of magma at depth produced the uplift; subsequent shrinkage or partial withdrawal of magma led to collapse of parts of the dome. Currier (1944) called the intrusion laccolithic. Brown et al. (1954) proposed crypto-explosive origin: intruding magma, encountering and vaporizing groundwater, caused subterranean explosions of steam; the resulting voids were propped open with mixtures of rubble and igneous material. Heyl et al. (1965) and Trace (1974) concur with this theory. An aeromagnetic survey by McGinnis and Bradbury (1964) showed no magnetic anomaly under Hicks Dome; this was taken as evidence against a laccolithic body at depth, and in favor of crypto-volcanic origin for the uplift.

In recent years many "crypto-explosive" features in the United States have been reinterpreted as sites of meteoritic impacts. Some geologists have suggested (apparently not in print) that Hicks Dome, also, may be an astrobleme. Conceivably an asteroid-sized body might have slammed into the earth, breaking the crust clear through to the mantle and allowing igneous intrusion; the rebound of the impact area might have created the dome. However, no field evidence, such as shatter cones or high-pressure minerals, ever have been produced to support an impact theory for Hicks Dome. We consider the meteoritic hypothesis unlikely and believe that crypto-volcanic activity offers the most reasonable explanation for Hicks Dome.

Concentric and radial faults. Many faults concentric and radial to Hicks Dome have been mapped by Baxter and Desborough (1965) and Baxter, Desborough, and Shaw (1967). Concentric faults encircle the uplift from the south-southwest clockwise to the east-northeast. They are concentrated primarily in the outcrop belt of lower Chesterian rocks 3 to 4 miles out from the center of the dome. Radiating faults are most prominent in the same zone, especially to the northeast, northwest, west, and southwest of the apex of Hicks Dome. Complex northeast-trending faulting obscures the radial and concentric fractures southeast of the domal crest.

Few structural details of these faults have been published. Like the great majority of fractures in the FAFC, radial and concentric faults appear to be vertical or steeply dipping. Most concentric faults are downthrown away from the center of Hicks Dome, but one, the Hamp Fault northeast of the axis, exhibits reversal of throw (Baxter and Desborough, 1965). Radial faults may be downthrown on either the right or the left side as viewed from the apex of Hicks Dome. Displacements vary from a few tens of feet to a maximum of about 500 feet; most fall near the low end of this range.

These faults clearly developed contemporaneously with Hicks Dome. Most probably are tensional features created during uplift, but some may have developed later because of local subsidence or collapse of portions of the dome.

Igneous intrusions. Dikes of mica peridotite and lamprophyre are common along the northwest-trending arch that transects the fluorspar district. Along with the dikes are explosion breccias (already described) on Hicks Dome.

Figure 35 shows that dikes lie along a north-northwest-trending belt approximately 55 miles long and up to 15 miles wide. The Hicks Dome lies near the center of this zone; dikes in the Cottage Grove Fault System (CGFS) make up the northwestern portion and intrusions in Crittendon, Livingston, and Caldwell Counties, Kentucky constitute the southeastern portion. Individual dikes trend subparallel to the zone as a whole with one exception--a northeast-striking dike near the core of Hicks Dome. As already noted, dikes in the CGFS form a splayed, fanlike pattern; a similar divergence of trend is shown southeast of Hicks Dome. In other words, the dikes radiate from Hicks Dome and are concentrated along a north-northwest-trending axis.

Dikes in the fluorspar district occupy north- to northwest-trending, vertically dipping, clean-cut faults. Strike-slip movement is indicated by horizontal slickensides and absence of significant vertical offset, and by the planar nature of the faults, contrasting with the curvature typical of northeast-trending fractures in the FAFC. Dikes and strike-slip faults are offset by (and therefore are older than) the northeast-trending faults. The intrusions have been dated radiometrically as early Permian, so the northeast-trending faults must have been active after early Permian time.

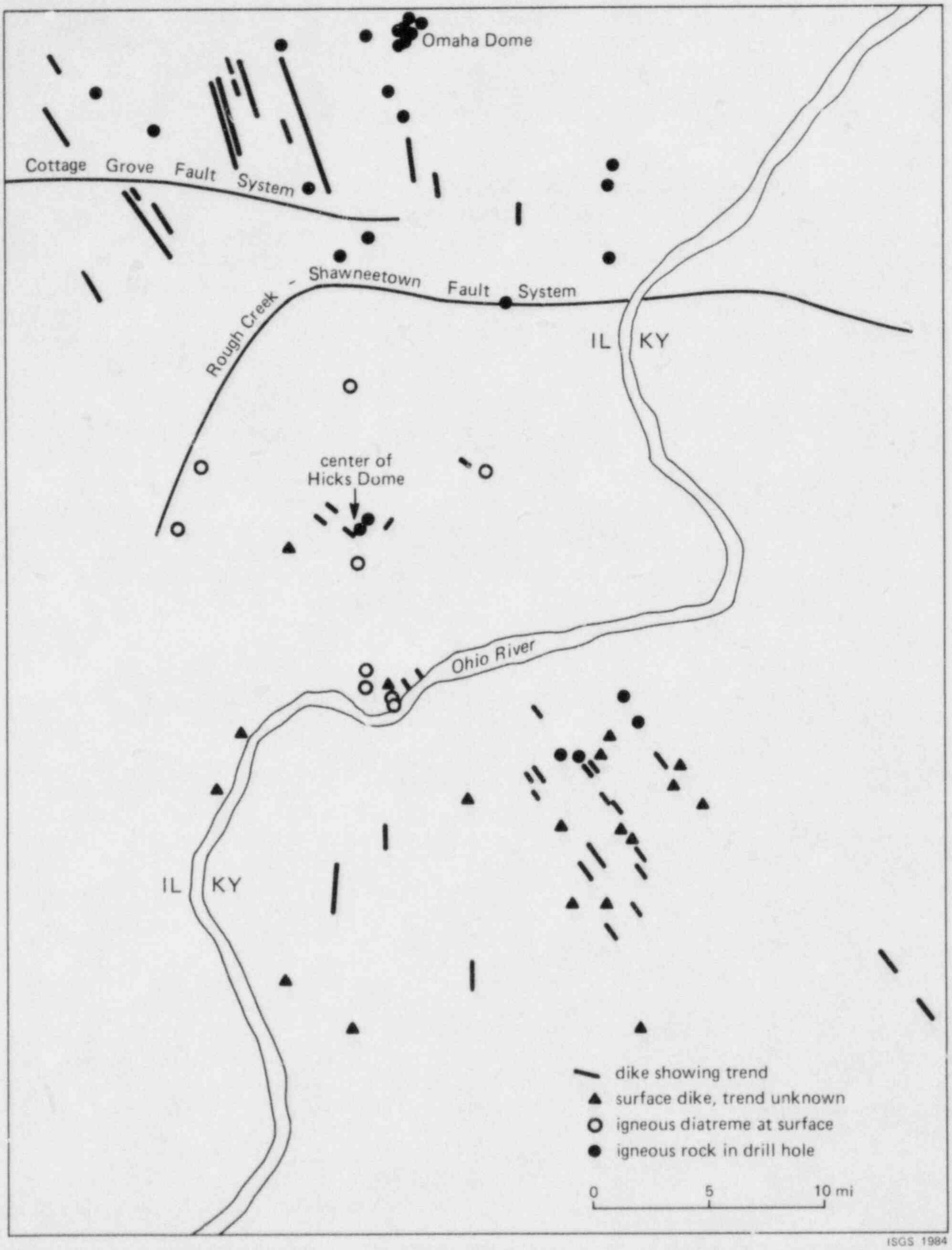


FIGURE 35. Igneous intrusions and diatremes in Illinois-Kentucky fluorspar district (modified from von Fresc, Hinze, and Braile, 1980).

Northwest-trending faults. Northwest-trending faults of the FAFC have attracted great economic interest because of their vein deposits of fluorspar and other valuable minerals; accordingly, these faults have been studied in great detail. Extensive surface mapping, exposures in dozens of underground mines, and closely-spaced exploratory drilling have yielded a wealth of data on the FAFC. More is known about structural details of these faults than about any other fault system described in this report.

Northeast-trending fractures continue well beyond the boundaries of the actual fluorspar-producing region (fig. 34). On the north most faults die out on the south flank of the Eagle Valley Syncline, but at least one fault in the Grindstaff Fault Zone may reach the Shawneetown Fault Zone. Southward, the faults disappear beneath Cretaceous and Tertiary deposits of the Mississippi Embayment. Intense faulting is bounded westward by the Shawneetown Fault Zone and its southwestward extension, the Lusk Creek Fault Zone; however, several important northeast-trending fracture zones, including the McCormick and New Burnside Faults, lie beyond. Eastward, the limits are even less definite, as northeast-striking faults of the FAFC curve eastward and merge with the Pennyrile Fault System and associated faults.

We emphasize that no clear demarcation exists between the FAFC and the southwest-trending portion of the Shawneetown Fault Zone (SFZ). For purposes of nomenclature, the SFZ ends in the S 1/2 Section 25, T. 11S., R. 6E., Pope County, where it merges with the Herod Fault Zone. The southwestward continuation of the combined Shawneetown-Herod Fault Zone is called the Lusk Creek Fault Zone (Baxter, Desborough, and Shaw, 1967). Detailed mapping (Klasner, 1982) shows that the southernmost tips of the SFZ curve as they connect with the Lusk Creek Fault Zone. The intersecting faults have similar magnitude of displacement and structural style. No indication exists that one system offsets the other, as would be expected were the SFZ and FAFC of different ages and stress regimes.

In short, the SFZ and the northeast-trending faults of the FAFC grade into each other in a manner strongly suggesting that they developed in the same action.

The transition between the FAFC and the Pennyrile Fault System is even more gradual, taking place by gentle eastward curvature of faults from northeasterly to easterly headings over most of Crittenden County (fig. 34). The Kentucky state geologic map of McDowell, Grabowski, and Moore (1981) shows this relationship clearly. The Pennyrile Fault System is a broad zone of subparallel high-angle faults, forming a braided pattern and overlying the southern edge of the buried Rough Creek Graben.

Therefore, one can view the FAFC as forming an oblique connection between the Rough Creek-Shawneetown Fault System and the Pennyrile Fault System--the two sides of the Rough Creek Graben.

Attitude and movement of faults

FAFC faults are high-angle: the vast majority of them are inclined more than 70° and many are essentially vertical (Weller et al., 1920; Baxter, Desborough and Shaw, 1967; Trace, 1974; Hook, 1974). A few faults dip as gently as 45°; most of these are small faults antithetic to adjacent larger high-angle faults

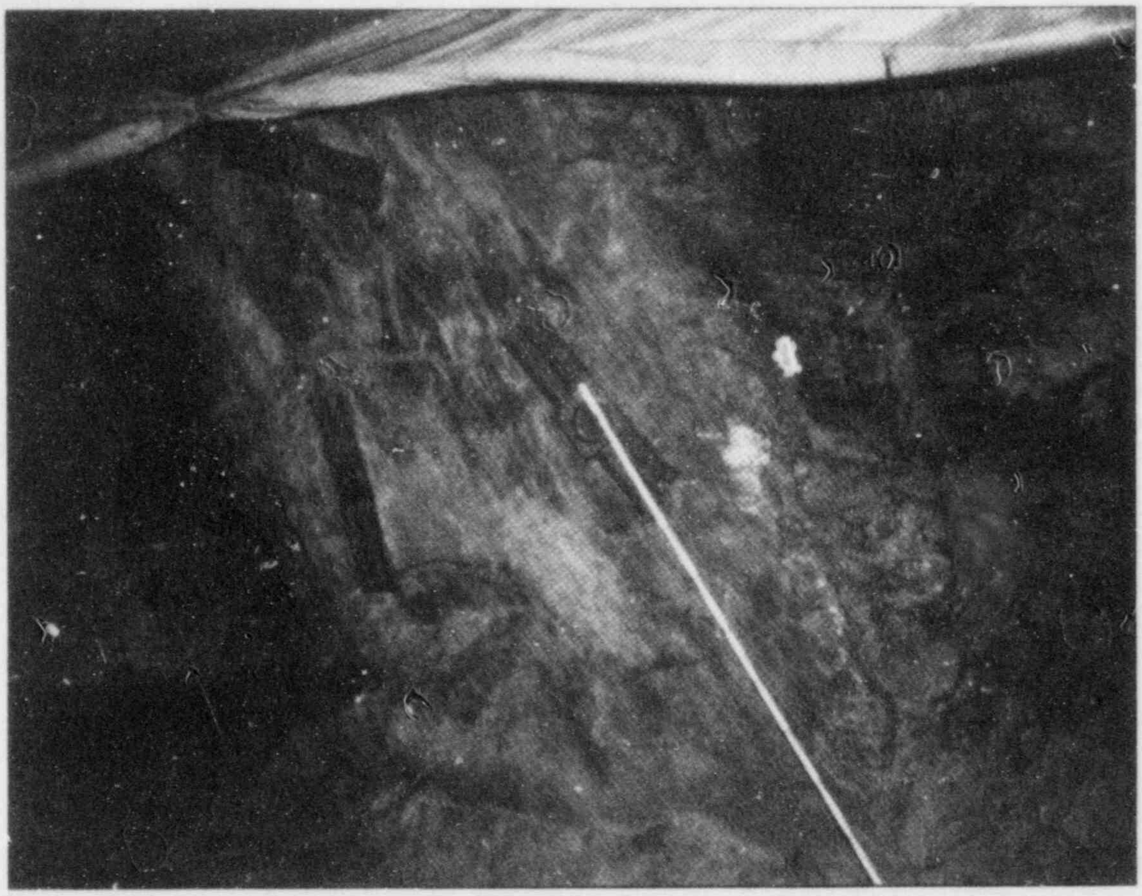


FIGURE 36. Plunging slickensides and mullion (parallel with 6-ft ruler) on hanging wall of West Vein in underground fluorspar mine of the Ozark-Mahoning Company. Attitude of slickensides is consistent throughout the mine and signifies oblique slip movement of the fault.

(Weller et al., 1920; Hook, 1974). None of the large faults are low- or medium-angle for any significant distance. As a result, curvature of faults in map view generally represents actual change in heading of the fault rather than interaction of irregular topography with inclined fault surfaces.

With few exceptions the faults are described as normal. Weller et al. (1920) cited the Shawneetown Fault Zone (southwestern terminus) and the connecting Lusk Creek Fault Zone, and possibly others as high-angle reverse faults. Weller et al. (1952) carefully examined the Lusk Creek Fault Zone and found it to be an exceedingly complex zone of normal and reverse faults, most of which dip southeastward. The overall downthrow is to the southeast and most of the strata in the narrow fault slices dip in the same direction. The Hogthief Creek and Illinois Furnace Faults, southeast of Hicks Dome, also are thought to include reverse fractures (Weller et al., 1952), but no details are available.

Many faults show evidence of strike-slip or oblique-slip motion. The Hillside Fault near Rosiclare has grooves and slickensides plunging 20^{o} to 30^{o} southward, indicating a combination of normal and left-lateral slip. Striations on the nearby Daisy Fault pitch at angles varying from 10^{o} to the south to 80^{o} to the north; movements must have differed in direction at different times (Bastin, 1931). Horizontal slickensides and tension fractures indicative of left-lateral movement were observed in the Gaskins Mine west of Hicks Dome (Hook, 1974), and on the West Vein in Section 28, T. 12S., R. 7E., Pope County, we found mullion and slickensides consistently pitching 38^{o} to 52^{o} northeast, testifying to combined normal and right-lateral offset (fig. 36). Slickensides on the adjacent, parallel Barnett Vein point to right-lateral and normal movement on that fault (Robert Diffenbach, Ozark-Mahoning Co., personal communication, 1983).

Geologists have debated the relative importance of horizontal and vertical displacement in the FAFC. Hook (1974) estimated that the cumulative heave components of northeast-trending normal faults is approximately 5,000 feet. That translates to roughly one mile of horizontal stretching. Reverse heave probably is not more than a few hundred feet. Strike-slip movments never have been quantified; such calculations would be difficult to obtain. In the examples cited above, the horizontal components are on the order of a hundred feet, and the directions of offset are inconsistent. Extensive detailed surface mapping has failed to disclose any large-scale lateral offsetting of stratigraphic horizons or igneous dikes (which, as noted above, are older than northeast-striking faults). Accordingly, we concur with Hook (1974) that wrench faulting is subordinate to dip-slip normal faulting in the FAFC.

Measured normal displacements of northeast-trending faults range from inches to several thousand feet, but most faults have several tens to about 1000 feet of throw. The largest known offset occurs in the southeast corner of the Smithland Quadrangle, Kentucky, where Ft. Payne and Caseyville Formations are juxtaposed, indicating displacement of 2,400 to 3,000 feet (Amos, 1967).

Complex horsts and grabens characterize the FAFC. Many fault zones are broad and intricate, composed of numerous step faults and/or antithetic faults bounded by master faults of large displacement. Fault slices may be tilted; drag is well-developed. Many slices are broken by cross-faults (Hook, 1974). Some faults have sharply defined planes, but wide zones of gouge and breccia are the rule. In relation to the amount of displacement, the amount of breccia is quite large.

Mineralization

Because mineral deposits of the fluorspar district are structurally controlled, their study is important in unraveling the region's complex tectonic history.

Most ore bodies are classified as vein deposits: fissure-fillings and replacement of breccia and/or wall rock along faults. Most veins trend northeastward, but some strike northward to northwestward; they range from a hairline to nearly 40 feet wide and are hundreds to more than 1000 feet long. Although minable deposits are concentrated in places where one or both walls of the fault are upper Valmeyeran or lower Chesterian sandstones and limestones, mineral showings exist in rocks as old as Ordovician and as young as Pennsylvanian. Faults of moderate displacement (50 to 500 feet) generally bear the widest veins.

In approximate descending order of abundance, minerals in vein deposits include calcite, fluorite, quartz, galena, sphalerite, ferroan dolomite, pyrite, marcasite, barite, chalcopyrite, and others; some veins also contain oil or bitumen. The paragenesis varies from vein to vein, but most calcite is an early deposit, and fluorite is partly contemporaneous and partly later than calcite. Metal sulphides largely postdate fluoride and typically occur in narrow fissures near the centers of veins; barite is younger yet. Some calcite and some purple fluorite are late vein-fillings that coat older crystals in vugs (Bastin, 1931; Trace, 1974).

The veins developed as minerals filled in open fissures and cavities along faults, or replaced limestone in the fault zone. Brecciated limestone was readily replaced and, although most veins have sharp boundaries, wall rock is locally mineralized. Evidence of replacement includes banded ore (alternating layers of calcite and fluorite), ragged remnants of limestone in veins, and relict structures such as stylolites (Bastin, 1931), oolites, and fossils (Trace, 1974) partially replaced by minerals.

Most geologists believe that the deposits are epigenetic, the ore elements having been carried upward along the faults in solution by water heated by deep-seated igneous activity (Trace,1974). Faults of moderate displacement in hard, competent rocks have the widest veins because such faults had the most and the widest fissures. Small faults had no or narrow openings, while large faults--or faults cutting shales and other weak rocks--became choked with gouge (Weller et al., 1952). The St. Louis-Bethel interval was the highest zone suitable for large-scale mineralization. However, deposits of moderate size have been found enclosed by rocks of middle Chesterian age with little indication of mineralization at lower stratigraphic levels.

The age of the ores is problematic. Clearly they postdate major movements on the host faults, which displace and hence postdate igneous dikes that have been dated as early Permian. Most geologists assume that the minerals are pre-Cretaceous, but solid evidence is lacking: Heyl and Brock (1961) reported a lead-alpha age of 90 to 100 million years (Cretaceous) on monazite from

Hicks Dome, but this age is questionable (Trace, 1974). No mineralization has been identified in Cretaceous rocks in the Mississippi Embayment.

Some mineral veins are offset by faults, indicating that tectonic movements continued in some cases after mineralization.

Besides vein deposits, bedded replacement and minor residual ores have been mined in the flurospar district. Bedded replacement or stratiform deposits--found mostly in the upper Ste. Genevieve, Renault, and Downeys Bluff Limestones--are associated with northwest-trending fracture zones or small faults that apparently acted as feeders. "Hybrid" vein-stratiform deposits also occur (Weller et al., 1952), suggesting that replacement occurred in the same episode during which the vein ore bodies developed. Residual (gravel) ores consist of fluorspar and other minerals selectively concentrated by weathering near the surface above vein or bedded-replacement deposits.

Fault zones and faults

The following structures enter or approach our area of detailed study.

McCormick and New Burnside Fault Zones. Northwest of and trending parallel with the Lusk Creek and Shawneetown Fault Zones are the McCormick and New Burnside Fault Zones (fig. 37). Formerly called anticlines, these structures actually are complex fault zones, as shown by recent detailed mapping (Jacobson and Trask, 1983). They extend from southeastern Saline County into northwestern Pope and eastern Johnson County, where they turn southward and disappear beneath the Mississippi Embayment.

The McCormick Fault Zone reaches the western part of the Rudement Quadrangle (plates I and II), where coal-test drilling indicates a fault having up to 65 feet of throw. Southwest of the study area high-angle faults appear in outcrops and can be traced on aerial photographs. The overall structure is either a faulted anticline or a series of tilted horsts bounded by sub-parallel, northeast-striking faults. Strata in the fault zone dip as steeply as 58^{0} and in places are intensely fractured, brecciated, and slickensided (Potter, 1957).

The main movements took place in post-Atokan (post-Abbott Formation) time, but Potter (1957) reports evidence of early Pennsylvanian activity in the McCormick Fault Zone. In the cuts immediately north of the Illinois Central Railroad tunnel (Sec. 19, T. 11S., R. 5E., Pope County), a thick deposit of megabreccia lies beneath the Grindstaff Sandstone Member. The breccia consists of lenses and blocks of sandstone up to 100 x 15 feet surrounded by a conglomeratic (shale pebbles) sandy matrix. Sandstone blocks contain primary structures (bedding, ripple marks, and crossbedding) and deformational features (rotated, isoclinal, and recumbent folds). The breccia clearly developed prior to lithification of the sediments. At the south end of the tunnel (Sec. 31, T. 11S., R. 5E) imbricate overthrusts in shale and siltstone are erosionally truncated beneath crossbedded Caseyville sandstone. Potter inferred that intermittent uplift in the McCormick Fault Zone triggered slumping and chaotic landsliding of unconsolidated Caseyville sediments.

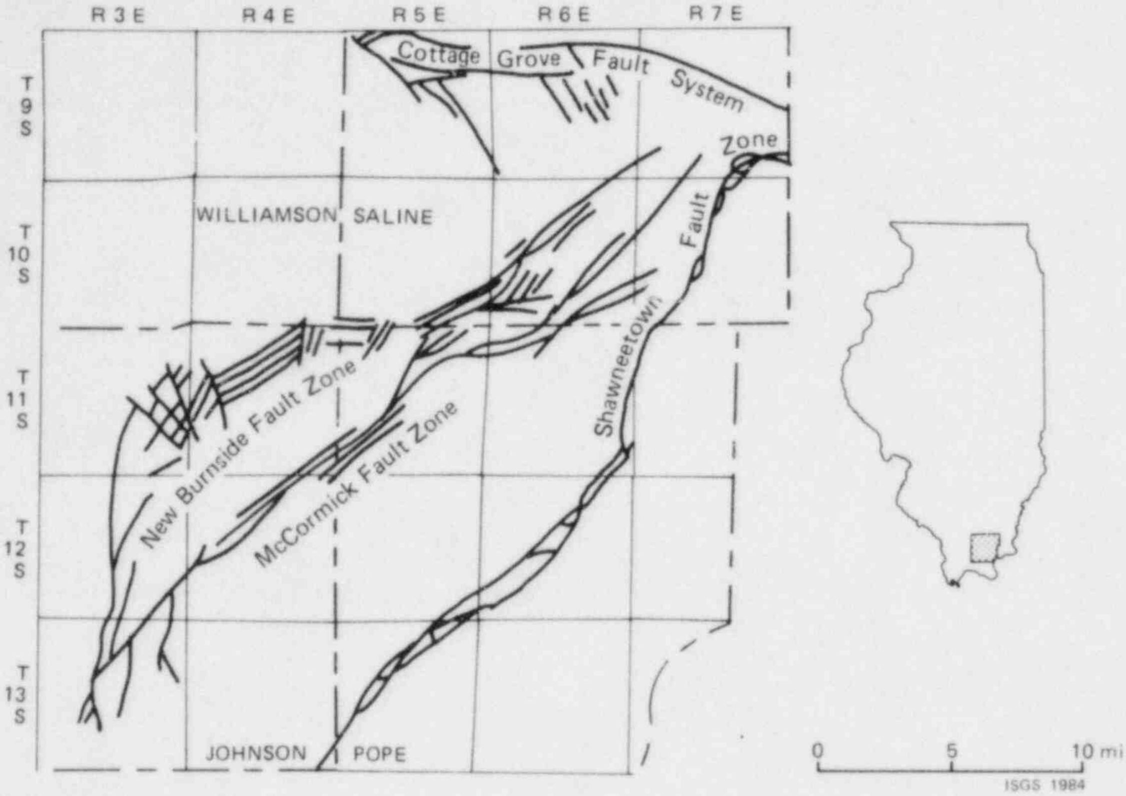


FIGURE 37. McCormick and New Burnside Fault Zones in southeastern Illinois (from Jacobson and Trask, 1983).

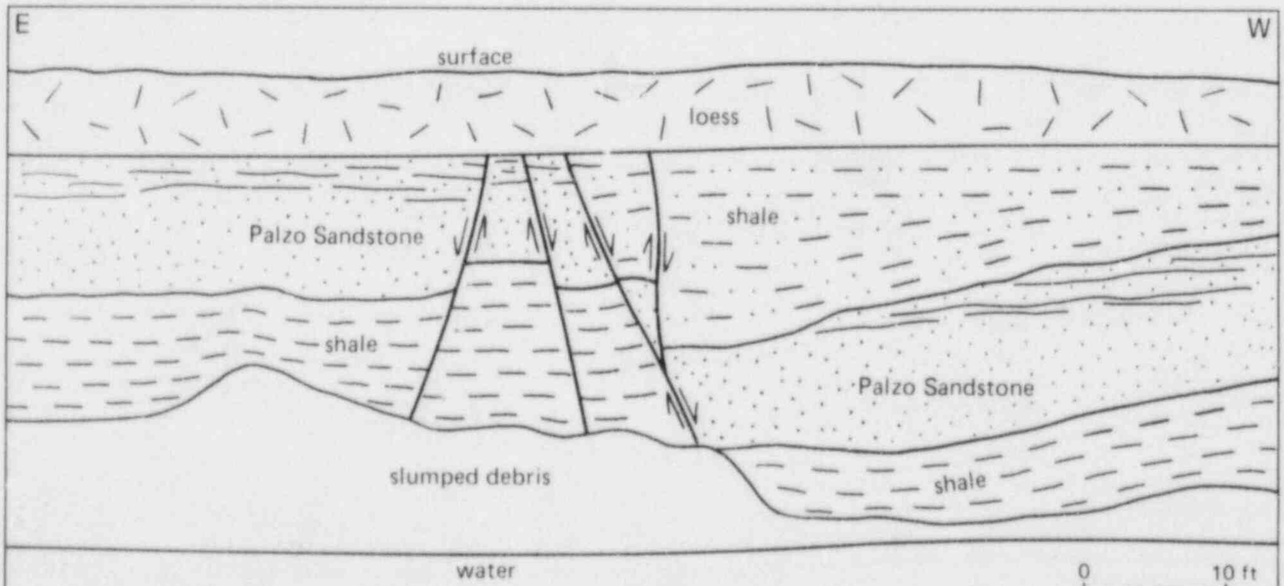


FIGURE 38. Exposure of New Burnside Fault Zone on highwall of strip mine in southern Saline County, Illinois. Faults displace Pennsylvanian bedrock but do not offset bedrock surface or overlying loess.

The New Burnside Fault Zone has been exposed by strip mining a few miles west of the Rudement Quadrangle, in Sections 19, 20, and 30, T. 10S., R. 6E., Saline County. High-angle normal faults, some having more than 100 feet of throw, outline a complex northeast-trending graben. Prominent slickensides and mullion on fault surfaces indicate dip-slip movement. The faults displace rocks of the Spoon Formation but do not affect overlying Pleistocene loess (fig. 38). Farther to the southwest, in the Creal Springs Quadrangle (northeastern Johnson County) Jacobson and Trask (1983, personal communication) have delineated a complicated pattern of high-angle faults (fig. 37). The zone curves from almost a westerly heading to a southerly heading across the quadrangle; dip-slip faults outline narrow horsts and grabens or a broken arch. Offsetting the dip-slip faults are strike-slip faults that trend normal to the zone and are marked by horizontally slickensided walls bounding wide gouge zones.

Although positive evidence of the ages of the McCormick and New Burnside Fault Zones is lacking, some inferences can be made. The major northeast-trending faults are post-Atokan, but Potter's evidence strongly suggests tectonic activity beginning in Late Morrowan to Early Atokan time, while the Caseyville and Abbott Formations were being deposited. These faults are offset, and clearly postdated, by the northwest-trending strike-slip faults. Elsewhere in the Fluorspar Complex, northwest-trending wrench faults are fixed in age as pre-Early Permian by the enclosed, radiometrically-dated igneous intrusions. Thus, the normal faults are probably Early to Late Pennsylvanian, and the strike-slip faults Late Pennsylvanian or Early Permian.

This, in turn, suggests three episodes of faulting in the Fluorspar Area Fault Complex: (1) northeast-trending normal faults (Pennsylvanian); (2) northwest-trending strike-slip faults (Early Permian); and (3) renewed northeast-trending faulting (post-Early Permian).

Herod Fault Zone. Faults in the southeastern part of the Rudement Quadrangle (plates 1a and 2) belong to the Herod Fault Zone, as defined by Baxter, Desborough, and Shaw (1967). Several faults are exposed on highwalls of abandoned coal mines; others are defined by drilling or inferred from lineaments on aerial photographs. The faults strike N 35^{o} W and form horsts and grabens. High-angle normal faults with throws ranging from inches to 65 feet are seen in the mines. Drag is inconspicuous; slickensides indicate dip-slip movement with little or no component of strike-slip. The affected rocks, of the Spoon and Carbondale Formations, apparently were fully lithified when faulted. No indications of offset were found in overlying loesses.

A possible strike-slip fault cuts the highwall at the north end of Colbert Hill, NE 1/4 SE 1/4 SW 1/4, Section 13, T. 10S., R. 7E., Rudement Quadrangle (fig. 39a). It trends approximately N 15^{o} W and has a slightly sinuous, vertical gouge zone of soft clay up to several inches wide (fig. 39b). Strata east of the fault are downthrown about 2 feet. Although no positive indicators such as slickensides have been found, the large amount of gouge relative to the slight vertical offset suggests horizontal movement.

Grindstaff Fault Zone. Butts (1925) mapped the Grindstaff Fault as a single fracture, but coal-test borings indicate at least three faults in the south-

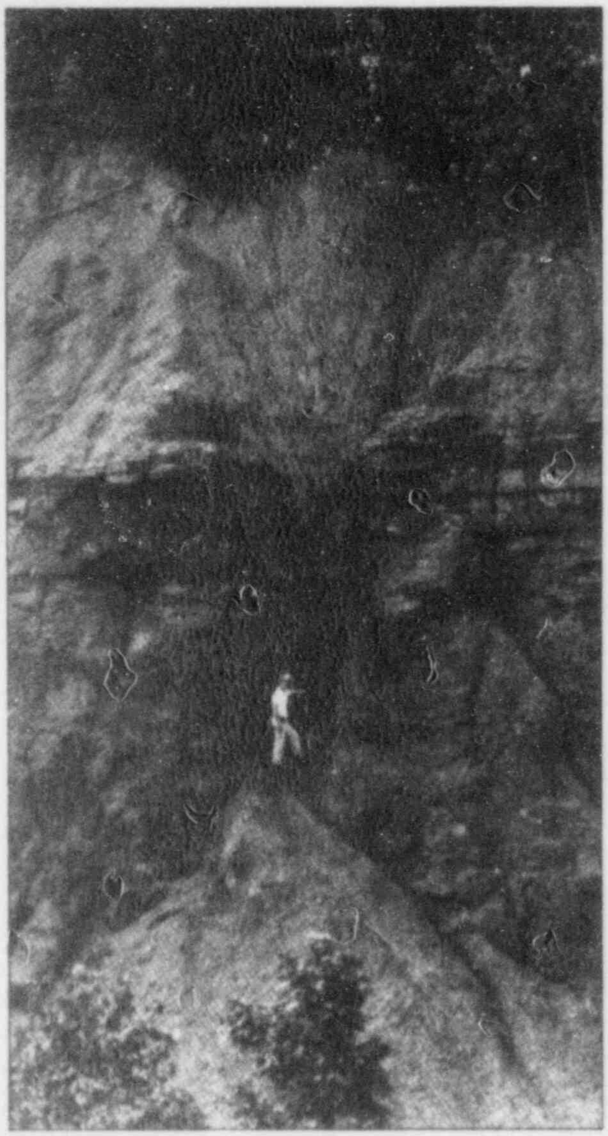


FIGURE 39. Left: Nearly vertical fault on strip mine highwall at north end of Colbert Hill, Rudement Quadrangle. East (left) side is downthrown 2 or 3 feet, but there are also indications of strike-slip movement on this peculiar fault. At top of highwall, weathered shale grades into residual soil; no Pleistocene sediments are present to indicate whether or not this fault was active in Quaternary time. Right: Closeup view of fault, showing sinuous zone of light gray soft clay gouge. Width and sinuosity of gouge zone on a fault of so little vertical displacement suggests a strike-slip component of movement.

central Equality Quadrangle (plates 1a and 2), Displacements reach at least 200 feet, with cumulative displacement down to the southeast. The small knob of Gimlet Sandstone north of Leamington (SW 1/4 SE 1/4, Sec. 15, T. 10S., R. 8E) occupies a graben bounded on both sides by Spoon Formation. These faults probably continue into the wide alluvium-filled valley of Hutt Creek, but die out near the southern edge of the quadrangle. Baxter and Desborough (1965) found no evidence of faulting along Hutt Creek in the Karbers Ridge Quadrangle south of the Equality Quadrangle. Aside from offsetting of outcrops, the only surface evidence for the Grindstaff Fault Zone is in locally closely-spaced vertical fractures in Abbott sandstone along Hutt Creek. The faults probably dip steeply, but whether they are reverse or normal is unknown. The Grindstaff Fault Zone is the only element of the Fluorspar Area Fault Complex to cross the Eagle Valley Syncline; whether it intersects the Rough Creek-Shawneetown Fault System cannot be determined because of lack of data.

Lee Fault and others. Baxter and Desborough (1965) mapped the northwest-trending Lee Fault in the Karbers Ridge Quadrangle. The fault extends into the southwestern corner of the Shawneetown Quadrangle, where test borings indicate two faults having a few tens of feet of offset. They cannot be followed more than a mile or so into the quadrangles; evidently they die out.

A northeast-trending fault, with its northwest side downthrown about 6 feet, was encountered underground in Peabody Coal Company's Eagle No. 1 Mine (abandoned) in Sections 8 and 9, T. 10S., R. 9E., Shawneetown Quadrangle; this fault is in line with the Lee Faults but dies out at both ends within the mine. No other faults can be mapped in the vicinity on the basis of available evidence, despite extensive mining and drilling.

Palmer (1976) mapped a fault projecting from the Grove Center (KY) Quadrangle toward the Shawneetown Quadrangle. The fault apparently was mapped on the basis of subsurface data; it runs entirely beneath Ohio River alluvium. We found no evidence for this fault extending into Illinois; neither could we confirm the presence of a fault that Baxter et al. (1963) showed as projecting into the Shawneetown Quadrangle from the south in Sections 25 and 26, T. 9S., R. 9E.

Origin and age of the FAFC

Considering the structural complexity of the region and the ambiguity of some of the data, it is not surprising that geologists disagree on the origin and history of the Fluorspar Area Fault Complex (FAFC). No single tectonic episode could have formed the myriad structures of the FAFC. Obviously, the fluorspar district has been subjected to several different stress fields at different times.

The northeast-trending block faults and the northwest-trending ultramafic dikes formed under different stress regimes and therefore cannot be contemporaneous. Tensional stresses were oriented northwest-southeast for the faults, and east-northeast to west-southwest for the dikes. The faults in most cases displace and offset the dikes; therefore, at least some of the slippage on the faults took place after the magma had hardened. Likewise, northeast-trending faults break Hicks Dome and the associated arch. Mineral

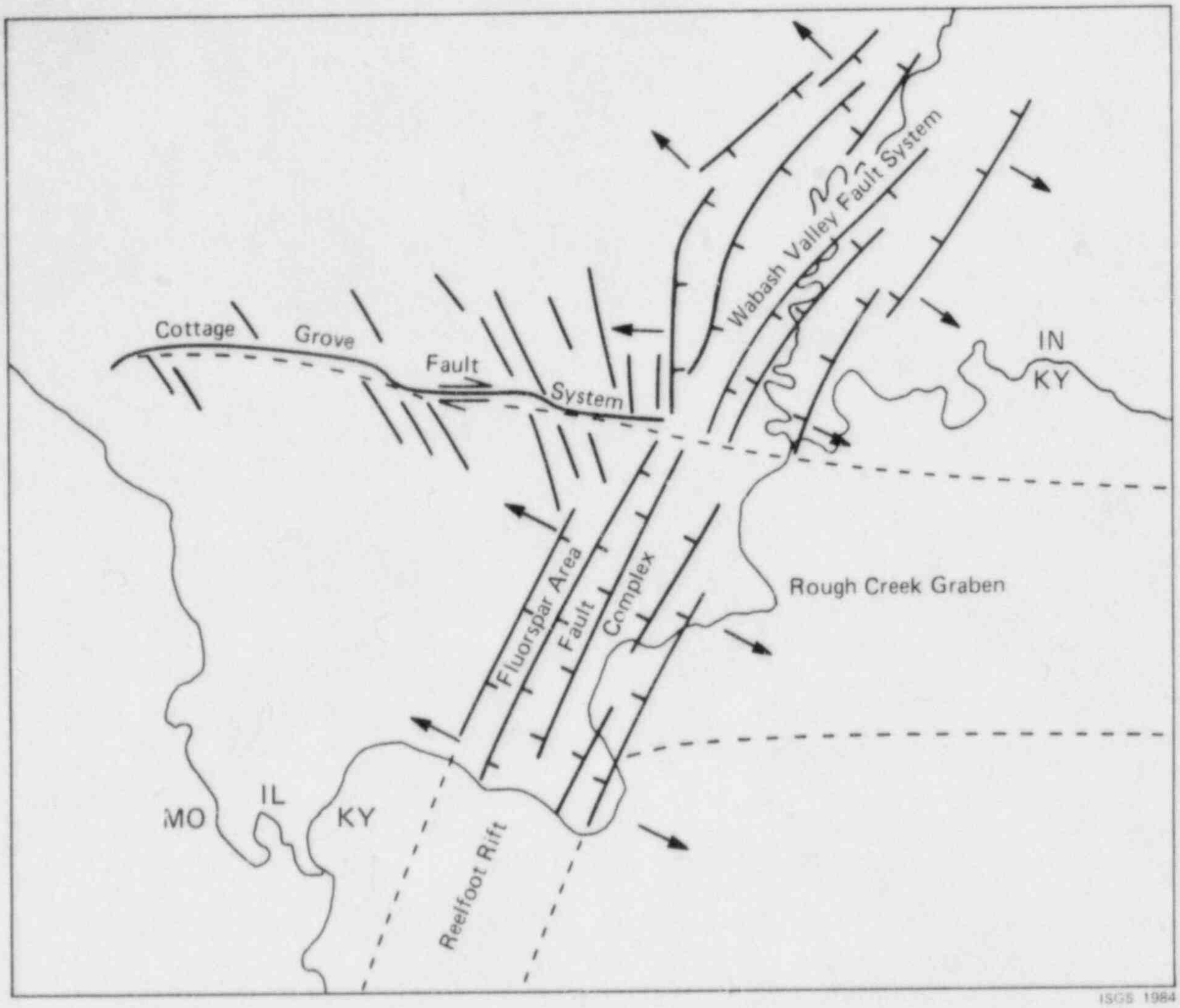


FIGURE 40. Tectonic events of Late Pennsylvanian-early Permian time. Approximately a mile of horizontal extension in the Reelfoot Rift area created northeast-trending normal faults in the Fluorspar Area Fault Complex. This rift was interrupted at the northern edge of the Rough Creek Graben; a smaller amount of extension farther northeast formed the Wabash Valley Fault System. The relative westward movement, which was greater south of the western part of the Rough Creek line than it was north of that line, set up a right-lateral stress that produced the Cottage Grove Fault System. A complementary left-lateral system might have developed eastward along the Rough Creek line, but no evidence for such a system can be found. If a strike-slip fault developed it was obliterated by later up-and-down movement along the Rough Creek-Shawneetown Fault System.

veins occupy and therefore must postdate initial movements on northeast-trending faults. These observations have led most researchers to infer the following order of events:

1. Igneous activity (dated as early Permian): intrusive and crypto-explosive events form arch and Hicks Dome and associated faults.
2. Northeast-trending block faults develop.
3. Mineralization.

Although this proposed sequence fits the facts in the fluorspar district, it conflicts with some of our findings in adjacent areas. We have shown that the Cottage Grove and Wabash Valley Fault Systems formed simultaneously in a common stress field, and that both fault systems contain early Permian intrusions. Therefore, according to this sequence, the Cottage Grove Fault System and the Wabash Valley Fault System are older than the northeast-trending FAFC faults. But this assumption leads to a mechanical contradiction. The Wabash Valley Fault System is a tensional or rift zone; the mass of rock east of the system moved eastward and the western mass moved westward. Yet the Cottage Grove Fault System is a right lateral wrench: the block north of the zone moved eastward relative to the south block. How could the same block move eastward and westward at the same time?

Rifting in the Reelfoot Graben provides a solution. Suppose that northeast-trending tensional faults were forming in the FAFC at the same time the Wabash Valley Fault System were developing. Suppose that the FAFC were rifting apart faster than the Wabash Valley Fault System (this fits the facts: the FAFC shows about 5000 feet of horizontal extension, the WVFS less than 1000 feet). So the block west of the FAFC moved 4000 feet (more or less) farther west than the block west of the WVFS. This differential movement could have been released on the Cottage Grove Fault System, as right-lateral slip (fig. 40).

But how can the northeast-trending FAFC faults be older than Hicks Dome and the igneous dikes, which they offset? Easily enough, if they are both older and younger. First the normal faults formed, along with the Cottage Grove Fault System and Wabash Valley Fault System, in late Pennsylvanian time. Then, in the early Permian, the stress field rotated and magma was injected along northwest-trending faults and fractures. Later the northeast-trending faults underwent renewed movement, displacing the dikes. (Some postintrusive movement took place in the Cottage Grove Fault System as well.) This second stage of activity in the FAFC took place in response to, or as part of the same action as, the major vertical displacements along the Rough Creek-Shawneetown Fault System. The northeast-trending faults of the FAFC show plenty of evidence of recurrent movements. The wide shattered breccia zones, the reverse faults interspersed with normal faults, the tilted blocks, the strike-slip and oblique-slip faults, all testify to multiple episodes of movement in the FAFC.

We propose the following sequence of events in the Fluorspar Area Fault Complex:

1. Extension northwest to southeast produces northeast-trending normal faults as the CGFS and WVFS develop in Pennsylvanian time.
2. Development of small, northwest-trending strike-slip faults and igneous activity, including intrusion of dikes, diatremes, and explosion-breccias, and creation of Hicks Dome and its associated radial and arcuate faults, in early Permian time.
3. Renewed movements, mostly vertical, on northeast-trending block faults, concurrent with action along RC-SFS, in late Permian and/or Mesozoic time.
4. Mineralization along northeast-trending faults, partly contemporaneous with (3).

Jacobson and Trask's (1983) new findings on the McCormick and New Burnside structures lend additional support to the above hypothesis.

Tectonism in the FAFC was winding down by Cretaceous time, but small movements may have continued into the Tertiary Era. The Smithland (Amos, 1967), Burna (Amos, 1974), Calvert City (Amos and Finch, 1968), and Little Cypress (Amos and Wolfe, 1966) Quadrangles in Kentucky show FAFC faults offsetting Gulfian (upper Cretaceous) sediments. Some faults juxtapose Paleozoic bedrock with Cretaceous Tuscaloosa and McNairy Formations; other faults have Cretaceous materials on both sides. Cross-sections indicate a few tens to possibly more than 100 feet of throw on these high-angle faults. Ross (1963 and 1964) examined subsurface data for extreme southern Illinois, and attributed local thickening of McNairy Formation and Wilcox Sand to tectonic movement in latest Cretaceous and post-Eocene time, respectively. He also reported steep dips and offset terraces in Mounds Gravel, suggesting Pliocene or younger faulting. Kolata, Treworgy, and Masters (1981), however, re-examined the drill-hole information, including logs of recently drilled holes, and disagreed with Ross, finding no evidence for thickness or facies changes that can be attributed to tectonism. They also inspected all reported field exposures of disturbed Tertiary and Quaternary materials. None of these sites showed conclusive evidence of tectonic faulting; most deformation is better explained by stream-bank failure, collapse of solution cavities in underlying limestone, and similar non-seismic causes.

Although several authors have asserted that tectonic activity continues to this day in the FAFC, none has presented any evidence to back such statements. No faults or seismic deformation of Pleistocene sediments have been reported; terraces and other landforms show no modifications that could be attributed to earth movements. Small earthquakes occasionally occur within the fluorspar region, but none has been related to bedrock faults, and quakes are no more concentrated in the FAFC than elsewhere in southern Illinois or western Kentucky.

Relationship of FAFC to Wabash Valley Fault System

One of the original purposes of this study was to determine whether or not the Fluorspar Area and Wabash Valley Fault Zones are physically connected. Our findings indicate that they are not, although they may share a common ancestral rift zone.

As noted previously, most of the Wabash Valley faults do not reach the Rough Creek-Shawneetown Fault System. The few that do intersect the RC-SFS definitely do not extend south of the front fault. Similarly, most of the Fluorspar Complex faults do not cross the axis of the Eagle Valley Syncline. In Illinois, only the Grindstaff Fault Zone possibly extends as far as the Shawneetown Fault Zone. Palmer (1976) mapped three northeast-trending faults as intersecting the south side of the Rough Creek Fault System in the Grove Center Quadrangle, Kentucky; however, the evidence for these faults is extremely slim. Their traces are entirely beneath Quaternary alluvium (one is under the Ohio River), and the available subsurface information is very sparse.

The Wabash Valley and Fluorspar Complex faults also show different trends and structural styles. The former mostly strike north to north-northeast and are simple normal faults, while the latter strike consistently northeast and show evidence of normal, reverse, and strike-slip movement.

East of Sebree, Kentucky, several sets of northeast- or east-northeast trending faults appear to cross the Rough Creek Fault System, but these fractures are not part of the Fluorspar Area Fault Complex or Wabash Valley Fault System.

We accept the possibility that an arm or extension of the Reelfoot Rift may have penetrated southwestern Indiana during the Cambrian Period. Future drilling and geophysical work may establish the existence of such an ancestral zone of weakness. Also, we have suggested that a horizontal extensional force created normal faults in the Wabash valley and fluorspar district during Late Pennsylvanian or Permian time. But these faults and stresses were not directly linked to each other: they were interrupted at the northern wall of the Rough Creek Graben. Since that time, the fault zones have not been connected, and the Wabash valley appears to have been tectonically quiet.

PENNYRILE FAULT SYSTEM

Extent and nature of faulting

Schwalb (1975) applied the name Pennyrile Fault System (PFS) to an east-trending zone of fractures 25 to 40 miles south of and roughly parallel with the Rough Creek-Shawneetown Fault System in west-central Kentucky. The PFS defines the southern edge of the Moorman Syncline; the RC-SFS marks the northern edge. The PFS emerges eastward from the FAFC from which it cannot be clearly separated in Caldwell County. The width, complexity, and amount of displacement in the zone decrease eastward; the system dies out near Mammoth Cave in western Edmonson County.

Although the PFS as a whole trends nearly due east, most individual faults strike east-northeast and thus form an en echelon pattern. Several sets of faults completely cross the Moorman Syncline, linking obliquely the RC-SFS with the PFS. Individual fault sets are composed of subparallel fractures that tend to exhibit a braided or interwoven pattern in map view. The multitude of such fractures blurs the distinction between the PFS and adjacent fault zones, especially to the west.

No continuous master fault, such as is found in the Cottage Grove and Rough Creek Fault Systems, is present in the PFS.

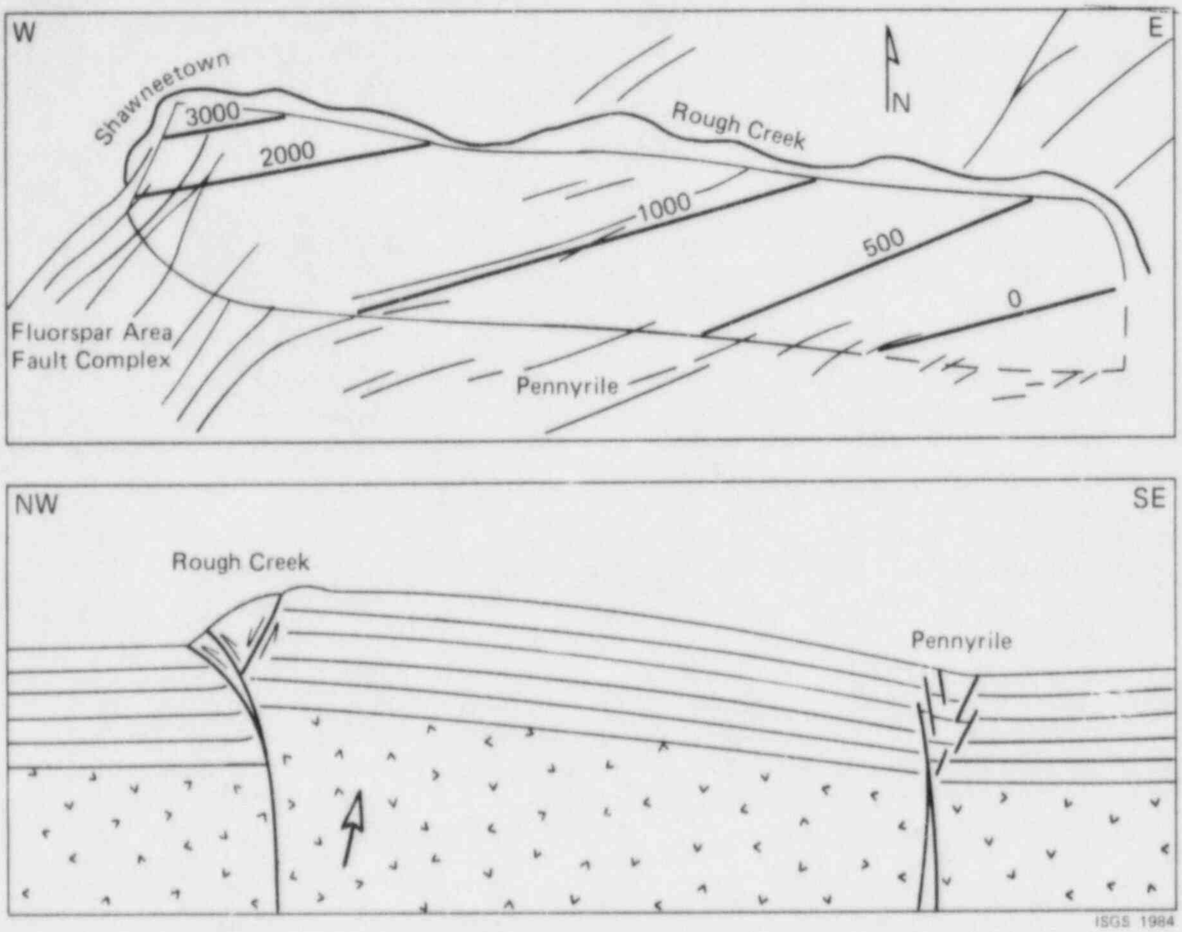


FIGURE 41. Development of Rough Creek and Pennyrile Fault Systems through rocking motion of major crustal block. Top: the approximate inferred outline of the fundamental block is shown; the minimum relative vertical movements given (in feet) are rough estimates. The block was hinged at the southeast; the greatest movement of the block occurred at the northwest in the vicinity of Cave Hill. Bottom: this schematic cross section illustrates the situation at the time of maximum uplift. Although the basement is drawn as if it were a rigid mass, actually it was probably bent and/or segmented by fractures.

The overall displacement of the PFS is down to the north. The aggregate throw may exceed 1000 feet near the western end of the system; the offset decreases eastward. Vertical separation on individual faults ranges up to several hundred feet. Fault zones consist of series of horsts and grabens, within which the strata generally are horizontal or only gently tilted.

According to the various geologic quadrangle maps and published reports (Schwalb, 1975), all the faults of the PFS are vertical and high-angle normal. Palmer (1969) measured attitudes of 21 fault surfaces in Hopkins and Christian Counties, and recorded dips ranging from 52^{o} to 90^{o}. Slickensides are prominent on many of Palmer's faults, and invariably indicate only dip-slip movement. Most of the breaks are linear or only gently curved along strike. Palmer also remarked on the scarcity of drag features, and on the scarcity of breccia. Even on faults with several hundred feet of throw, the gouge zone rarely is wider than 1 or 2 feet.

Age and origin

Schwalb (1982) noted that the Pennyrile Fault System approximately coincides with the southern edge of the Rough Creek Graben, which developed during the Cambrian time; however, no direct evidence of Cambrian faulting has been found. Strata displaced at the surface are of Mississippian and Pennsylvanian age, and drilling has revealed offsets in the Devonian. No Mesozoic or Tertiary deposits are present, and no deformation of Quaternary sediments along the fault system has been detected. Because the PFS blends into the FAFC, it is reasonable to infer that the two systems are contemporaneous: post-Pennsylvanian and largely, if not entirely, pre-Gulfian (late Cretaceous).

Extensional tectonics are clearly indicated by the pattern of normal faults showing no evidence of reversed or strike-slip movement. A twisting component, however, is apparent from the en echelon arrangment of northeast- and north-northeast-trending fractures along an east-trending fault system. In other words, the tension was directed toward the northwest, but the line of faulting was controlled by an east-trending feature--the buried southern wall of the Rough Creek Graben.

We propose that the PFS marks the southern edge of the elongate rectangular crustal block that rose and fell to create the RC-SFS. The western and eastern ends of this block are marked, respectively, by the FAFC and by the southeastward-trending end of the RC-SFS in Grayson County, Kentucky (fig. 41). Dimensions of this rectangle are approximately 150 miles east to west, and 25 to 40 miles north to south. The greatest vertical movements, at least 3500 feet, took place at the northwestern corner of the block, where the Shawneetown Fault Zone abruptly bends to the south-southwest. Relative offset diminished eastward along the RC-SFS; the termination of the zone in Grayson County marks an area of little or no movement. Although the southern margin of the block experienced much less displacement than did the northern edge, offsets were still greater to the southwest (FAFC) than to the southeast.

The great crustal block apparently rocked up and down, like an obliquely-hinged trap door, with the hinges at the east and southeast, and the greatest opening at the north and northwest. The Pennyrile Fault System developed when the sedimentary strata draped over the hinged block failed under flexure. The northeast-trending faults that cross the Moorman Syncline are essentially parallel to the hinge line (fig. 41) and may reflect bending of the rectangular block as it rocked up and down.

The nature of the movements, if not their cause, can be defined rather clearly. When the action began, this great crustal block was already bounded on three sides by ancient zones of weakness--the northern and southern walls of the Rough Creek Graben, and the Reelfoot Rift on the west. Only the eastern and southeastern sides, buttressed against the Lexington and Nashville Domes, had not experienced prior movement. Some force from below--deep in the crust or even in the mantle--pushed upward at the northwest corner of the block, raising it at least 3500 feet, and then letting it back down. The block remained hinged along its southeastern corner, where no faults appear, but elsewhere the movements were sufficient to break the sedimentary strata, produce the RC-SFS and PFS, and reactivate existing fractures in the FAFC.

What kind of force could have raised and lowered the block? Strunk (1984) suggests the intrusion and subsequent deflation of a great body of magma. The magnetic survey of McGinnis and Bradbury (1964) revealed a large, roughly oval magnetic high centered 5 1/2 miles northeast of the apex of Hicks Dome. McGinnis and Bradbury interpreted this anomaly as representing a large body of basic igneous rock, the top of which is roughly 11,000 feet below the surface. This pluton, if it exists, probably is the parent body of the various intrusions, diatremes, and explosion structures found throughout the region. This interpretation suggests an early Permian age for the alleged pluton and also for the uplifting phase of the Rough Creek-Shawneetown Fault System. The deflation phase and lowering of the crustal block may have occupied much of the Mesozoic Era. In any event, the purported pluton occurs in the right place to be the motor of uplift and subsidence. We are aware that many practical and theoretical objections can be raised to this idea. We offer it not so much as a firm hypothesis, but more as a stimulus to further research.

TECTONIC HISTORY

The tectonic evolution of the study area began in late Precambrian or early Cambrian time, when tensional movement produced the Reelfoot and Rough Creek Grabens. The floors of the two grabens sank several thousand feet below sea level as the earth's crust was stretched. Adjoining upland areas were worn down, furnishing vast quantities of sediments to the troughs. As the grabens filled, the weight of detritus probably triggered renewed faulting; but by the end of Cambrian time tectonism had ceased, the grabens were mostly filled, and the entire Illinois Basin lay under a shallow sea.

Renewed intermittent movements took place here and there during the Ordovician, Silurian, Devonian, Mississippian and Pennsylvanian Periods. Major tectonism returned to southern Illinois in the late Paleozoic, concurrent with the Appalachian and Ouachita Orogenies. The first episode, in late Pennsylvanian and/or early Permian time, produced the Cottage Grove and Wabash Valley Fault Systems and part of the Flurospar Area Fault Complex (fig. 40). This action took the form of rifting along the southeastern side of the Reelfoot Graben. Northeast trending high-angle normal faults in the FAFC and WVFS developed in response to northwest-southeast horizontal stretching of the earth's crust interrupted by the buried northern scarp of the Rough Creek Graben. Extension was greater south of this ancient fracture zone than north of it. In other words, the rocks on both sides of the scarp moved westward, but the block south of the scarp moved farther west than the north bank (fig. 40). Right-lateral shear thus developed, and reactivated the Cambrian graben fault, as the Cottage Grove Fault System.

Conceivably these movements may have produced a corresponding left-lateral shear to the east, along the Rough Creek-Shawneetown Fault System. If such strike-slip faulting took place, it was of small magnitude, and most, if not all, traces of it subsequently were erased by the much larger vertical displacement along the RC-SFS.

The pattern, as we believe it developed, is not unlike that seen on mid-oceanic ridges--a line of rifting or spreading, offset by strike-slip transform faults that trend perpendicular to the rifts. In this analogy the WVFS and FAFC represent rift zones and the CGFS is a transform fault.

Shortly afterward, molten magma welled upward along a north-northwest-trending arch in the fluorspar region. Tensional stresses temporarily aligned themselves north-northwest, allowing igneous material to intrude north-and northwest-trending fractures, including those in the eastern part of the CGFS and on the Ridgway Fault. Omaha Dome was produced by laccolithic intrusions. Tremendous subterranean explosions of steam created Hicks Dome and associated breccia pipes; radial and concentric faults developed either during original upheaval or subsequent collapse of Hicks Dome.

Following solidification of the magma in early Permian time, extension may have been renewed along the Reelfoot Rift, rejuvenating FAFC faults so that they offset dikes. This step, however, is not essential to our tectonic hypothesis.

Some time during or after the early Permian, the Rough Creek Graben was uplifted. On the north side, most slippage took place along a single high-angle south-dipping fault, the front fault of the RC-SFS. Lesser, hinge-type movements on the south side of the inverted graben produced the Pennyrile Fault System. In the fluorspar district, northeast-trending faults were reactivated, and probably new faults were formed. Most movements were normal but some were reverse; some blocks rotated, twisted, or slipped laterally. Uplift reached at least 3,500 feet at the northwest corner of the block. The upraised block must have been subjected to erosion, shedding detritus to its flanks and profoundly influencing sedimentation; however, none of these sediments seem to have survived to the present.

After a time the uplifted graben-block fell back to more or less its original position. As they sank, the rocks along the RC-SFS bent sharply, forming the north limb of the Eagle Valley-Moorman Syncline. Many secondary faults developed; slices of Devonian and Mississippian rocks became trapped along the fault zone far above their original positions. These blocks rotated in place, under the influence of drag, until their strata dipped steeply southward or even were overturned.

This episode renewed slippage in the Pennyrile Fault System and the Fluorspar Area Fault Complex. During the later stages of faulting, hydrothermal solutions, heated by magma at great depth and charged with fluorine, sulfur, metallic ions, and other elements, moved upward along northeast-trending fractures in the FAFC. These minerals precipitated or replaced carbonates at favorable spots, mostly in the hard, strong upper Valmeyeran and lower Chesterian strata. There were many overlapping events of mineralization, occasionally interrupted by renewed movements on the faults that served as conduits for the hydrothermal fluids.

Tectonism probably wound down gradually in the region. Some faults were still active early in late Cretaceous time when terrestrial sediments began to accumulate in the Mississippi Embayment. Intermittent slippage may have even continued into the Tertiary Period, but any such late movements certainly were minor compared to those that produced the great faults cutting Paleozoic bedrock.

MODERN STRESS FIELD AND SEISMICITY

Every earthquake in southern Illinois testifies to the presence of unrelieved tectonic stresses in the ground. Blame for thse quakes naturally has fallen upon the bedrock faults, especially the Fluorspar Area Fault Complex and Wabash Valley Fault System, which project toward the New Madrid area, but also the RC-SFS. Failure to find any trace of Pleistocene displacement on any of these structures has not deterred geologists from labeling them active.

A map of earthquake epicenters in the central Mississippi Valley (fig. 42) shows a great seismic concentration along a line running southwestward from Cairo, Illinois into northeastern Arkansas. New Madrid, Missouri lies near the heart of the active zone. All earthquakes of magnitude 6.0 or greater since 1811 occurred in or near the New Madrid line. Away from that line, only small to medium (mag. 5.9 or less) quakes have been recorded. Their epicenters are almost randomly scattered across the map and show no significant alignment or concentration. Earthquakes are no more common and no larger along bedrock faults than in unfaulted areas. In fact, few tremors have taken place on or close to any of the mapped fracture zones. Thus, the known faults are neither actively developing, nor are they slipping in reaction to earthquakes that originate elsewhere.

EVIDENCE FOR MODERN FORCE FIELD

Several independent lines of evidence show that the study area today is subjected to a force field unrelated to those responsible for the fault systems discussed above. This modern stress field is one of compression, and not only is causing earth tremors, but also appears to be forming new faults in the southern part of the Illinois Basin.

Focal-plane solutions

When a sufficient number of seismograms is obtained for a given earthquake from stations surrounding the epicenter, the orientation of the causative stresses and of the plane of movement (fault) can be determined. The result of such calculation is known as a focal-plane solution. Several earthquakes close to the study area have been subjected to focal-plane analysis, and the results substantially agree with one another.

The nearest quake for which focal-plane data are available is the Broughton, Illinois tremor of November 9, 1968. This event registered a magnitude of 5.3 and damaged a number of brick walls, chimneys, tombstones and similar structures near the epicenter, which was fixed at Lat. 37.96° N, Long. 88.46° W, approximately 15 miles northwest of Equality. The focal depth was calculated at 19 km (about 12 miles). Gordon et al. (1970) crudely calculated the focal mechanism by noting the sense of rotation of gravestones and other heavy objects in relation to their distance and direction from the epicenter. They concluded that the maximum compressive stress was aligned east-west and that the tensional axis was vertical. Focal-plane solutions, based on seismograms, confirm these results (Stauder and Nuttli, 1970). They show one nodal plane striking N 15° E and dipping 45° west, and a second striking N 1° W and dipping 47° east, signifying nearly pure dip-slip reverse faulting in response to horizontal east-west compression.

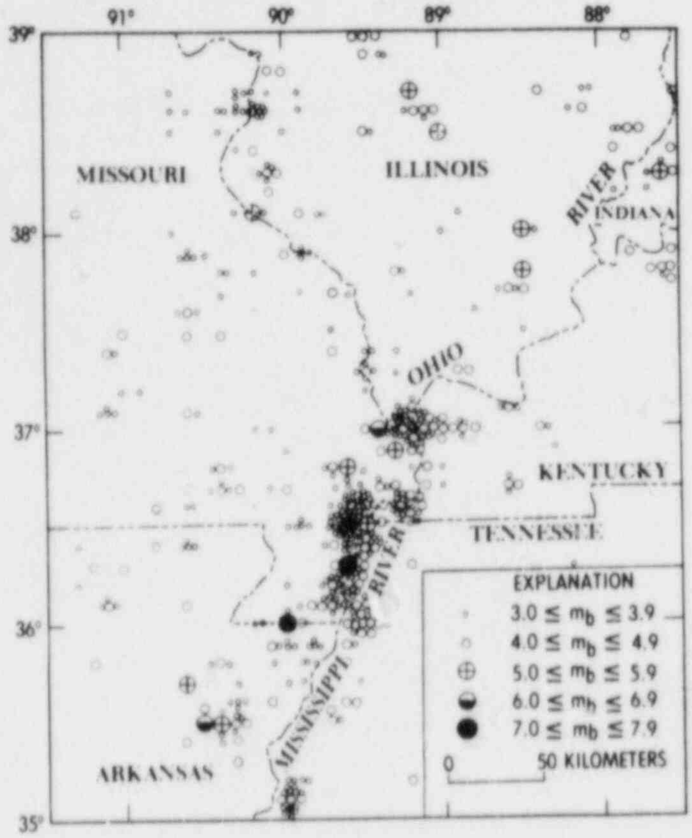


FIGURE 42. Epicenters of 488 earthquakes (magnitude 3.0 and greater) that occurred in the Mississippi Valley from 1811 through mid-1974. New Madrid seismic zone is clearly indicated (Stauder, 1982).

Herrmann (1979) gave focal-plane solutions for three additional earthquakes in Illinois, and two out of three indicated maximum compression oriented east-west to east-northeast-west-southwest, like the Broughton quake. The axis of compression trended N 83° E for the Olney quake of April 3, 1974, and N 59° E for the Thebes quake of August 14, 1965. The epicenters of these were located about 65 miles north and 75 miles west-southwest, respectively, from Shawneetown. In both cases the resulting movement apparently was strike-slip along a fault trending about 45° from the direction of compression. The third earthquake, nearly 300 miles north of the study area in Lee County, showed maximum compression oriented N 38° E.

A tremor of magnitude 3.8, centered northwest of Memphis, Tennessee, was the result of east-northeasterly compressional stress (Arch Johnston, personal communication, 1982).

Observations and stress measurements in coal mines

Coal miners in southern Illinois have experienced the effects of in situ stresses for many decades. Workers in deep underground mines have long noted that the mine roof is considerably more prone to failure on north-south than on east-west headings. The effect is most severe in parts of Franklin, Jefferson and Hamilton Counties, where the deepest seams are worked. Typically, failure begins a short distance back form the working face. The rock layers in the immediate roof buckle downward and snap, either near the center of the entry or along one side. This sag, which Krausse et al. (1979) labelled a "kink zone," propagates north-south, or slightly east of north, with successive fracture of layers higher in the roof (fig. 43). If left untended, the "kink zone" may develop into a major fall. "Kinks" affect all common roof lithologies but are most noticeable in brittle, well-laminated shales and siltstones. Their progress appears to be unrelated to such factors as method or sequence of mining, or local geology.

Faced with severe loss of production and hazard to miners at the No. 2 Mine near McLeansboro, the management of Inland Steel Coal Company launched a comprehensive investigation into the cause of and cure for "kinking." They soon realized that lateral stresses were to blame for the trouble. Observations of the "kinks" showed that after the rock layers buckled downward and snapped, the broken ends were pushed together so that they overlapped. The miners cut vertical slots 6 inches wide into the roof ahead of the face, in an attempt to relieve the stress. These slots narrowed 1 1/4 to 1 1/2 inches within 24 hours after cutting. Finally, a team from the Mine Safety and Health Administration (MSHA) installed strain gauges in the rock ahead of the faces. The gauges showed maximum compressive force of 2721 psi on an axis trending N 86 1/2° E, and minimum compression of 862 psi oriented N 3 1/2 ° W. In other words, maximum lateral stress is more than three times greater than vertical loading (Blevins, 1982).

Inland Steel revised its mining plan so that main entries run NE and NW instead of due north; this change resulted in markedly improved roof stability.

The silty shale above the coal at Inland No. 2 contains conspicuous planar vertical joints that clearly are the result of extensional stresses. Some of

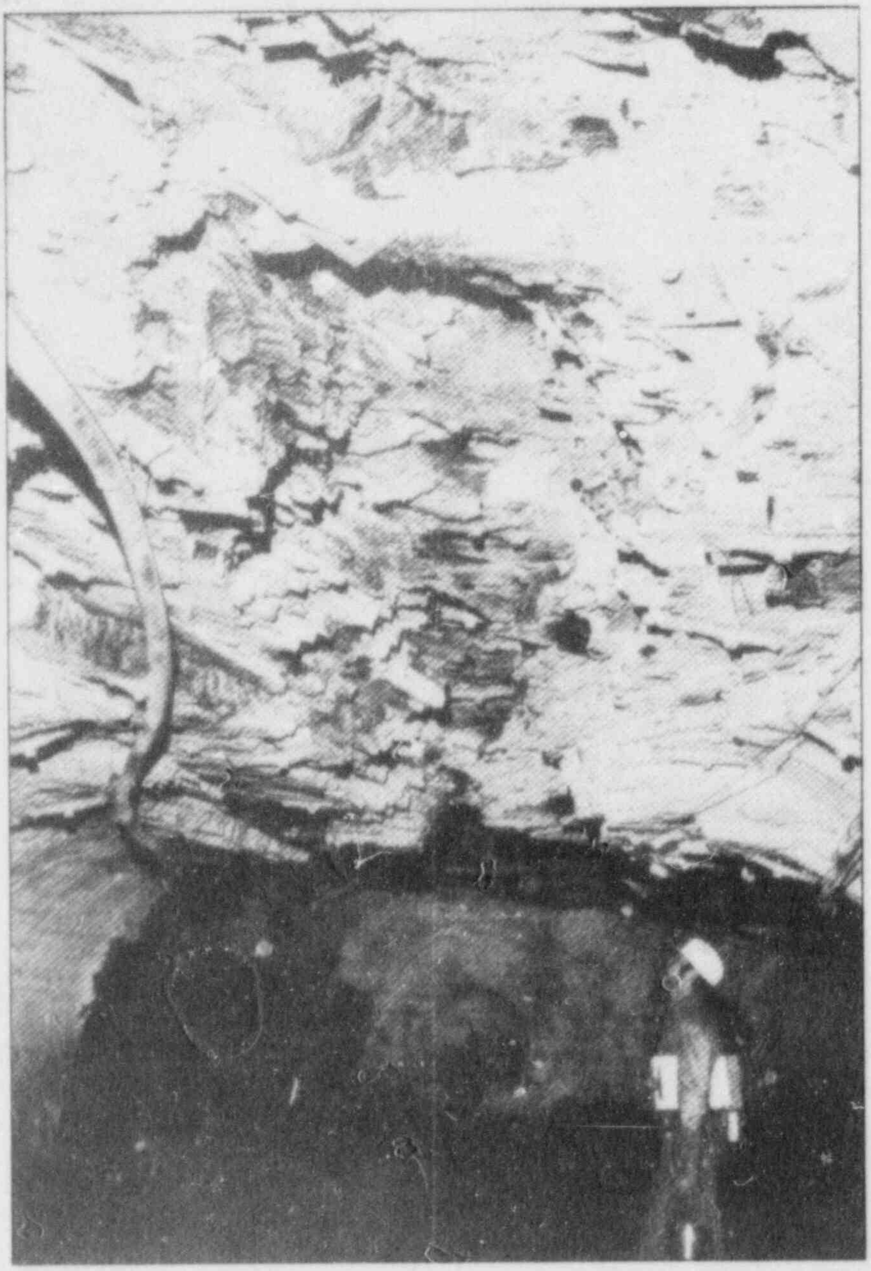


FIGURE 43. North-south "kink zone" caused by large horizontal compressive forces, in roof of Old Ben Mine No. 24, Franklin County, Illinois (Bauer and DeMaris, 1982).

the joints are 1/8 inch or more wide and others are filled with clay or calcite. In some places these fractures are concentrated in narrow zones, up to a foot wide, in which not only the roof rock, but also the coal, is pulverized; however, none of the fractures show any offset, slickensides, or other evidence of shearing movement. The average trend of joints in the mine is N 84° E--perpendicular to the minimum compressive stress, just as one would anticipate (Blevins, 1982).

The orientation of joints in roof shales is remarkably consistent in mines around the state. Except in the immediate vicinity of fault zones, such as the Cottage Grove Fault System, these fractures trend N 60° E to N 85° E. These cracks are best developed in black fissile shales and gray laminated siltstone or silty shale, but also have been observed in sandstone and limestone. They are coated with pyrite or calcite in some mines. Although many mines having joints do not experience high lateral stresses, we believe joints and "kink zones" owe their origin to the same stress field.

Results of hydrofracturing experiment

Haimson (1974) reported results of an experiment designed to measure in situ stresses in boreholes. At an unspecified location in Illinois--Zoback and Zoback (1980) stated it was near Hillsboro, in the west-central part of the state--the researchers drilled five holes, ranging from 298 to 338 feet deep. A portion of each borehole was sealed with rubber packers, then water was pumped into the sealed interval at high pressure to fracture the rock. This procedure, known as hydrofracturing ("fracking"), is widely used in the oil industry to increase porosity and stimulate production from tight reservoirs. After fracking the holes, Haimson and colleagues inserted and inflated soft rubber impression packers that retained impressions of fractures in the walls of the well. When the impression packers were withdrawn, the orientations of the fractures were measured. The average for five holes was N 62° E, with a range of N 49 to 72° E, indicating maximum compressive stress trends N 62° E.

North-trending thrust faults

Numerous small, low-angle reverse faults have been mapped and described at underground coal mines in southeastern Illinois and western Kentucky (fig. 44). The northerly trend of these thrusts indicates that they are the product of east-to-west horizontal compression. Although they occur in or near major bedrock fault systems, these thrusts do not fit the stress fields that formed the large faults. We believe the north-trending reverse faults are modern features, developing under the present-day stress field.

Nelson and Krausse (1981) discussed north-striking reverse faults found in mines of Williamson and Saline Counties, Illinois. The thrusts occur either singly or as bundles of small faults and tight compressional flexures that trend almost due north. These faults have small displacements--a fraction of an inch to a few feet--but they are extensive: one was traced 1.5 miles across several adjacent mines. Inclinations of fractures vary from 45° to horizontal; locally, they follow bedding planes in the rock. Coal and roof shales along these thrusts are slickensided and crushed, so roof control is

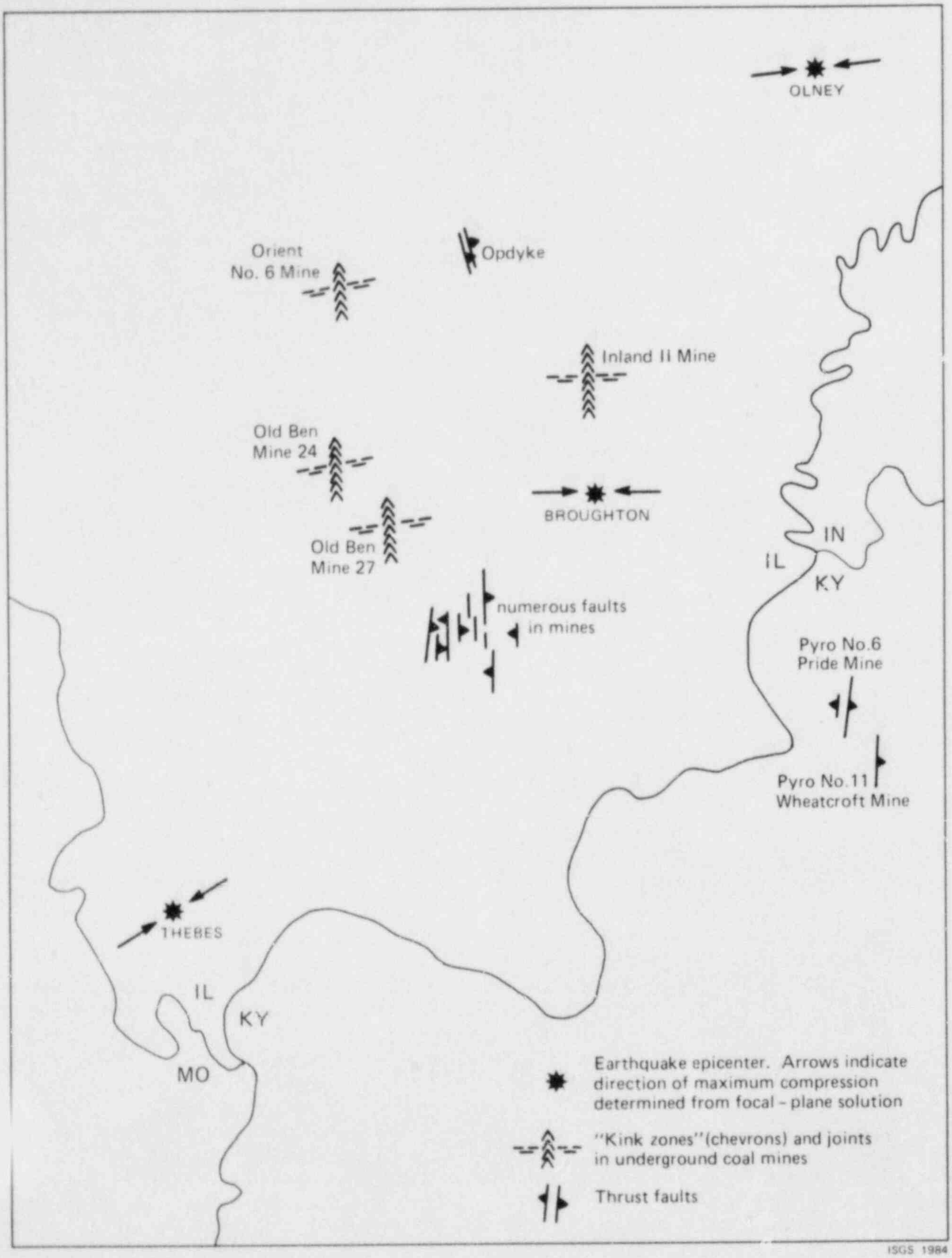


FIGURE 44. Features and measurements indicative of modern stress field.

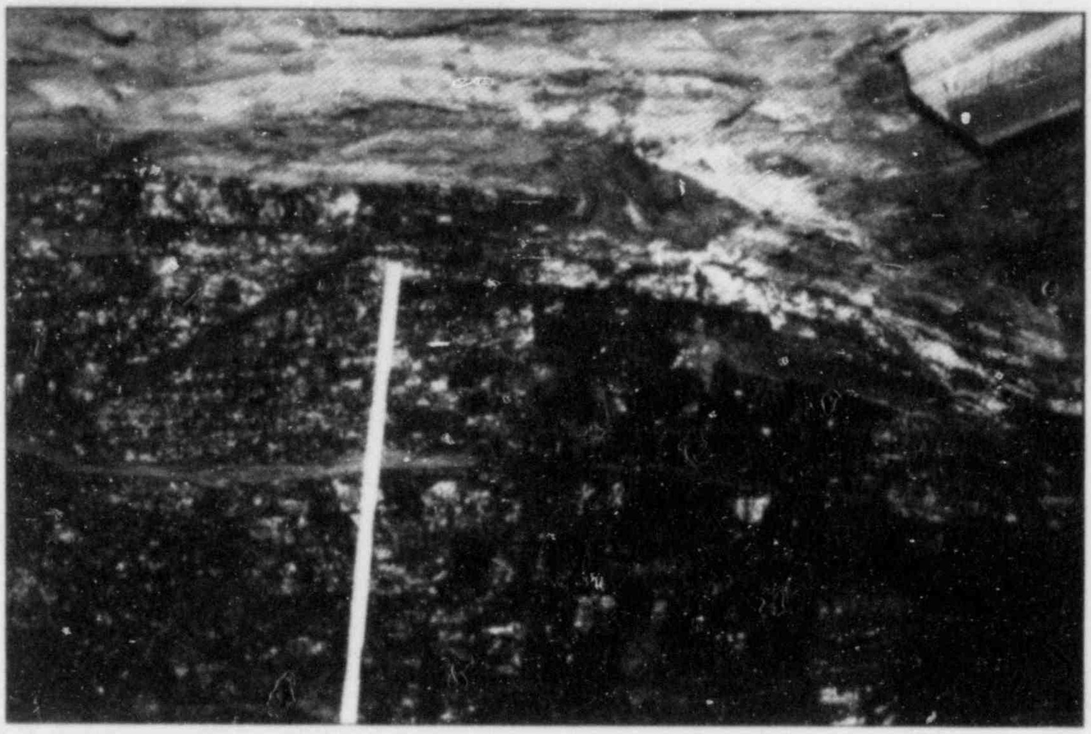


FIGURE 45. North-trend ng thrust fault, dipping about 30 degrees to left, offsetting upper part of Herrin Coal at Pyro Mining Company's No. 11 Wheatcroft Mine, Webster County, Kentucky.

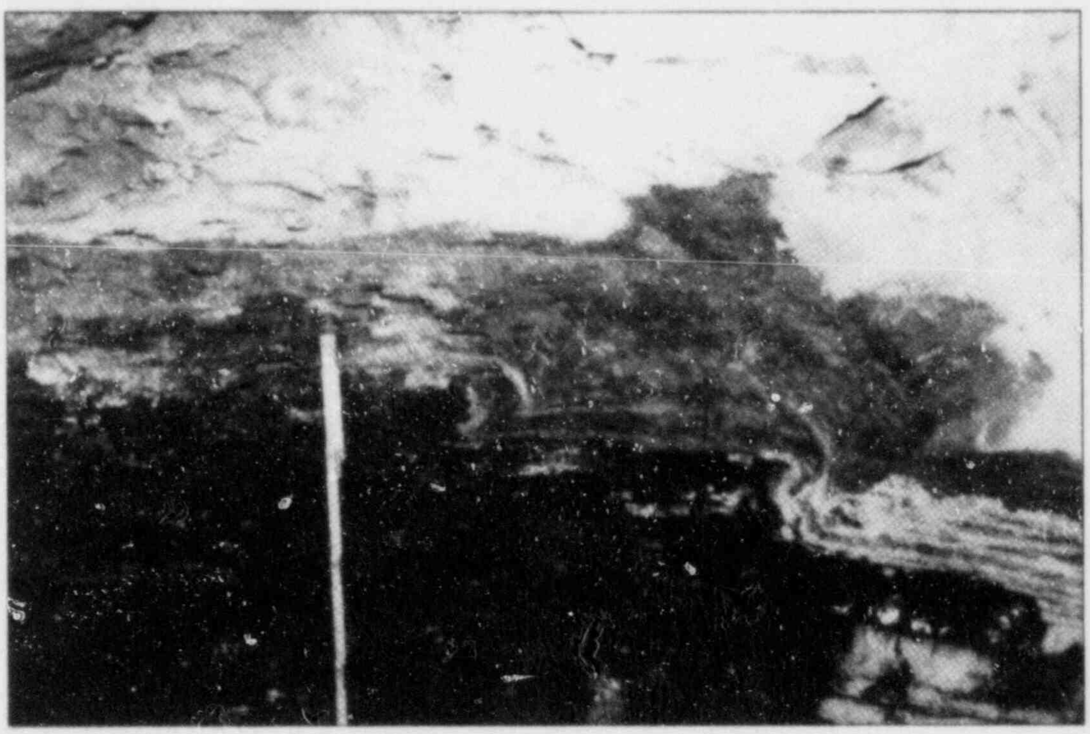


FIGURE 46. Pair of thrust faults offsetting top of Herrin Coal and overlying shale. The faults are not clean breaks, but rather zones along which coal and shale were crushed and "smeared out."

difficult in the vicinity of faults. Coal companies tend to leave the coal unmined along the thrust faults, making the faults easy to trace on mine maps.

The thrust faults in Illinois lie within the Cottage Grove Fault System but, as Nelson and Krausse noted, are not genetically related to that system. The CGFS developed under right-lateral shear in which maximum compressive forces were oriented northwest-southeast. These stresses resulted in formation of anticlines whose axes trend northeast to east-northeast and lie close to the master strike-slip fault, but the north-striking reverse faults signify east-to-west compression.

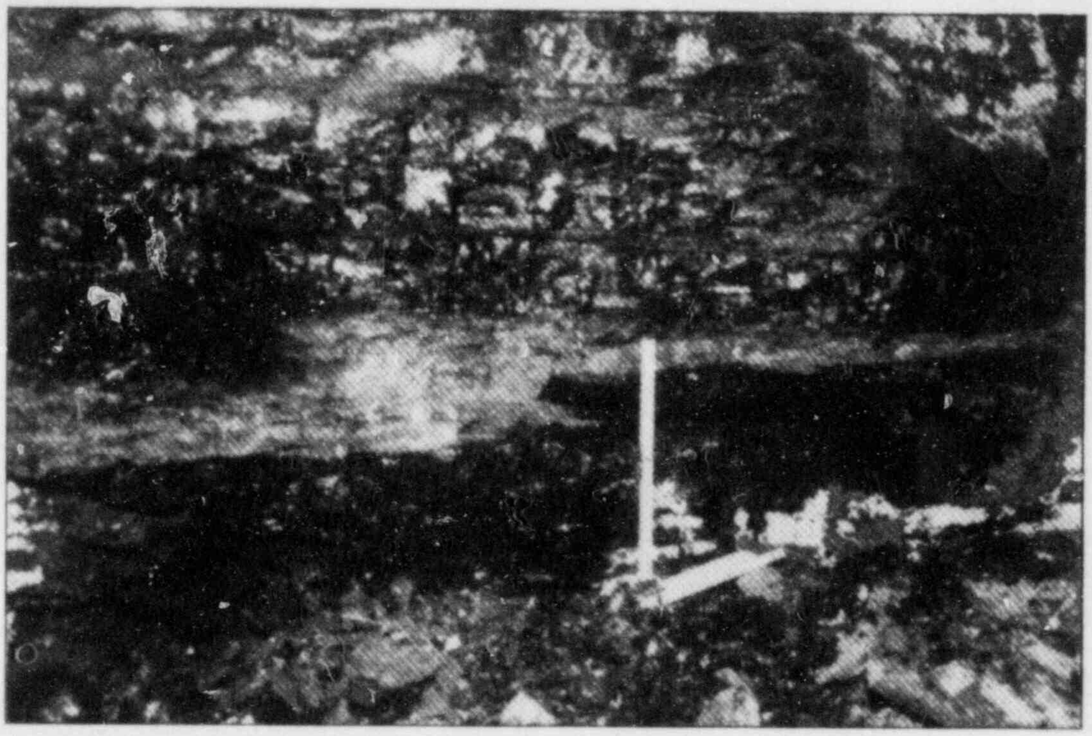
We have observed the same type of structure at two underground mines in Kentucky. Several low-angle thrust faults, with a few inches to about a foot of displacement, were encountered in Pyro Mining Company's No. 11 Mine in the Herrin Coal in Webster County. Sketches and photographs (figs. 45-47) show crushed shale and coal along the surface of movement, and sharp drag folds or flexures along the faults. These thrusts strike north to slightly east of north. At Pyro's No. 6 Pride Mine in Union County, similar thrust faults cut the Davis Coal. These faults extend for thousands of feet along strike, and also reportedly were encountered in surface mines in the Springfield (W. Ky. No. 9) Coal, about 260 feet stratigraphically above the Pride Mine (Larry Spencer and Rick Dempsey, 1982, personal communication).

The two Pyro mines are situated along the southwest limb of the Moorman Syncline; the strata dip northeastward at less than 5°. Aside from the thrusts, no other faults occur in the mines. The region is south of the Rough Creek Fault Zone and generally east to northeast of the Fluorspar Area Fault Complex (fig. 44). Neither the RC-SFS nor the FAFC involved east-to-west compression, as would be required to produce the north-trending thrusts.

In 1977 the senior author of this report observed a thrust fault and a narrow asymmetrical anticline at a surface mine in southeastern Jefferson County, Illinois, about 50 miles northwest of Shawneetown. The structures affected the Opdyke Coal Member of the Mattoon Formation, of late Pennsylvanian age (fig. 44). The thrust fault had a strike of N 20-25° W and a dip of 10° east-northeast, with the northeast block overriding the southwest block by about 3 feet. Both above and below the fault the coal layers were sharply folded and fractured (fig. 48), the fractures trending parallel and perpendicular to the strike of the fault. The surface of slippage was marked by a zone of pulverized coal about 0.1 foot thick. The anticline lay northeast of the thrust fault and parallel with it, being traceable across the full width of the pit. Its northeast limb was gentle and the southwest limb steep. On the highwall the shale was intensively slickensided above the steeper limb of the fold. Neither the fault nor the anticline visibly affected the Pleistocene materials overlying the bedrock; however, weathering and slumping material obscured the relationships.

Mine officials stated that similar features were common, in almost every pit the company mined, over an area roughly 5 by 2 miles. No other faults have been documented in the vicinity.

These structures, like those described above, clearly are compressional and signify a maximum compressive stresss oriented N 65 to 70° E.



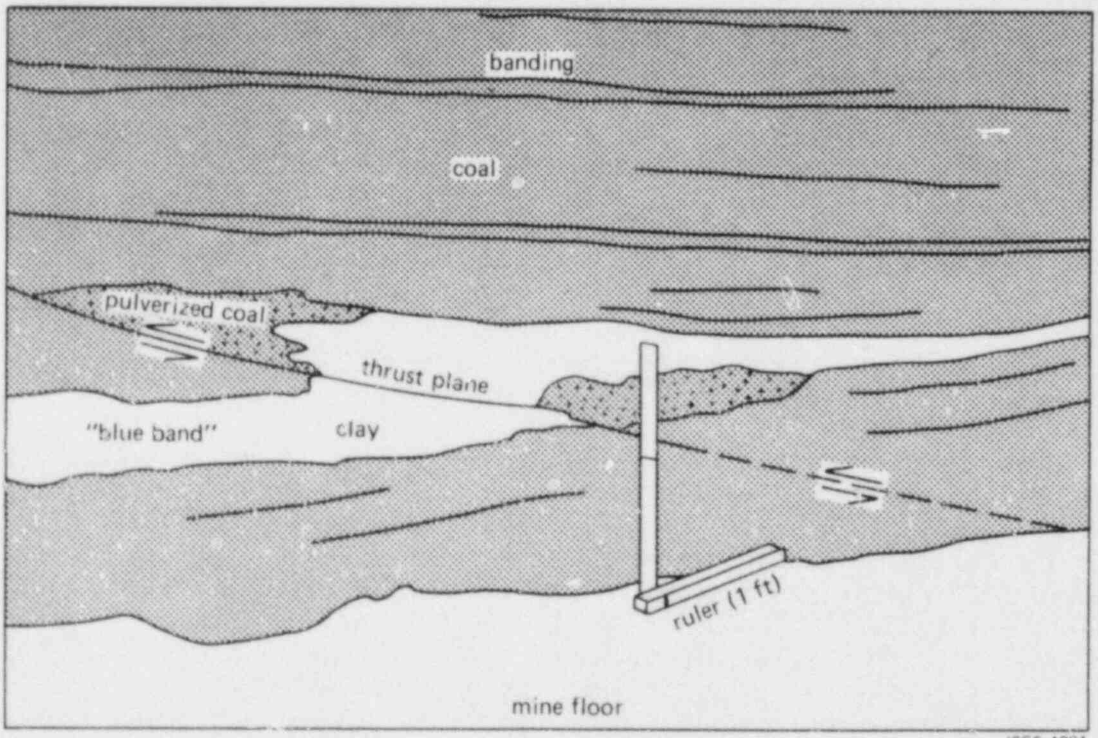


FIGURE 47. Offsetting of "blue band" clay parting and lower layers of Herrin Coal by low-angle thrust fault in Pyro M..ning Company's No. 11 Wheatcroft Mine, Webster County, Kentucky.

To date we have no proof that the north-trending reverse faults are recent features, although we have solid circumstantial evidence. We have not yet found any place where thrusts intersect other faults or potentially offset Pleistocene materials. Such exposures should be vigorously sought; active or unreclaimed surface mines probably provide the best hunting grounds.

Conclusions based on this evidence

Southern Illinois and adjacent areas are currently subject to compressional stress with the major axis striking east-west to east northeast-west southwest. This force field has been determined by earthquake focal-plane analysis, hydrofracturing experiments, observations of joints and "kink zones," and by in situ stress measurements. The latter indicate that maximum force is approximately three times the vertical overburden pressure. These stresses apparently are creating thrust faults in near-surface strata and are producing earthquakes through reverse and strike-slip offset in deeper rocks.

Comprehensive regional studies have shown that east-west to northeast-southwest compressional forces are active in much of the eastern United States (Sbar and Sykes, 1973; Zoback and Zoback, 1980).

East-west compression apparently is a modern phenomenon and did not play a role in forming any of the major fault systems in the study area. The WVFS is an extensional structure, the CGFS is strike-slip, the RC-SFS the result of vertical movements, and the FAFC the result of combined extensional and vertical slippage. Bedrock faults are predominantly vertical or steeply dipping and show little or no evidence of compressional tectonics except in localized, secondary structures in the RC-SFS and near the master fault of the CGFS. This means that few bedrock faults are properly oriented to be reactivated under east-west compression--in other words, the stresses will have to form new faults, because they cannot be relieved by slippage along old ones.

Thus, the danger of earthquakes in Illinois probably is no greater along bedrock faults than away from faults. Available data on epicentral locations bear out this statement.

Although the nature and cause of faulting in the New Madrid area are beyond the scope of this investigation, some comments are in order. Geologists regularly speak of the "Reelfoot Rift." This term is properly applied to Paleozoic, Mesozoic, and perhaps early Cenozoic time, when the region was subject to recurrent extensional tectonics. In connection with modern seismicity, however, the term "rift" appears inappropriate, and can mislead structural interpretation. Both Sbar and Sykes (1973) and Zoback and Zoback (1980) found that the Reelfoot area, like southern Illinois, is under east-west to northeast-southwest compression. Focal-mechanism studies of earthquakes confirm these findings and indicate strike-slip and reverse faulting--not rifting (Stauder, 1982). Zoback et al. (1980) produced seismic reflection profiles of the Mississippi Embayment near New Madrid and interpreted them as revealing high-angle reverse and strike-slip faults cutting Tertiary sediments.

In light of the above, the ideas that the Reelfoot "rift" is an active zone of continental spreading, and that it extends into Illinois via the FAFC and WVFS, should be rejected.

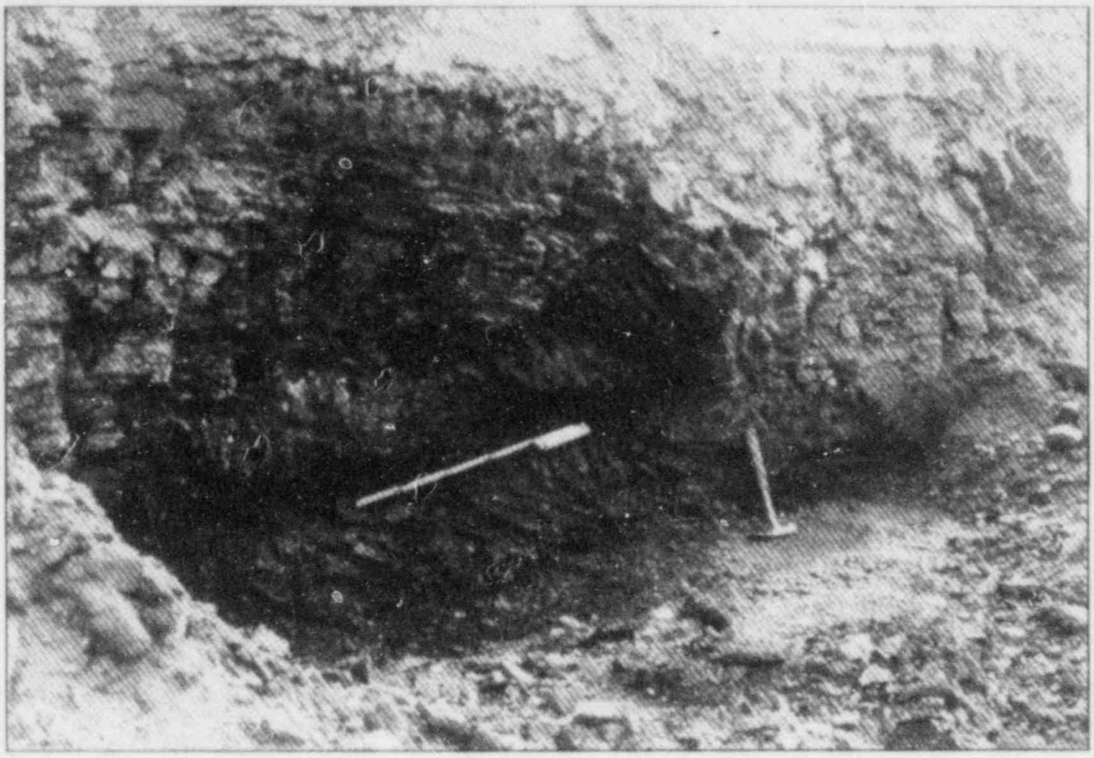


FIGURE 48. Thrust fault in Opdyke Coal at now-abandoned strip mine in southeastern Jefferson County, Illinois. This fault and a parallel asymmetrical anticline strike N 20 W and indicate compressional stress from the ENE and WSW.

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13. ABSTRACT *(200 words or less)*

Southeastern Illinois is the locus of several converging fault systems of differing orientations. The specific research goals of this project were to determine the relationship of these fault systems (i.e. the Fluorospar District, the Wabash Valley, Shawneetown and the Cottage Grove) to each other and whether or not any of them have been active in the Quaternary. Detailed field mapping indicated that southern Illinois and adjacent areas are currently subject to a compressional stress field in which the major axis is east to east-northeast. North-trending thrust faults of small magnitude may be forming in response to these stresses, but the major fault systems are neither active or likely to be reactivated in this modern stress field.

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