THE REND LAKE FAULT SYSTEM IN SOUTHERN ILLINOIS

John N. Keys and W. John Nelson

Illinois Institute of Natural Resources
ILLINOIS STATE GEOLOGICAL SURVEY, URBANA, ILLINOIS
Jack A. Simon, Chief

CIRCULAR 513
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COVER PHOTO: Closely spaced shear fractures in the Herrin (No. 6) Coal in the Rend Lake Fault System. Size of view: 1 ft.^{2}

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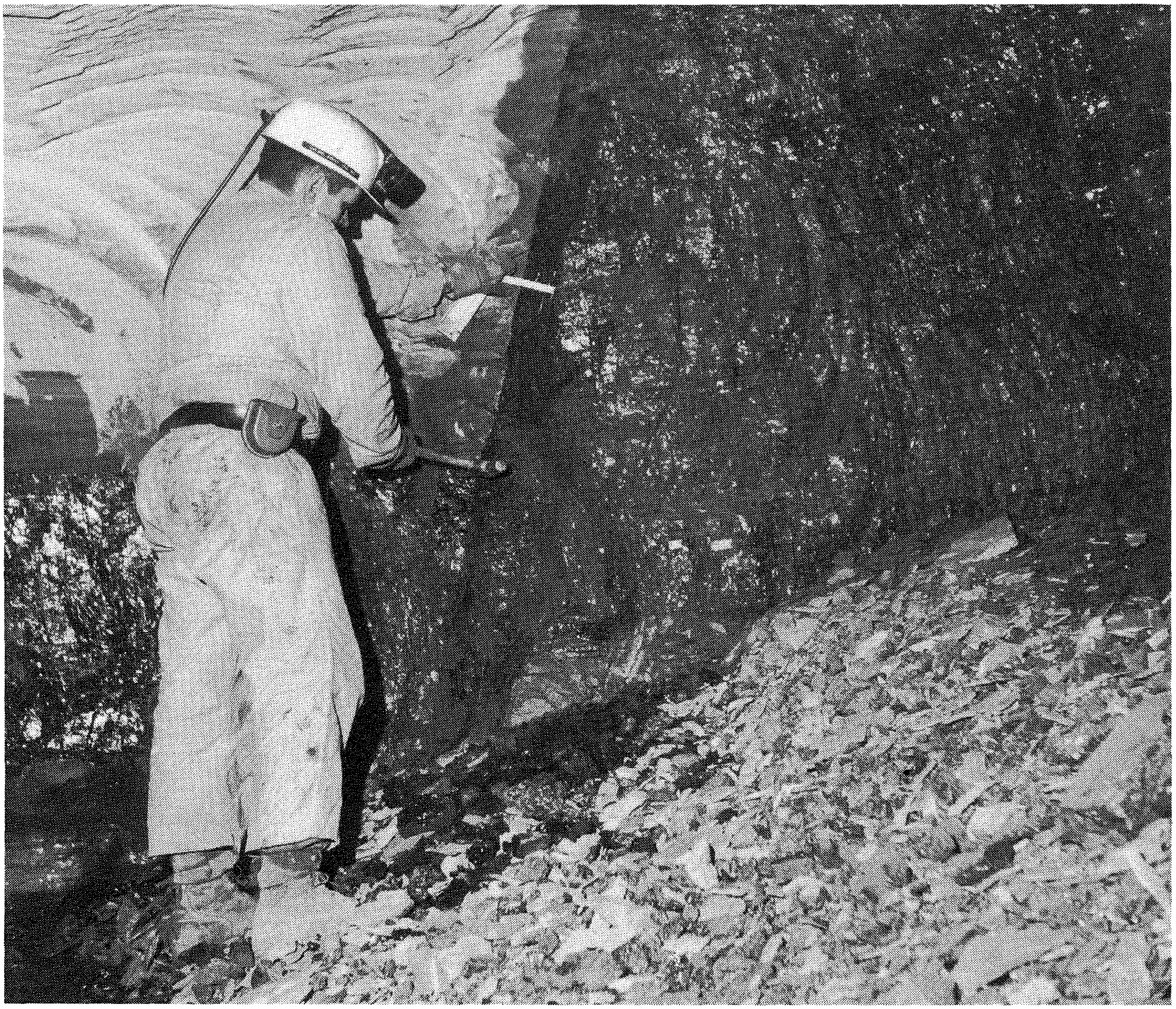

A typical fault of the Rend Lake Fault System exposed in the Orient No. 6 Mine. The Herrin (No. 6) Coal is offset about 6 feet; this necessitates mining the rock to maintain grade. Features to note include: steep angle of fault plane, absence of drag, and narrow zone of gouge. Photo by Heinz Damberger.

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ABSTRACT

The Rend Lake Fault System was discovered through numerous exposures in underground coal mines and through a small number of coal-test holes in Franklin and Jefferson Counties, Illinois. The system strikes due north except near its northern end, where it curves to a heading of N. 15° W. The known length of the system is about 24 miles, and the width varies from a few tens of feet to about half a mile. The faults in the system are predominantly high angle, and arranged in parallel or en echelon fashion. The maximum throw observed on a single fault is about 55 feet. Individual faults are discontinuous along strike; a few are miles long, but most are much shorter.

The faulting was produced by east-west horizontal extension of the affected strata. The extension is believed to have resulted from north-south-trending differential uplift and subsidence. These differential vertical movements began prior to the deposition of the Herrin (No. 6) Coal Member and probably increased in rate after the deposition of the Shoal Creek Limestone Member. The age of faulting, therefore, can only be defined as post-Shoal Creek Limestone (upper Pennsylvanian) and pre-Pleistocene.

ACKNOWLEDGMENTS

This report was originally prepared by the senior author in 1978 as a Master's thesis in geology at the University of Illinois at Urbana-Champaign. The Illinois State Geological Survey (ISGS) provided travel expenses to visit the coal mines of southern Illinois and supplied access to its computer terminals. We are grateful to several ISGS staff members for their help: Stephen R. Hunt and Heinz H. Damberger, who originally suggested the study area; Hans-Friedrich Krausse, who assisted in underground mapping and participated in many discussions pertaining to the Rend Lake Fault System; and Jay Hoeflinger, who was invaluable in helping to put together the computer programs necessary to generate the contoured structure and isopach maps. We acknowledge Old Ben Coal Company and Freeman United Coal Mining Company for allowing us to do field work in their mines. We also wish to acknowledge Inland Steel Company, Freeman United Coal Mining Company, Kerr-McGee Resources Corporation, Ziegler Coal Company, and Old Ben Coal Company for permitting us to use their drill hole data in the preparation of the subsurface maps.

INTRODUCTION

Purpose of study

The primary objectives of this study were to determine the cause of faulting and to produce a detailed map of the fault system. Secondary objectives were: (1) to bracket the age of faulting; (2) to determine the directions of principal stress responsible for faulting; (3) to determine the state of lithification at the time of faulting; (4) to determine the extent of the fault system into unmined areas on the basis of the interpretation of subsurface drill hole data; (5) to assess the potential of the fault system as a source of seismicity; and (6) to document the effects of faults on coal mining.

Methods of investigation

The Rend Lake Fault System is exposed only in the underground workings of the Herrin (No. 6) Coal Member (Pennsylvanian) in southern Illinois. Numerous field visits to southern Illinois were undertaken between July of 1976 and July of 1977 to examine in detail all the active mines that contain the fault system. The field work involved measuring the strike and dip of faults, and recording observations of the fault planes, associated subsidiary fractures, fault filling, and the effect of faulting on adjacent rocks. In addition, an extensive photographic record was kept. A compilation map (fig. A of plate 1) of the fault system was made by combining these data with data obtained from maps of abandoned mines.

In order to determine whether faulting had affected Pleistocene sediments, surface field work was done along the bluffs of the Big Muddy River, which overlies the Rend Lake Fault System, and which may be geomorphically controlled by it. The relatively rare bedrock outcrops were examined for evidence of faulting.

To ascertain the lithification state of the rocks at the time of faulting, thin sections of limestone cut by shear fractures were prepared, then observed under the petrographic microscope to determine whether clasts were fractured.

Data from over 3000 oil- and coal-test drill holes were collected and used to construct subsurface structure and isopach maps. In the case of oil tests, only electric log data were used because of the general unreliability of drillers' logs in the coal-bearing sequence. Drillers' logs of coal-test drill holes were used, however, because they are generally accurate and usually contain core data. Mine elevations were available as an additional data source for the construction of the structure contour map of the Herrin (No. 6) Coal. The subsurface maps were made to: (1) ascertain whether there is a relation of the structural relief of the area to the fault system; (2) determine whether rock units younger than the Herrin (No. 6) Coal were penetrated by the faults; (3) determine the extent of the fault system into unmined areas; and (4) determine the cause of faulting.

Drill hole data and elevation data for all locations were stored by the IBM 360 computer at the University of Illinois, then processed through ILLIMAP and STAMPEDE programs to create contour maps. ILLIMAP (Swann et al., 1970) provides a base map of sections, townships, and ranges in any designated region in Illinois. STAMPEDE (IBM commercial program) creates a numerical surface that is converted to contour lines via the Calcomp 563 drum-type plotter. The contours produced in this manner ignore channels that cut out the mapped unit, do not respect all data point values, and lack interpretation. As a consequence the maps were thoroughly modified by hand. Nevertheless, the programs were very useful in that they furnished a base map, provided a framework of easily modifiable contour lines, identified bad data points by creating a pyramid or cone of contour lines, and in general facilitated the task of contouring.

Description of study area

The Rend Lake Fault System is located in Franklin and Jefferson Counties in southern Illinois, extending north from the east-west-trending Cottage Grove Fault System for at least 24 miles (fig. 1). It strikes due north for its first 15 miles, beyond which it strikes at approximately 345° (N. 15° W). The faults are exposed only in underground workings of the Herrin (No. 6) Coal Member of the Carbondale Formation (Pennsylvanian). Because this is a region of thick, fairly shallow, and relatively low-sulfur bituminous coal (known as the Quality Circle area), the coal has been mined extensively, which has resulted in a high degree of resolution for tracing the path of the fault system, especially in the southern half of Franklin County (fig. A of plate 1).

The fault system is composed primarily of north-striking parallel normal faults of modest displacements—no single fault is known to exceed 55 feet in throw. The youngest rock unit observed to be penetrated is the Bankston Fork Limestone Member, and the oldest rock unit known to be penetrated is the Harrisburg (No. 5) Coal Member (fig. 2). The interval between these two members in the area of the faults is about 100 feet. Data from drill holes indicate that the Shoal Creek Limestone Member, about 500 feet above the Herrin Coal, is offset by the faults.

The faults dip both to the east and the west; the dips vary in angle between 45° and vertical, with most lying in the 60° to 70° range. The dominance of high-angle normal faults indicates a vertical maximum compressive stress yielding an east-west extension along the southern part of the fault system and an east-northeast to west-southwest extension along the northern part.

The fault system varies in width from a few tens of feet to over half a mile, depending on the number of faults

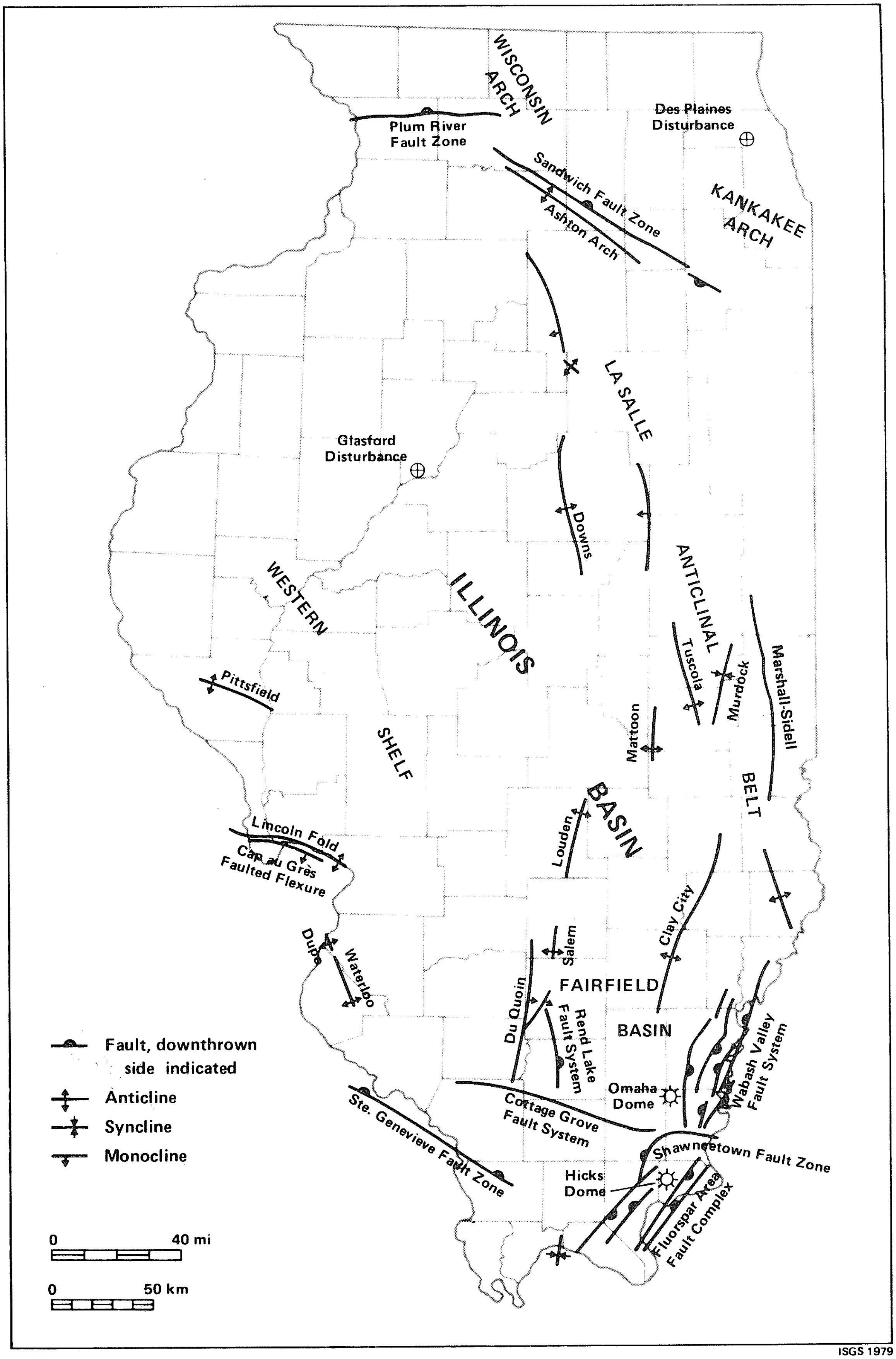
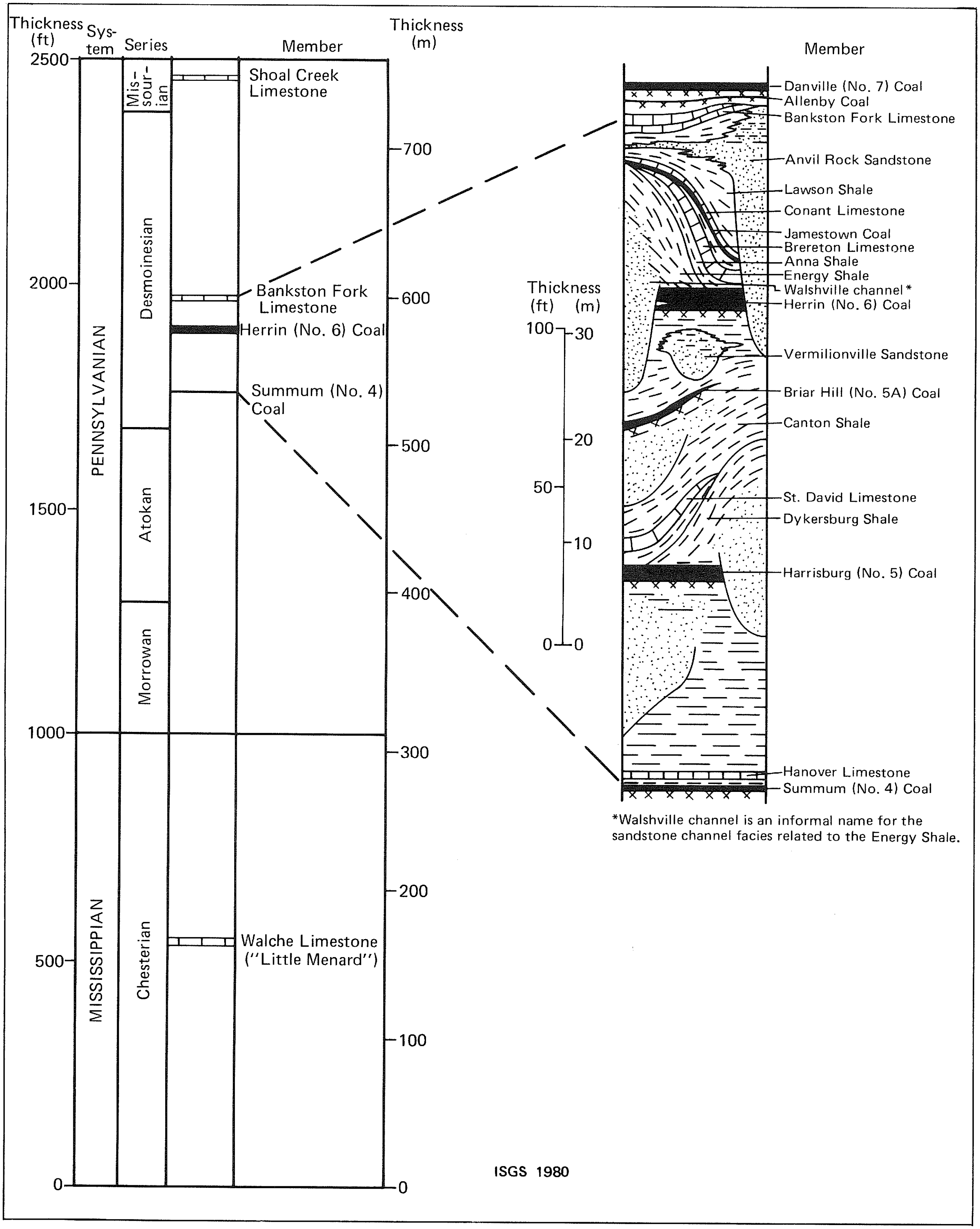


Figure 1. Geologic structures of Illinois (modified after Krausse et al., 1979).



*Walshville channel is an informal name for the sandstone channel facies related to the Energy Shale.

Figure 2. Stratigraphy of units mentioned in text; thicknesses of members not to scale. Detailed column after Allgaier and Hopkins (1975).

and the spacing between them. The number of faults and the spacing are in turn a function of the amount and distribution of total displacement along individual faults. The largest known Rend Lake fault (55 feet of throw) was encountered in a set of entries at Old Ben Mine No. 26. Here, the fault zone is narrow. Almost all the displacement has occurred on this largest fault. Wider sections of the fault system are composed of numerous smaller faults. Total displacement is not constant along the length of the fault system (fig. A of plate 1).

Individual faults are extremely discontinous, even more so than indicated in plate 1. A longitudinal section along any single fault would show the downthrown strata bowed downward the deepest in the central portion of the section, then tapering upward to no displacement at either end. Typically, as one fault dies out, another begins, staggered slightly. These staggered faults do not have the same direction of dip. This situation is best exemplified in the southern part of C. W. & F. Orient Mine No. 1 and in Old Ben Mines No. 14 and No. 21 (fig. A of plate 1). Surveyors of older mines tended to treat these slightly offset faults as one continuous fault. This is because room-and-pillar mining makes discrimination of individual fault planes difficult, since one fault can die out and another begin within the same pillar.

The probable reason for this discontinuous staggered faulting is that stretching affected all areas along the entire length of the fault zone at the same time, so that individual faults along strike developed simultaneously. Hence, individual faults die out very quickly where strain has already been taken up by another fault.

Four active mines completely traverse the fault system. In three of these, the dominant fault dips to the east (Freeman United Orient No. 6 Mine and Old Ben Mines No. 24 and No. 26). In the fourth, Old Ben Mine No. 21, the system is composed of numerous minor faults which dip mainly to the west. In abandoned mines south of Old Ben Mine No. 24, no preferred direction of dip for major faults is present.

Previous studies

There is little work published on the Rend Lake Fault System. Stonehouse and Wilson (1955) included the extreme southern portion of the fault system on a compilation map of faults in southern Illinois. Nieto and Donath (1976) examined faults in Freeman United Orient No. 6 Mine and Old Ben Mines No. 24 and No. 26 to determine whether the faults would adversely affect the integrity of the Rend Lake Dam, which directly overlies the fault system just north of Old Ben Mine No. 24. They concluded that further displacements along the faults are unlikely, and their field examination revealed no evidence of leakage from the reservoir through the fault zone. In addition, they suggested that faulting could represent local stresses produced by differential uplift and subsidence. In another report, Krausse and Keys (1977) briefly described deformational features associated with Rend Lake faulting.

The impetus for our study was a proposal in 1976 by H. H. Damberger and S. R. Hunt to T. C. Buschbach (all of the Illinois State Geological Survey), regarding fault systems and seismicity in southern Illinois. In their proposal, they postulated that Rend Lake faulting might be penecontemporaneous with sedimentation, as was the case with growth faults in soft sediments of the Gulf Coast (Cloos, 1968; Garrison and Martin, 1973). One purpose of this study was to test the hypothesis of contemporaneous faulting; another purpose was to determine whether the Rend Lake Fault system has any potential for seismicity, or association with areas of historical seismic activity.

STRUCTURAL SETTING

The Rend Lake Fault System lies near the southern margin of the Illinois Basin on the western flank of the subsidiary Fairfield Basin. The Fairfield Basin is bounded by the Du Quoin Monocline to the west, the Cottage Grove Fault System and the Shawneetown Fault to the south, and the La Salle Anticlinal Belt to the northeast (fig. 1).

The Du Quoin Monocline trends slightly east of north. Its eastern flank dips down into the Fairfield Basin, and to its west is the gently dipping Western Shelf. The monocline bifurcates near the northeastern corner of Perry County, and the eastern branch extends northeast through Jefferson County to become the eastern flank of the Salem Anticline (fig. 1).

From its exposure in the Herrin (No. 6) Coal, it seems that the Cottage Grove Fault System is composed of an east-west-trending master fault zone and a large number of en echelon northwest-trending faults in pinnate position to the master fault (fig. A of plate 1). The faulting is complex, consisting primarily of normal faults, but including high-angle reverse faults, low-angle thrust and bedding-plane faults, and definite strike-slip faults (Nelson and Krausse, in preparation). There is subsurface evidence that in deeper strata the fault system is dominated by east-west-striking, high-angle reverse faults, with the north side downthrown (Hubert Bristol, personal communication). The origin of the fault system has been attributed to right-lateral strike-slip faulting of the Precambrian basement (Heyl, 1972; Nelson and Krausse, in preparation).

FIELD AND LABORATORY INVESTIGATIONS

Field studies were carried out in all five active mines through which the Rend Lake System passes. Room-and-pillar mines provide fresh exposures of broad areal extent. In most mines the entries cross the faults at nearly right angles, allowing cross-sectional views that are rarely obtainable in surface exposures. The primary disadvantage of working in underground mines is that observations are limited to a small portion of the stratigraphic column.

The modest displacements of Rend Lake faults are sometimes revealed within the limited field of observation in underground mines. The small faults encountered in Old Ben Mine No. 21 have created examples of horst and graben features (figs. 3a and 3b). In one such horst (fig. 4), although there is approximately one foot of vertical displacement on both faults at the top of the coal, there is no indication of one fault plane offsetting the other in the Energy Shale roof, where the two intersect. This is proof of the true conjugate (i.e. contemporaneous) nature of the faulting and permits determination of stress orientations. Evidently movement along the fault planes occurred in alternating increments, creating the highly sheared zone at their intersection. This situation is not universal, however, as shown in the graben in figure 5, where the right-dipping fault plane apparently was postdated and offset by the left-dipping fault plane.

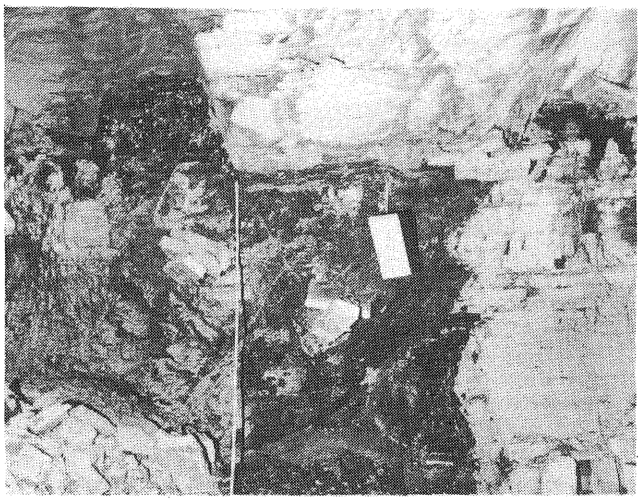


Figure 3a. Series of small normal faults at Old Ben Mine No. 21. Three main faults are present, forming a horst (left) and a graben (right). Mainly brittle failure is exhibited, but locally the rocks display ductile deformation. Photo by H.-F. Krausse.

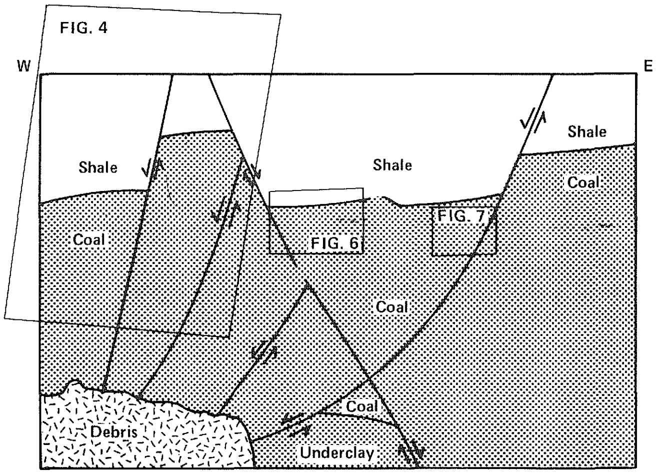


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Figure 3b. Sketch of figure 3a, showing its relation to figures 4, 6, and 7.

A graben in Old Ben Mine No. 21 shows the results of both brittle and ductile deformation (fig. 6). On the left-hand side of the graben, pyritic bands of clay are displaced by a number of small shear faults. The coal has been folded adjacent to the right-hand boundary fault (fig. 7). This ductile deformation within the coal seam is rarely observed in the Rend Lake Fault System, and possibly is caused by compressive forces that are a localized secondary effect of the faulting. Folding was enhanced by the increased anisotropy and ductility provided by thin layers of gray clay in the upper portion of the coal seam (top center in fig. 7).

Within the coal seam, crushed and powdered coal and mineralized vein fillings occur along fault planes. Mineralization usually occurs as calcite, but occasionally barite is found in the more northerly extent of the fault system. Usually the veins are thin (less than one-fourth inch) and parallel to the fault plane, and fill voids created by the non-

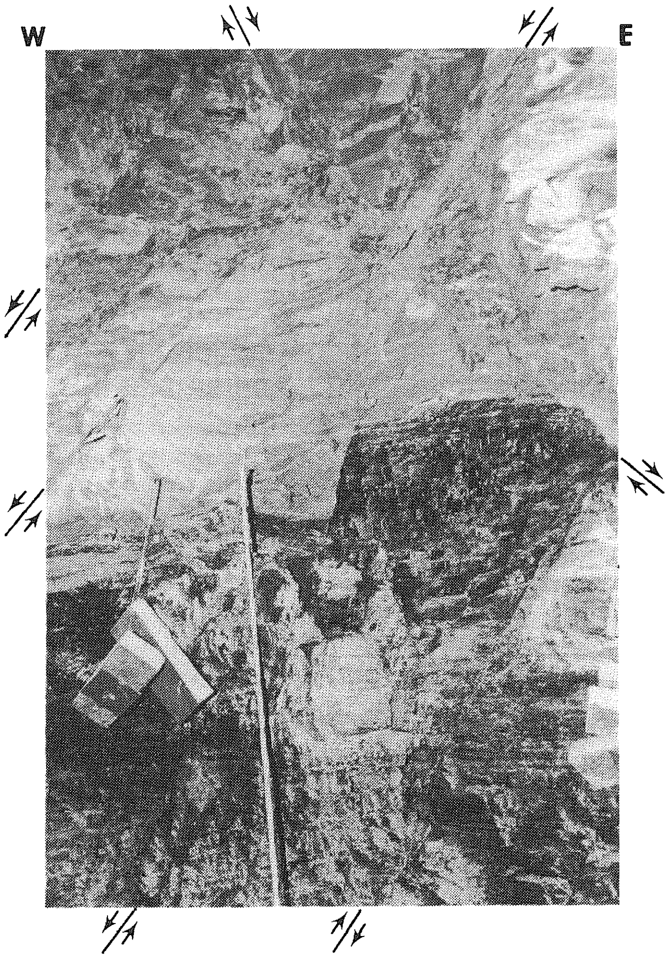

Figure 4. Detail of figure 3a. Intersecting faults form a horst in the coal and a graben in the overlying Energy Shale. Several additional high-angle fractures are visible in the coal and shale. Photo by H.-F. Krausse.

planarity of the fault surfaces. Sometimes the presence of larger voids has permitted the formation of euhedral calcite. Mineralization along the fault plane is not as prominent in the shales as in the coal, but is still common.

Within the Energy Shale roof and the overlying Anna Shale (fig. 2), primarily clay is found along fault planes. Presumably, the clay is the result of wetting of the crushed shales. Many of the fault planes are wet, thus admitting water into mine workings. The source of the water is probably in slightly permeable sandstones above the coal. In most cases, seepage of water ceases after several months or years.

The widths of individual zones of gouge and breccia vary from less than one-fourth inch to over two feet. Generally, large faults have wide gouge zones, but some larger faults have inordinately thin zones, and conversely some small faults have fairly wide gouge zones. Evidently strain rate, angle of dip, and other factors as yet unknown had a hand in determining the width of zones of crushed rock. Most of the faults exhibit slickensides on which the striations trend in the direction of dip, which suggest dip-slip movements on the faults. Many fault zones exhibit multiple fault surfaces, each with its own set of slickensides. A few of these slickensides indicate there may have been oblique-slip movements on the faults; however, the dominant movement on these was dip-slip. On some faults, a multiplicity of slip surfaces have created a planar fabric parallel to the fault plane, especially in shales.

Small reverse faults and sharp flexures with a maximum throw or height of about 3 feet have been observed at several places in the fault zone in Old Ben Mines No. 24 and No. 26. These faults generally exhibit moderately high (above 45°) angles of dip, although a few low-angle reverse faults have been mapped; invariably they occur adjacent to

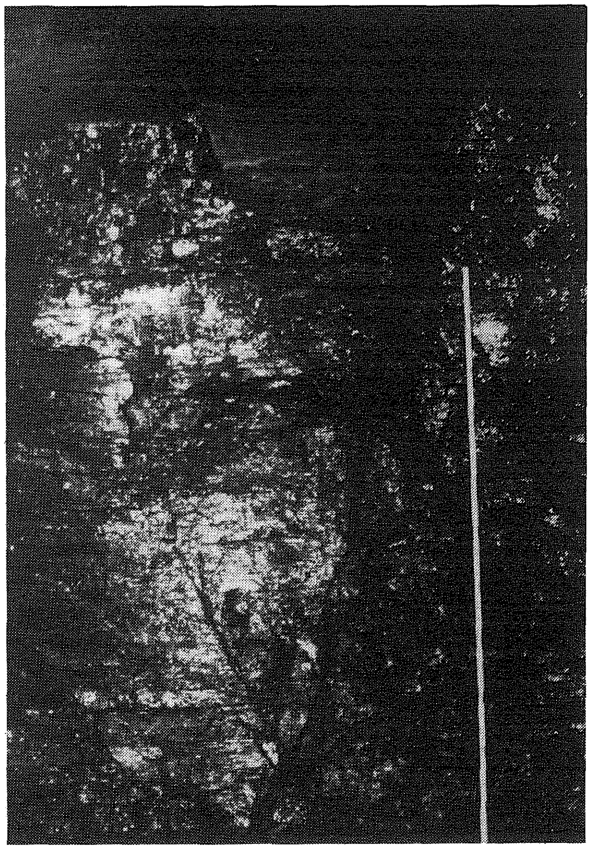

Figure 5. Conjugate faults forming a small graben in Orient No. 3 Mine. The right-hand fault apparently intersects and offsets the left-hand fault near the center of the photo. This indicates the possibility that the Rend Lake faults developed through a series of incremental movements, rather than through a single event of deformation, at least locally.

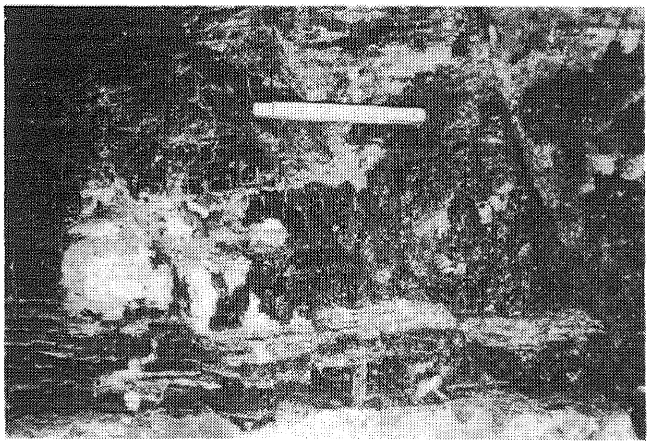

Figure 6. Detail of figure 3a, showing brittle deformation on the left side of the small graben. The coal is offset cleanly, with no drag, along a series of high-angle fractures that dip to the right (east). Light-colored bands of gray clay indicate the offsetting.

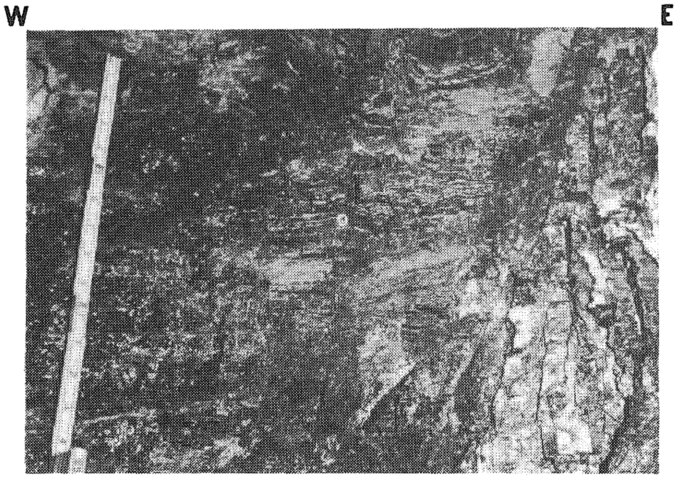

Figure 7. Another detail of figure 3a, just to the right of the area in figure 6, showing ductile deformation within the coal. The layers of gray clay are finely folded and contorted, especially in the upper part of the photo. Photo by H.-F. Krausse.

and parallel with larger normal faults, which they may join. The reverse faults and flexures have little lateral continuity. They probably formed in response to purely local compressive forces developed within the major blocks moving along normal faults.

One fault in the Rend Lake Fault System at Old Ben Mine No. 24 shows a consistent westward dip; however, in some places the east side of the fault is upthrown, and in others, the west side. The fault thus changes along strike from an apparently normal fault to an apparently reverse fault. Striations on the fault show a variety of orientations, ranging from nearly dip-slip to nearly strike-slip. As many as three superimposed sets of slickensides have been observed upon the same surface (Robert A. Bauer, personal communication). The field relationships suggest that the apparent reverse and strike-slip movements resulted from rotation or wedging of blocks during successive movements on adjacent, larger normal faults. In any case, the presence of superimposed slickensides demonstrates that the Rend Lake Fault System developed by a series of incremental movements rather than by a single event of rupturing.

The effect of faulting on adjacent rocks varies with their lithology. The vertical fault shown in figure 8 illustrates the typical behavior of the coal. The banding within the coal abuts the fault plane with no drag whatsoever. Evidently, the coal seam reacted to faulting as a single homogeneous isotropic unit, indicating that the laminae were not mechanically effective in promoting folding or drag. In contrast, the upthrown Canton Shale Member, a unit directly above the St. David Limestone Member (fig. 2), exhibits considerable drag and folding.

A sample of rock, shown in figure 9, was taken from a prominent fold and cut and polished so that the fold mechanisms were more easily seen. In this sample—a thoroughly fractured slab of rock—neither flexure nor continuity of the laminae are detectable across the fold hinge. Rather, the laminae have merely been tilted and fractured into a fold across the axial plane; this creates compressional forces towards the core of the fold. Indeed, near the bottom of the fold is another small fold, rotated out of place, along which the laminae are continuous across its hinge. Even in this truly compressional fold, the laminae do not thicken in the hinge region, indicating a fold mechanism of flexural slip, not flow (Donath and Parker, 1964). All fractures are filled with calcite, and inspection of thin sections reveals that the calcite has been sheared and offset, indicating there was more than one period of fracturing in the fault zone (fig. 10).

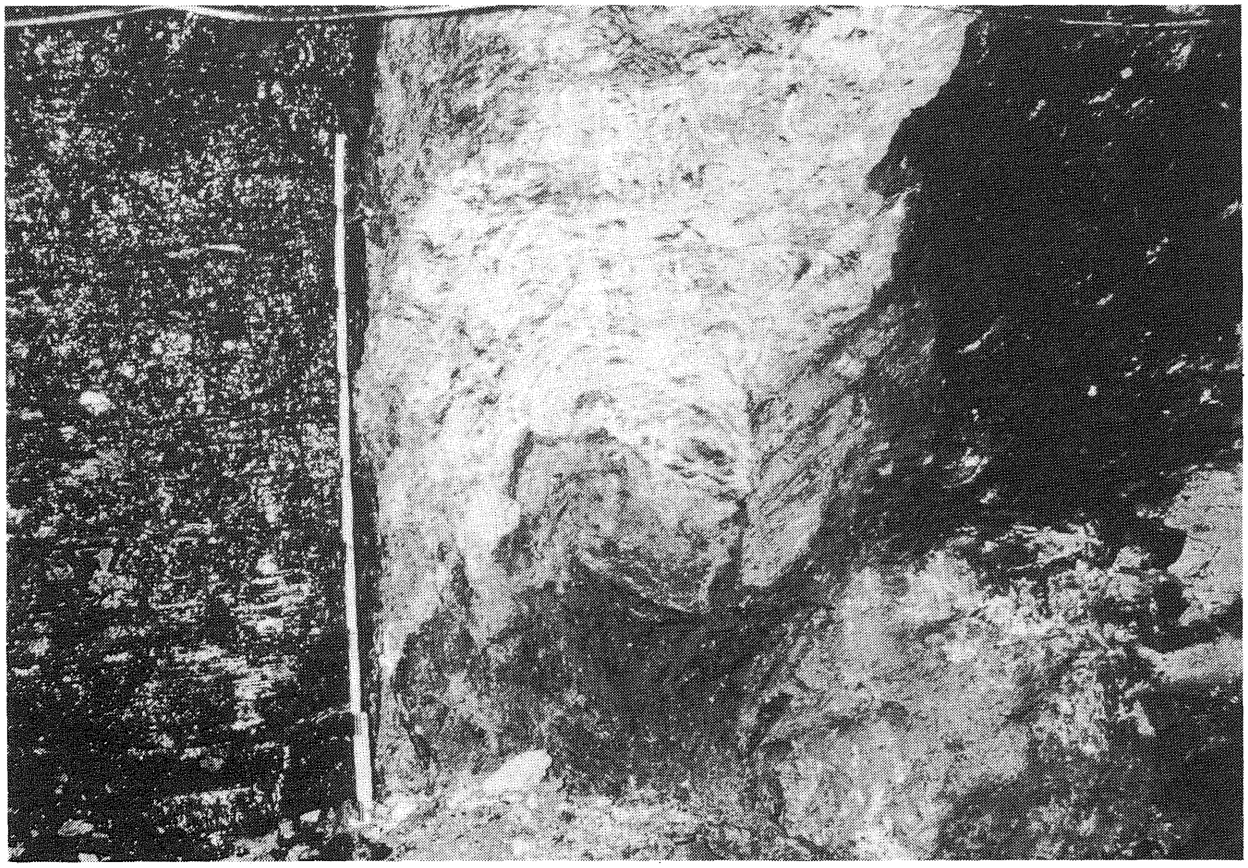

Figure 8. Effect of faulting on contrasting lithologies in Old Ben Mine No. 24. Coal is cleanly sheared with no drag, whereas shale is intensely crumpled and folded.

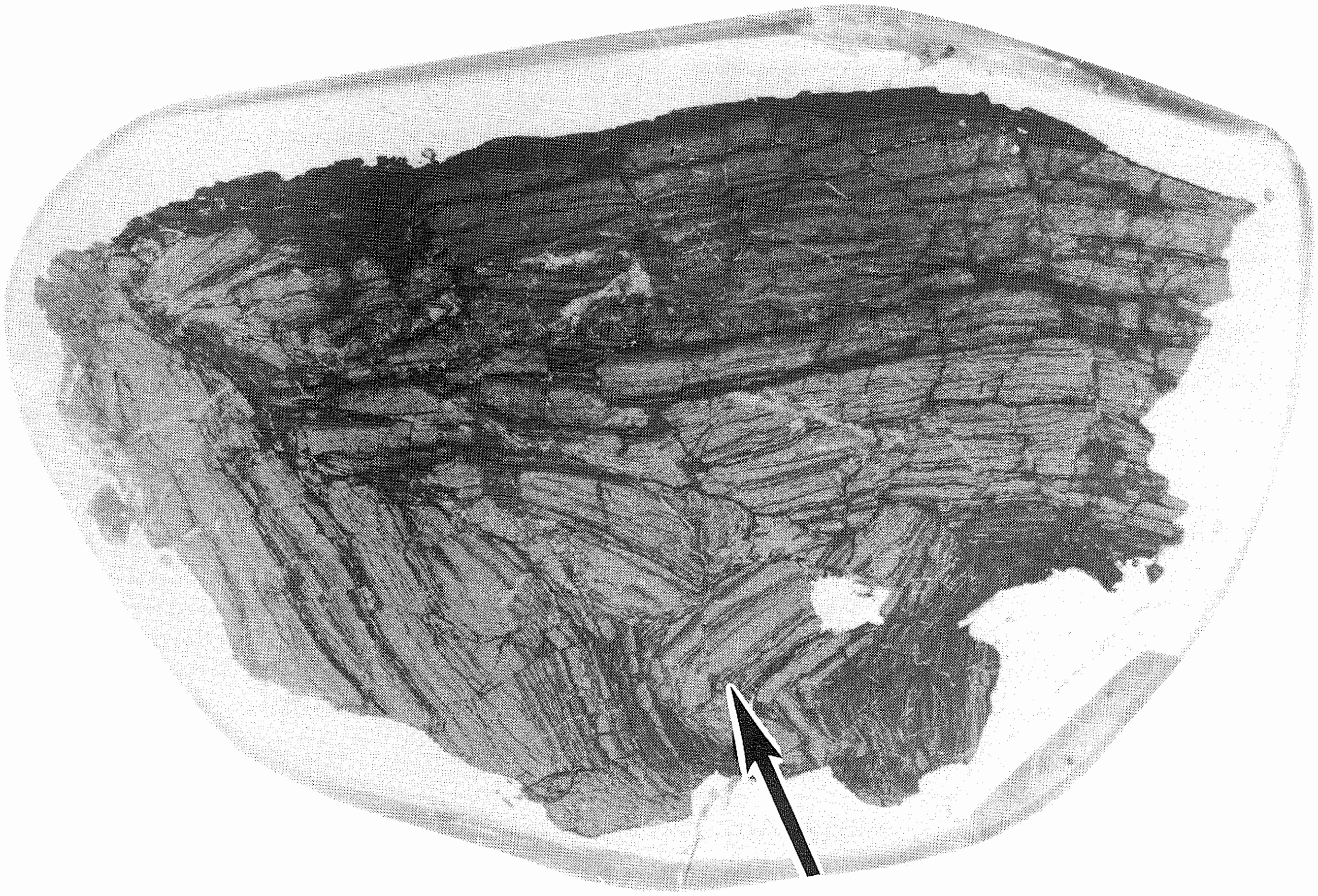

Figure 9. Cut and polished slab of Canton Shale from right side of fault in figure 8, showing a prominent fold hinge. In this compressional fold, the deformation is mainly brittle (fracturing), and contains what is probably flexural slip in the small, rotated fold indicated by the arrow.

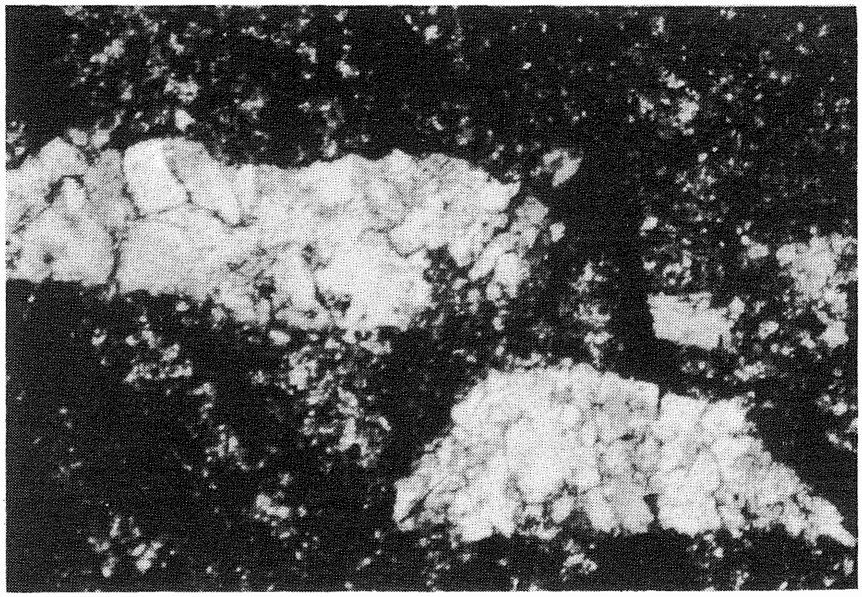

Figure 10. Sheared and offset calcite vein in the Canton Shale (crossed polars, gypsum plate inserted, magnifications = X25).

Another faulted exposure of the Canton Shale (fig. 11) exhibits "differential drag." The lighter colored, coarser grained siltstone abuts directly to the fault plane with absolutely no folding; however, the finer grained, thinly laminated shale below it is considerably folded. This has been brought about by two mechanisms: (1) the low-angle curved antithetic shear fractures that allowed rotation of the laminae, and (2) a certain amount of ductile flow, indicated by perceptible thinning of the thinly laminated shale as it approaches the fault plane. In fact, for "differential drag" to occur at all, there must be differential flow. In this case, at the beginning of faulting, the coarser grained silty unit fractured, while the finer grained, thinly laminated unit was stretched and bent into its present shape without the loss of cohesion. With continued movement it, too, was fractured and displaced (fig. 12). In this case, at least, the term "drag" is a misnomer and is not related to frictional forces accompanying faulting.

High ductility is commonly exhibited by the "blue band," a thin (½ inch to 2 inches), laterally continuous claystone located about 1.5 feet from the bottom of the Herrin (No. 6) Coal (fig. 13). Where the "blue band" is cut by shear fractures to the left of the fold-out ruler, it is stretched and squeezed rather than cleanly fractured. As it approaches the main fault, it thickens considerably, and to the right of the ruler it has been pulled apart entirely. Normally, over as short a distance as this, the "blue band" is consistent in thickness.

Shear fractures

Shear fractures are present not only immediately adjacent to faults, but throughout the fault zone and on either side of it for at least 1700 feet in some cases. Most have no visible displacement; a few show up to several inches of throw and so are small normal (shear) faults. There are numerous examples of conjugate shears (fig. 14), with both east-dipping and west-dipping shears offsetting each other, indicating contemporaneous movement and vertical maximum compressive stress resulting from an east-west extension.

Shear fractures commonly increase in frequency along strike of a fault which decreases in throw; that is, the additional shear fractures take up the strain that farther up

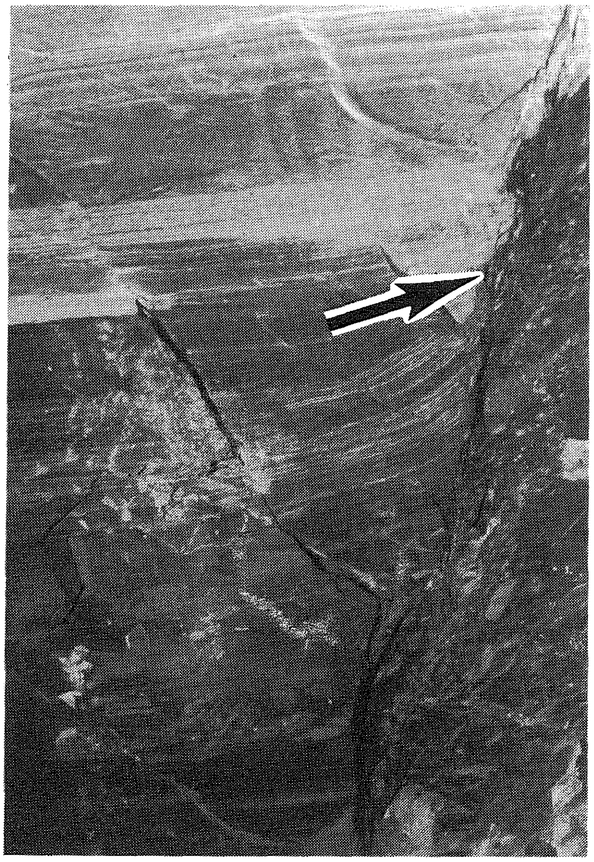

Figure 11. "Differential drag" in the Canton Shale at Old Ben Mine No. 24. Note right-dipping antithetic shear planes and thinning of "dragged" unit as it approaches the fault plane (at arrow).

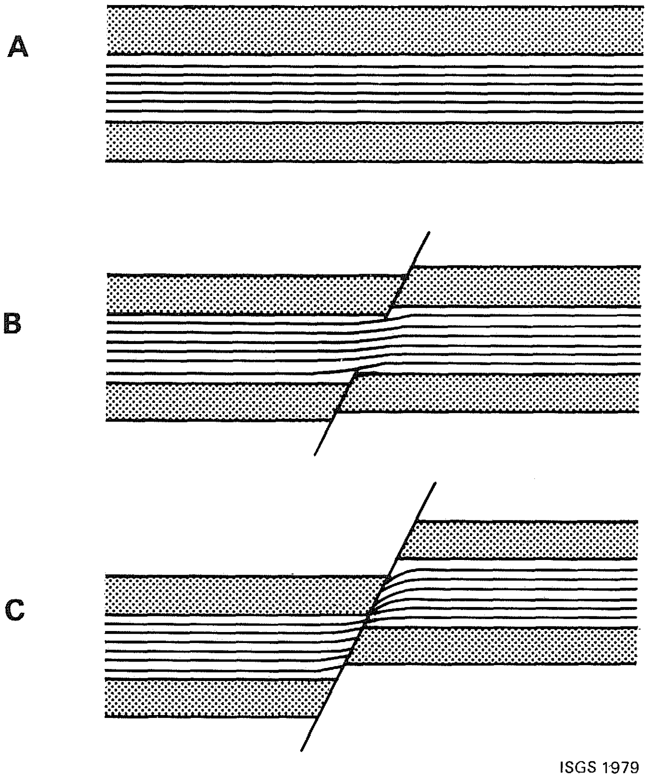

Figure 12. Development of "differential drag" in three stages: (A) two beds of competent siltstone (stippled) separated by a layer of less competent shale, prior to faulting; (B) initiation of faulting—the siltstone reacts by loss of cohesion (resulting in fracture) while the shale maintains cohesion by ductile stretching parallel to its bedding planes and thinning perpendicular to its new dip; and (C) with continued offsetting, the shale reaches its limit of ductility and loses cohesion, resulting in faulting within this unit also.

along strike is absorbed by the single fault plane. Individual shear fractures are extremely discontinuous, rarely traceable from one mine entry to the next. Commonly along strike, as one shear fracture dies out, another begins (fig. 15). In this respect, they are small-scale replicas of the fault system as a whole.

Shear fractures tend to branch downward in the coal, as shown in figure 16. A closer look at the lower portion of this exposure (fig. 17) reveals another prevalent phenomenon: as the shear fracture in the center of the photo approaches the "blue band," shearing action dies out and is replaced by vertical extension fractures. This occurs not only above the "blue band," but also above the underclay floor and immediately below the Energy Shale roof (fig. 18). Four inches of displacement in the center of the coal seam dissipates to no offset at all at the top of the coal (fig. 19). Apparently, ductile extension in the fine-grained "blue band," underclay, and Energy Shale allowed extension fractures or bedding-plane slippage, negating the necessity for shearing action. Extension fractures are prevalent in the coal within the fault zone even where they are not replacing shear fractures (fig. 20). Extension fractures indicate brittle deformation, and it should be noted that within the report area, they have been observed only in the Herrin (No. 6) Coal and in the Brereton Limestone (fig. 2).

The relationship of shear fractures to larger faults in a set of entries at Old Ben Mine No. 24 is shown in fig. B of plate 1. The largest faults, marked A and B, form an asymmetrical graben near the center of the area mapped and are accompanied by many parallel shear fractures. The distribution of the fractures is asymmetrical with respect to the large faults. Densely-spaced shear fractures occur at least 1700 feet west of the graben, continuing to the edge of the mapped area. Only scattered fractures occur more than 300 feet east of the graben.

The lack of continuity of shear fractures along strike is evident in figure B of plate 1. Some of the larger faults also undergo rapid changes in displacement along strike. For example, the fault marked "A" has a throw of about 12 feet in the two southernmost entries of Old Ben Mine No. 24, but the throw decreases to zero within 300 feet to the north. Across the six north entries, the east fault of the graben (B in fig. B of plate 1) has about 20 feet of throw, but southward, it appears to split and its displacement diminishes. An increase in the number and density of accompanying shear fractures coincides with a decrease of throw on the fault.

Cleats

Cleats are joints in the coal which are usually normal to the bedding. They are commonly described as two mutually perpendicular (orthogonal) sets—the face cleat and the butt cleat. Their origin is unclear, and is variously attributed to compaction, dehydration, and shrinkage (von Höfer, 1915); tectonic stress (McCulloch et al., 1974); or penecontemporaneous syneresis (Arthur White, personal communication).

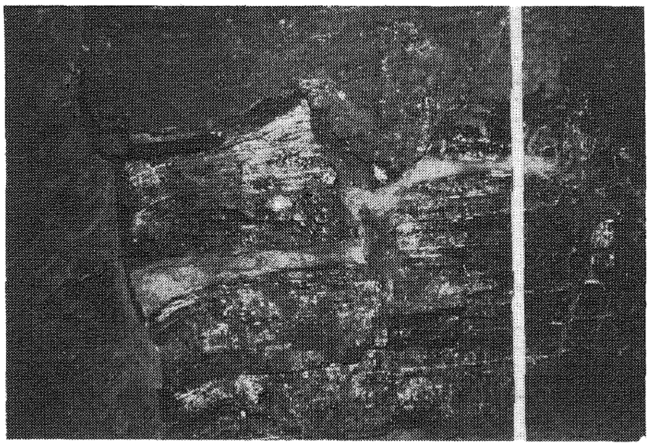

Figure 13. Ductility of the "blue band" adjacent to a major fault at Old Ben Mine No. 24. Minor ductile bending of the coal is very close to the fault. The left side of the fault is downthrown.

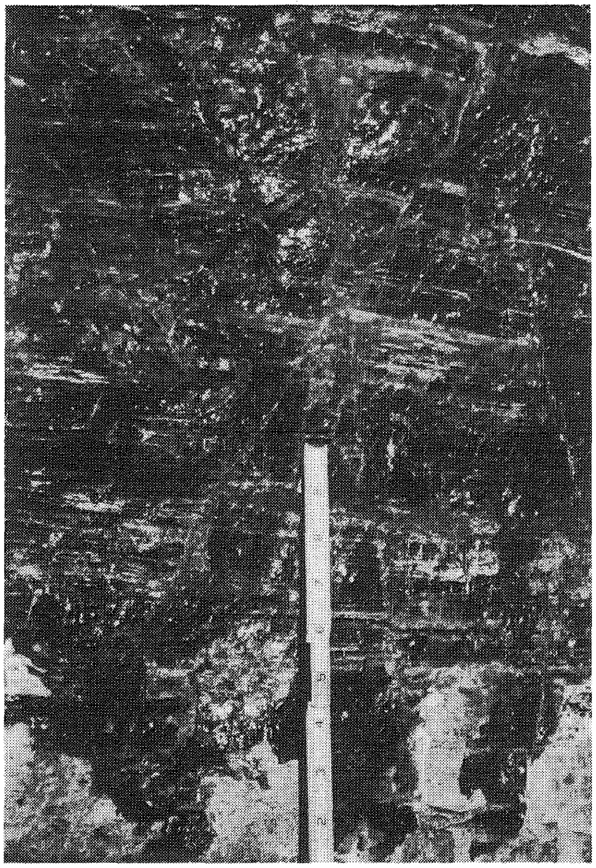

Figure 14. Calcite-filled conjugate shears in coal at Old Ben Mine No. 24.

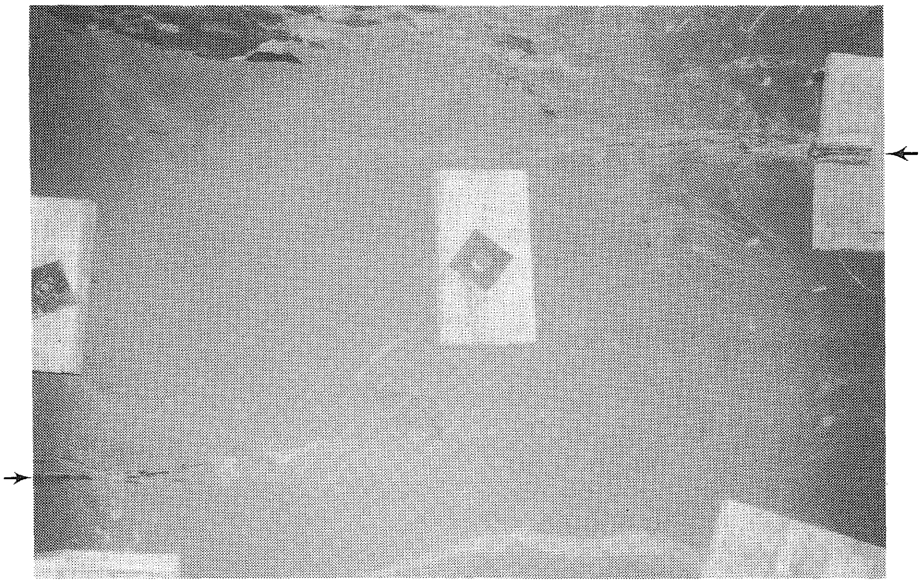

Figure 15. "Worm's-eye view" of discontinuous shear fractures in Energy Shale in the roof of Orient No. 6 Mine.

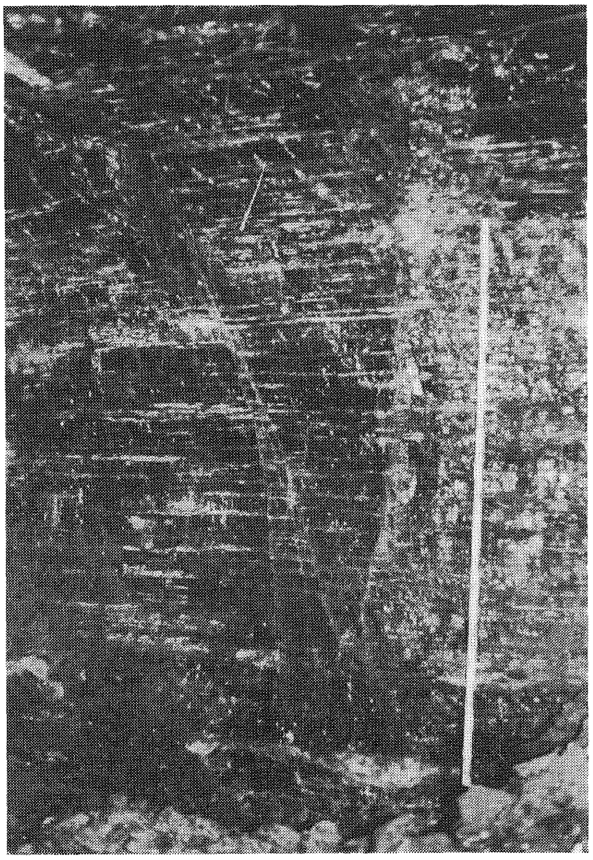

Figure 16. Typical downward-branching shear fractures at Old Ben Mine No. 24.

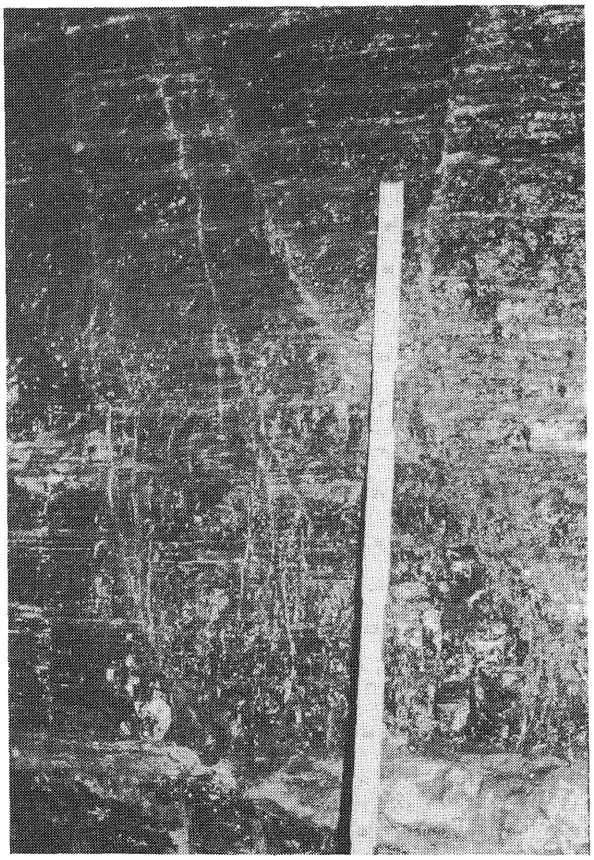

Figure 17. Transformation of shear fractures (upper half of photo) into sets of vertical extension fractures. Thick lens of gray at lower right is a pyritic concretion.

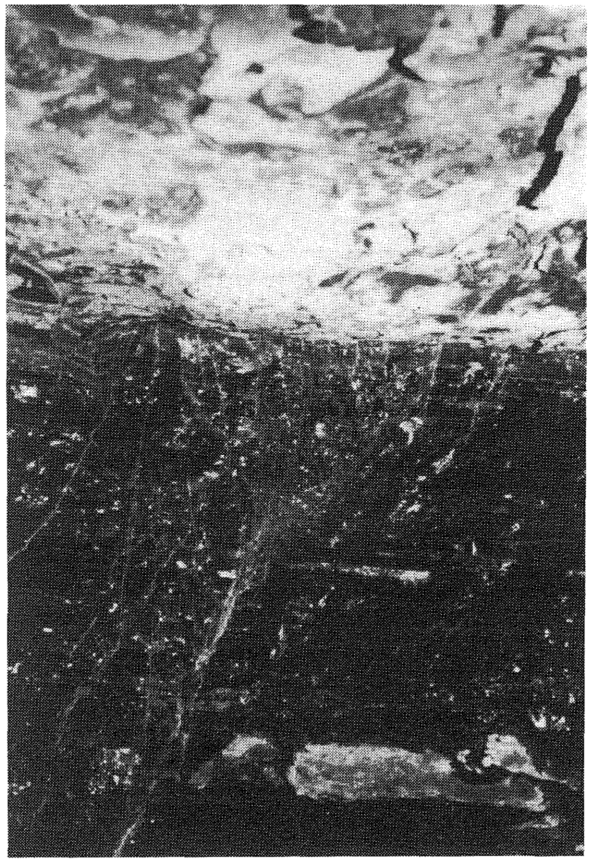

Figure 18. Upward transformation of shear fractures into vertical extension fractures at the top of the Herrin (No. 6) Coal at Old Ben Mine No. 24.

The cleats in the mines studied do not fit the common view of orthogonal jointing mentioned above. The two dominant cleat orientations are regular and strike at approximately N. 30° E. and N. 30° W., forming an acute angle of 60°. In cleat sets near the Rend Lake shear fractures, however, the cleat orientations become irregular. In the vertical view (fig. 21), the east-west-trending cleats in the upper right area terminate against the north-south-trending shear fracture (flanked by parallel extension fractures), and are not parallel to their analogues on the other side of the shear fracture in the lower left area. Also the southeast-trending cleats in the lower left area become asymptotic to the shear fracture as they draw near it. In at least one other instance, cleat sets were seen to die out entirely as they approached a shear fracture. Nowhere were cleats found to continue cleanly across shear fractures and nowhere were cleats systematically offset by shear fractures.

These observations suggest that cleat formation occurred either contemporaneous with or later than faulting. The orientations of the cleat sets, however, argue for stresses other than those associated with Rend Lake faulting. Evidently the Rend Lake discontinuities were present in the coal prior to cleat formation, and the stresses responsible for cleat formation were altered in the vicinity of these discontinuities, resulting in deflected directions of cleat sets and/or the interruption of cleat formation. This interruption is shown in figure 17. The flash reflection on the right-hand side of the left-dipping shear fracture is due to a prominent cleat set which ends abruptly near the shear plane.

Figure 19. Shear fracture with displacement decreasing from center of seam to top of coal at Orient No. 6 Mine.

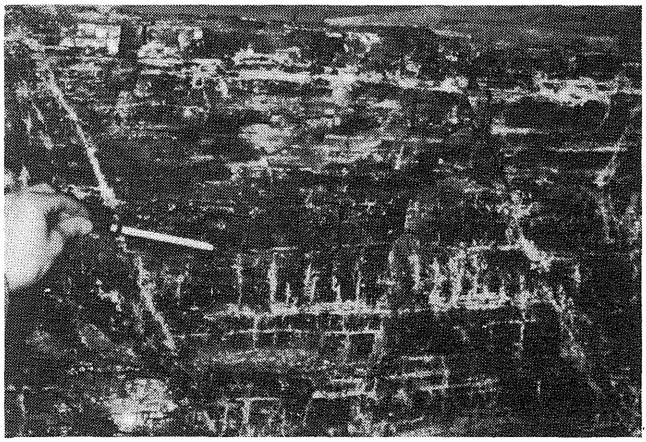

Figure 20. Vertical extension fractures (to the right of pen point) in the coal, close to the major faults at Orient No. 6 Mine. One right-dipping shear fracture (small normal fault) is seen just to the right of the hand, and more shear fractures are right of center in the photo. All fractures are accentuated by light-colored mineral deposits.

Fracturing of clasts

Some researchers have suggested that the Rend Lake faults may be penecontemporaneous with sedimentation. One criterion of soft-sediment faulting is the absence of fractured clasts across the fault plane (Rettger, 1935). Accordingly, we sought samples that were coarse enough to determine this. Unfortunately there are no coarse clastic silicate rocks near the Herrin (No. 6) Coal in the vicinity of the

Rend Lake Fault System. The only rock suitable for study was the Brereton Limestone (fig. 2), a calcisiltite containing bioclasts of brachipods, foraminifera, crinoids, and fusilinids. Thin sectioning of the Brereton Limestone revealed the fracturing of bioclasts across shear fractures (fig. 22). Thus, faulting must postdate lithification of the Brereton Limestone.

Effects of faults on mining

The effect of Rend Lake faulting on mining operations is twofold: increased costs and more difficult working conditions. Where large faults are encountered, entries must be graded through rock that is more difficult to penetrate than coal. Conventional coal mining machinery is not designed for or capable of this type of work; therefore, the rock must be drilled and blasted frequently. The result is not only a slowdown in advancement, but a cessation of coal production until the grade is completed. The instability of the strata in the vicinity of shear fractures and faults increases the chances for roof falls. In these areas, more roof bolts and timbering are required. These unstable areas are especially prevalent in north-south crosscuts containing north-south shear fractures, as shown in figure 23.

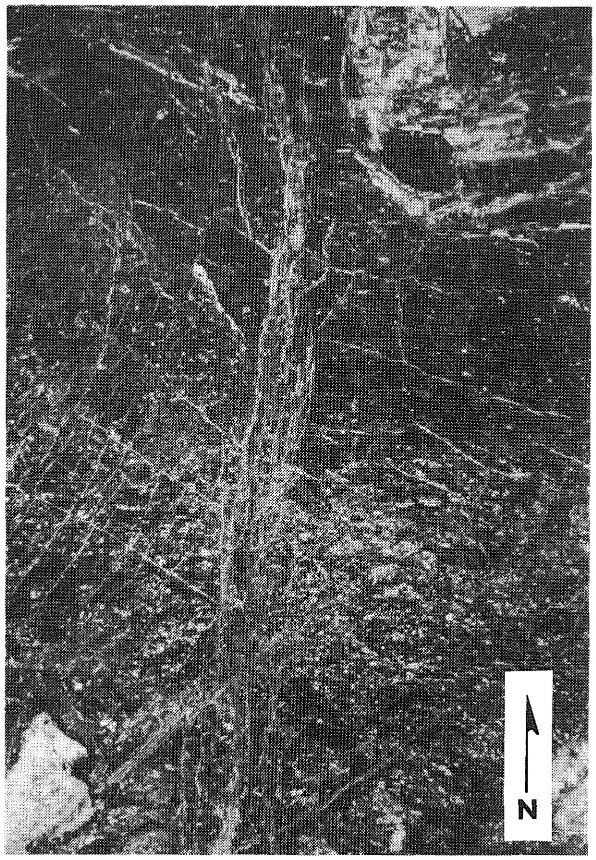

Figure 21. Deflection of cleats and termination of sets of cleats against a north-south-trending shear fracture in Old Ben Mine No. 24. View looking up at coal left in mine roof.

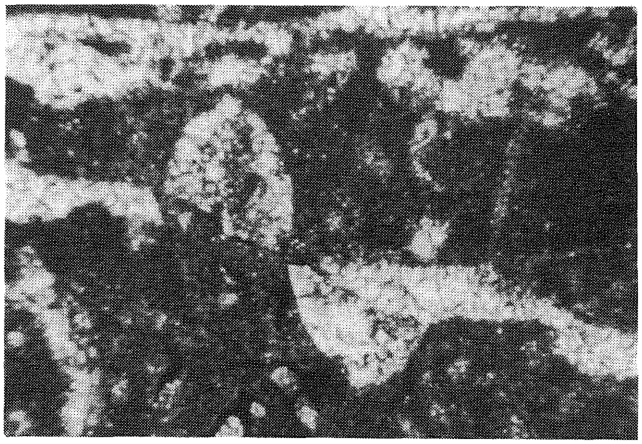

Figure 22. Fractured bioclasts in Brereton Limestone, slightly offset along shear fractures. Upper view in plane-polarized light, lower view in crossed polars, both at X25.

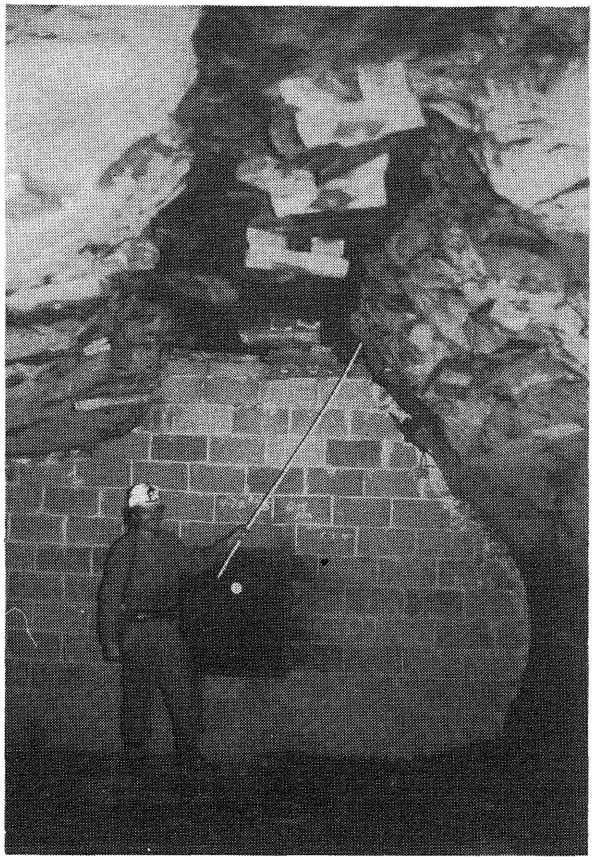

Figure 23. View looking north along roof fall caused by shear fractures (not visible in photo) near major fault of Rend Lake System at Old Ben Mine No. 26.

The effect of faults on roof stability is demonstrated in figure C of plate 1 (which is part of the workmap for Old Ben Mine No. 24) in the next set of entries north of those shown in figure B of plate 1. The faults are typical, parallel, discontinuous normal faults; the largest has a little over 5 feet of throw. Roof falls and zones of weakness in the roof are highly concentrated at intersections and in north-south headings within and adjacent to the fault zone. Some of the falls can be directly attributed to faults because of the slickensided and crushed rock along the faults, but in other falls, no faults are visible in the surrounding area.

Preferential north-south roof failure has been observed far from the Rend Lake faults. Figure 24 is a map of part of a mine located over 1000 feet east of the faults; falls and zones of weakness in figure 24 are virtually limited to north-south headings. No faults or shear fractures of the Rend Lake Fault System were observed within this map area. In some cases, the belt of north-south failure may even be much wider than that shown in figure 24. For example, in mines located as far as five miles east of the Rend Lake Fault System, the roof has been difficult to support in north-south headings, whereas east-west entries

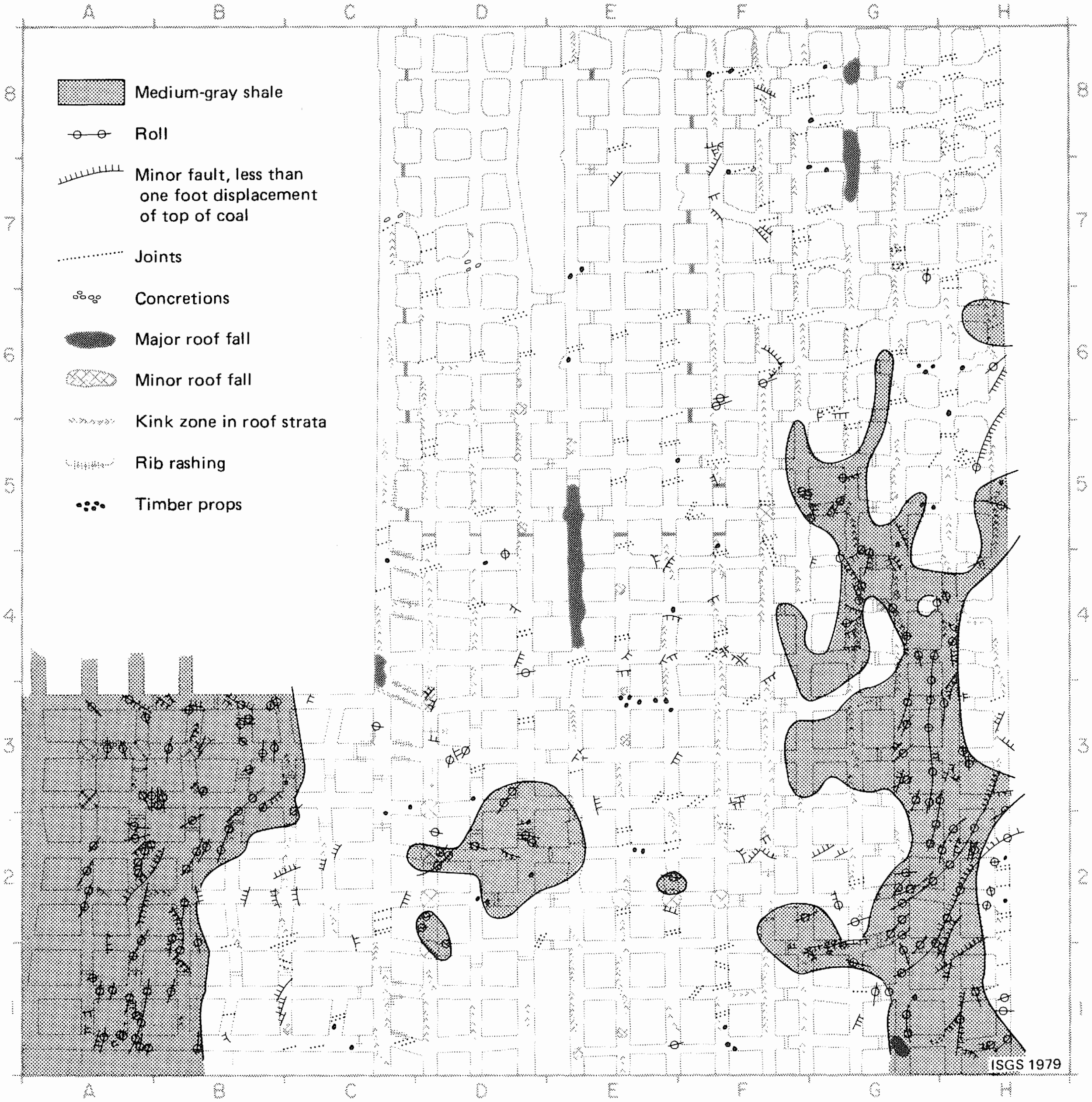

Figure 24. Area in the Orient No. 6 Mine about 1000 feet east of the main faults of the Rend Lake Fault System. Roof falls and kink zones (lines of bending or sagging roof) are strongly concentrated in north-south headings, whereas east-west headings are virtually free from roof troubles (figure from Krausse et al., 1979).

remained stable. The cause for this preferential weakness in mine roofs is not known, but it may reflect either a structural grain imparted to the rock by the faulting, or the effect of unrelieved stresses acting parallel with the faults.

Surficial exposures

Limited field observations on the surface of the Rend Lake Fault System disclosed no evidence of faulting that affected Pleistocene sediments. Only one outcrop of bedrock exists that partially overlies the fault system. It is located approximately 500 feet from the south line and 1000 feet from the east line of Sec. 22, T. 6 S., R. 2 E., on the south bank of the Big Muddy River. The outcrop comprises a 2-foot-thick section of thinly laminated siltstone (stratigraphic position unknown), and is exposed fairly continuously for approximately 300 feet in an east-west direction. One fracture that could possibly be a part of the Rend Lake Fault System was observed. This fracture is filled with gouge, and the bedding is tilted upward on either side. There were no slickensides, and no displacement could be detected because of the uniformity of the rock and the lack of vertical exposure. This fact, coupled with the fact that the laminae are tilted upward on either side of the fracture, makes it doubtful that this is a shear fracture or a fault associated with the Rend Lake Fault System.

DISCUSSION OF FIELD AND LABORATORY INVESTIGATIONS

Under stress, the coal became brittle, and its laminae were not mechanically effective, that is, no slippage could take place along them. Therefore, fracture and brecciation, not folding or drag, occurred near faults. Other more anisotropic and less brittle lithologies (shales and siltstones) exhibited more intensive drag and folding. In these cases, ductile flow was minimal, and bending or folding of the strata was accomplished mainly by bedding-plane slip or shearing. A certain amount of ductility is indicated, however, by "differential drag" and by the fact that some shear fractures fail to extend beyond the coal. But even these apparently more ductile lithologies had sufficient strength after faulting occurred to maintain void space, which was subsequently mineralized.

No thickening of sediments occurred on the downthrown side of faults, thereby ruling out growth faulting. The fracture of bioclasts across shear fractures indicates that the limestone was lithified at the time of faulting; thus, the greater ductility of some of the rocks is a function of lithology, not their state of lithification.

Since little is known about the mechanisms of cleat formation, the supposition that Rend Lake faulting predates cleat formation reveals little about the age of faulting. It does, however, rule against syneresis as a cleat-forming mechanism. On the basis of field evidence and drilling, therefore, the age of faulting can only be said to postdate deposition of the Shoal Creek Limestone and predate the deposition of the Pleistocene sediments.

LOCAL STRUCTURAL DEVELOPMENT

Four subsurface maps and two cross sections were produced to illustrate the history of local structural development (figs. 25, 26, 27, 28, 29, and 30). A structure map of the base of the Herrin (No. 6) Coal was made (fig. 25) because there are more data concerning this unit than any other, and as a consequence, it best reflects the structure of the area. The coal is a prominent marker unit on oil-well electric logs, and is easy to map because many coal-test drill holes exist—some of which are closely spaced across the Rend Lake faults. The base of the coal was picked because this is the level surveyed in the mines and shown in mine maps.

On the west side of the map in figure 25 is the Walshville channel. This channel is presumed to be at least partly penecontemporaneous with accumulation of plant material, and is filled primarily with sandstone. The Energy Shale in part is interpreted as a crevasse-splay deposit from the Walshville channel (Johnson, 1972; Allgaier and Hopkins, 1975). The Herrin (No. 6) Coal commonly is split adjacent to the channel. Most splits are probably overbank deposits laid down during accumulation of plant material.

At the north edge of the map is a channel filled with Anvil Rock Sandstone. This channel, which postdates deposition of the Herrin (No. 6) Coal, is an erosional feature which cuts out the coal (Hopkins, 1958). The northeast-trending structure in the northwest portion of the map is the eastern branch of the Du Quoin Monocline.

The Rend Lake Fault System is expressed by the prominent syncline that runs due north from the southern edge of T. 7 S., R. 2 E., to near the northern border of T. 5 S., R. 2 E., beyond which it curves northwest to Sec. 36, T. 3 S., R. 1 E. Throughout most of its length the fault system occupies the steep portion of the western limb of the syncline.

The faults are mapped separately in figure 26. They are not depicted on the structure map because most of the structure on the western limb of the syncline is not the result of faulting, but is rather the result of increased dip of the coal, as is shown in figures 27 and 28. Furthermore, the net displacement across the fault system is not everywhere down to the east (fig. 26 and fig. A of plate 1). Only in cross sections E-E′ does faulting dominate the structure. The faults are parallel to the contour lines and are omitted for the sake of legibility.

A definite relationship exists between the folding in the area and the fault system. The syncline curves to the northwest exactly where the fault system curves northwest (figs. 25 and 26); they both become offset to the east in the southern part of T. 7 S., R. 2 E. Fault displacements are at a minimum in Old Ben Mine No. 21, near the

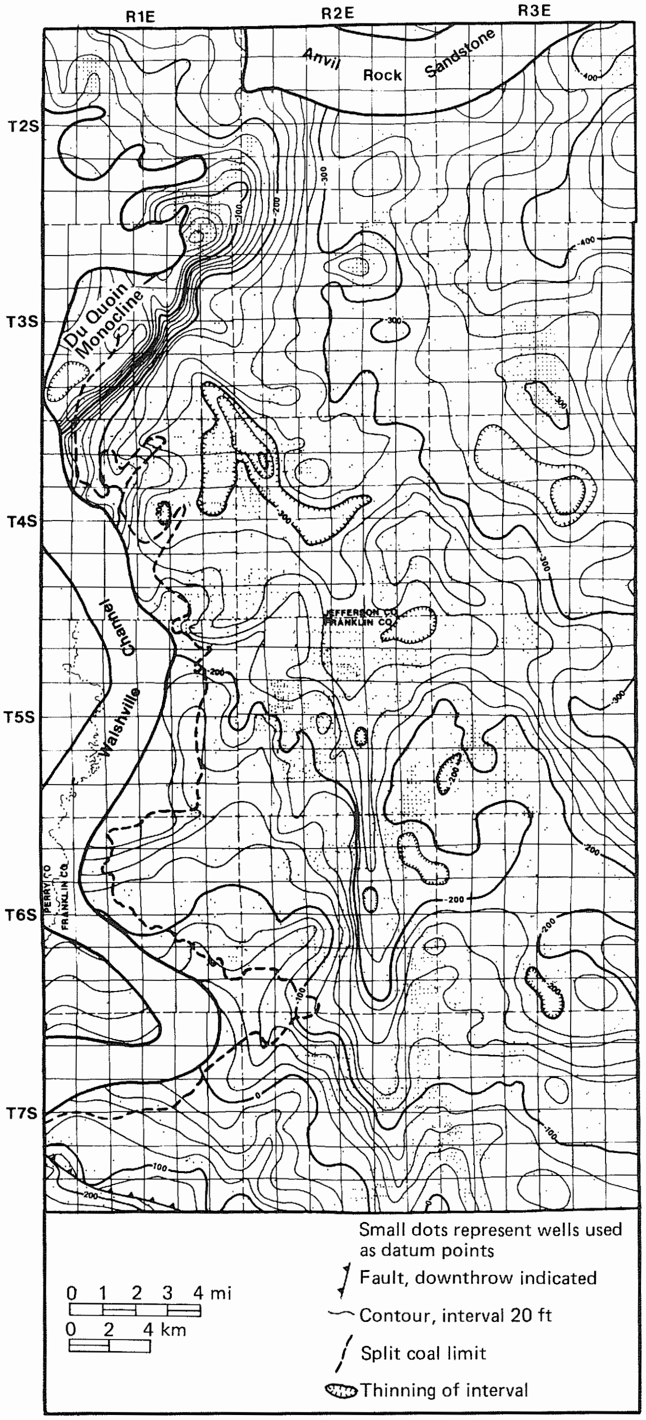

Figure 25. Structure of the Herrin (No. 6) Coal in western Franklin and southwestern Jefferson Counties, Illinois.

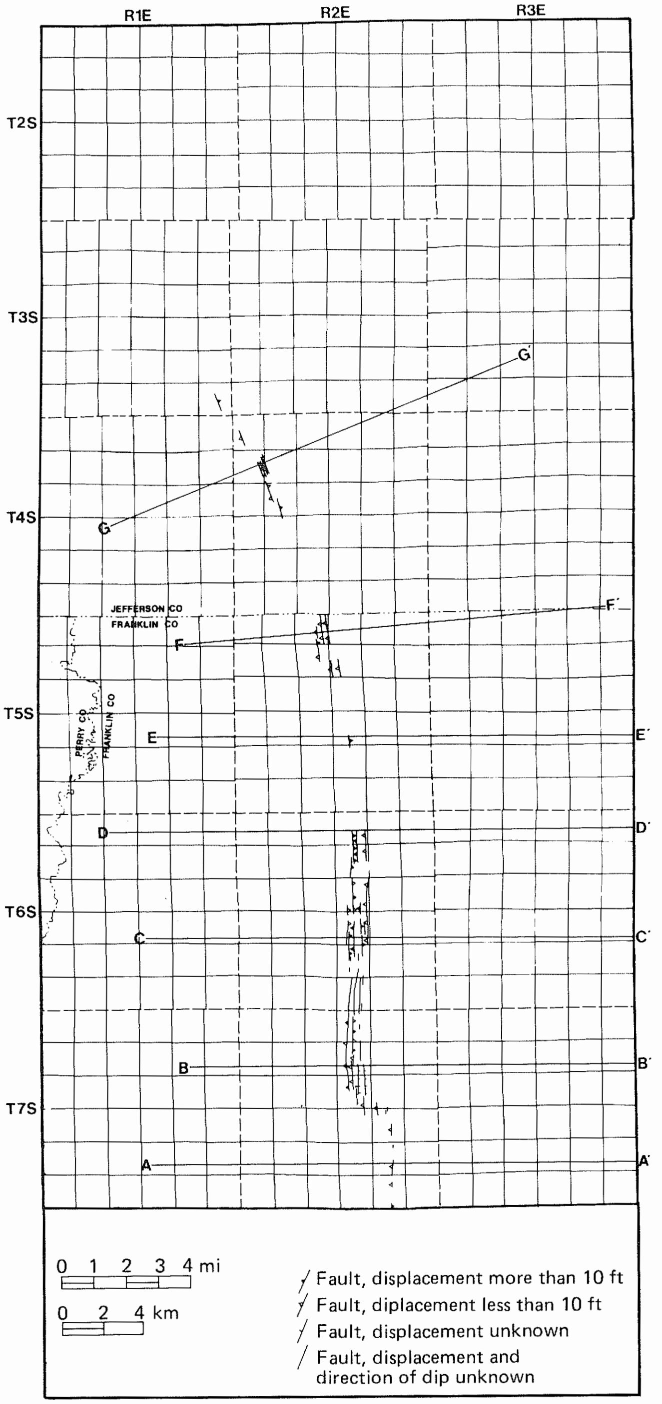

Figure 26. The Rend Lake Fault System in southern Illinois. Lines of cross sections (in figs. 27 and 28) are shown.

northern border of T. 5 S., R. 2 E. Here, structural relief is minimal because it is the only spot where the anticline east of the fault system is interrupted by a structural low.

One possible reason for the parallelism of the faults and the folding in the area is that the folding may be the result of faulting, as outlined by W. K. Hamblin (1965). He maintained that the reverse drag of downthrown sediments adjacent to Rocky Mountain faults was the product of subsidence of the downthrown side into the void created by extensional separation of curved faults (fig. 31).

We consider this to be a doubtful explanation for the syncline east of the Rend Lake Fault System because the net displacement of the faults is not everywhere down to the east. Also, Rend Lake faults are not known to curve in dip direction. Nevertheless, to further evaluate this explanation, an isopach map of the interval between the Walche

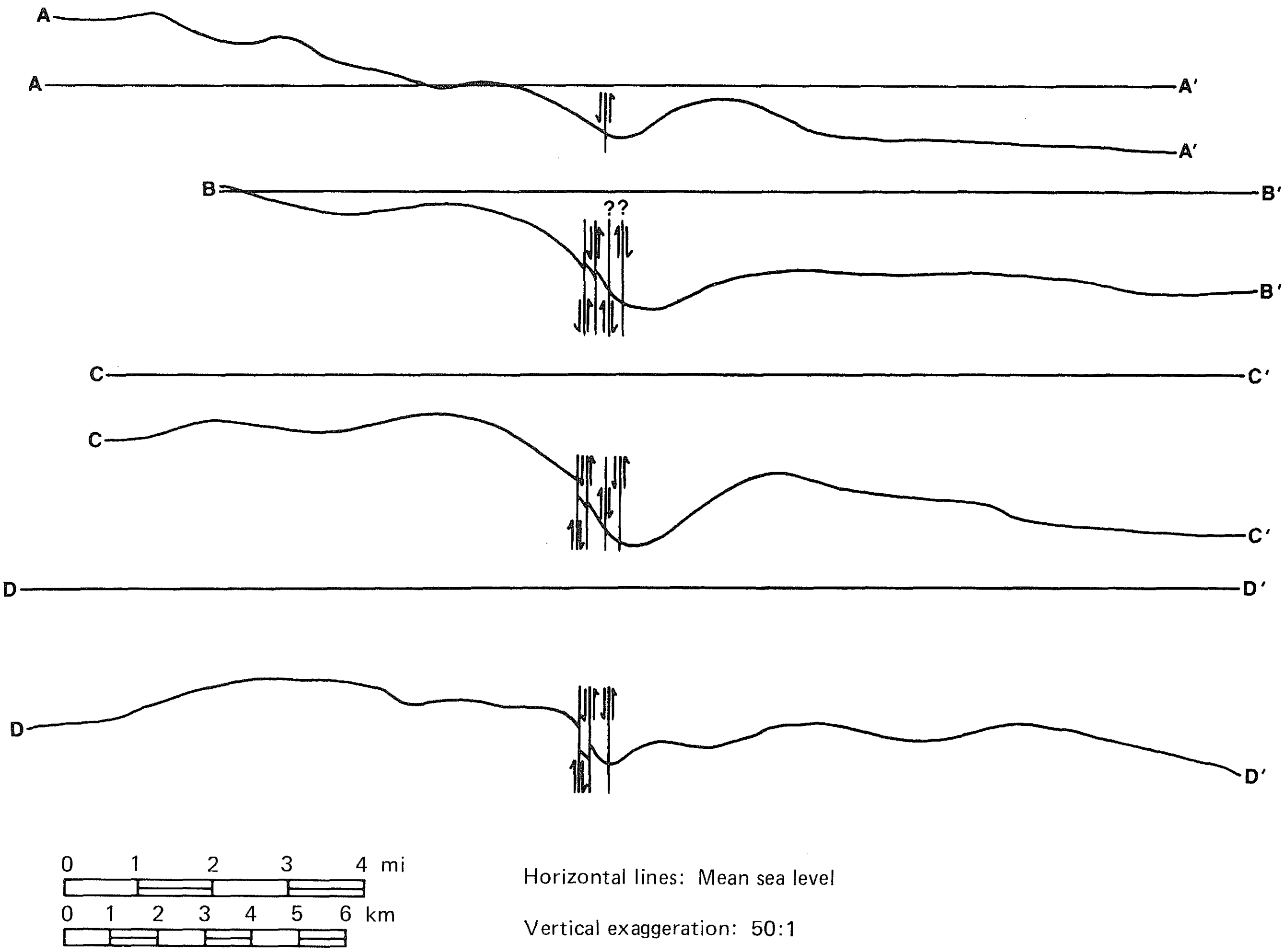

Figure 27. Cross sections of the Herrin (No. 6) Coal through the Rend Lake Fault System in southern Illinois. Locations of cross sections are shown in figure 25.

Limestone Member of the Menard Formation (Mississippian) and the Summum (No. 4) Coal Member was prepared (fig. 32). This interval was deposited prior to the Herrin (No. 6) Coal, and therefore prior to Rend Lake faulting. A prominent thickening of the interval occurs directly below the central syncline of the Herrin (No. 6) Coal, and thinning occurs below the east- and west-flanking anticlines. A local thickening of the strata in the northeast corner of T. 5 S., R. 2 E. coincides with the interruption of the low anticline east of the central syncline, as shown in the structure map. Northwest of this point in T. 4 S., R. 2 E., the belt of thinned interval resumes and its location closely corresponds with that of the low anticline. Evidently the structure of the area had begun to take shape prior to the deposition of the Herrin (No. 6) Coal; therefore, folding cannot be the result of faulting.

In the interval of time between deposition of the Herrin (No. 6) Coal and deposition of the Shoal Creek Limestone Member (fig. 29), the low anticline east of the central syncline continued to rise. This is evidenced by the thinning of the strata that coincide with the trend of the anticline of the Herrin (No. 6) Coal. The area to the west over the syncline is less well defined and composed of nonlinear zones of thickening and thinning, but it is in general an area of thickened strata. A small part of the irregularity here may be due to the splitting of the coal as it approaches the Walshville channel. Since the bottom of the coal was chosen as the datum, the lower bench of the coal was selected where the coal was split. This may have led to abnormal thickness on the isopach map near the Walshville channel, but it should not have affected the thickness outside of the split-coal limit.

The structure map of the base of the Shoal Creek Limestone (fig. 30) indicates that renewed movement occurred along the central syncline and west-flanking anticlines following Shoal Creek Limestone deposition. The east-flanking anticline continued to rise, but was subdued in its northern portion. It is interrupted again in the northeast corner of T. 5 S., R. 2 E. by a structurally low area. Closely spaced coal-test holes in Sec. 10, T. 6 S., R. 2 E., and Sec. 34, T. 5 S., R. 2 E., reveal that Rend Lake faulting offsets the Shoal Creek Limestone.

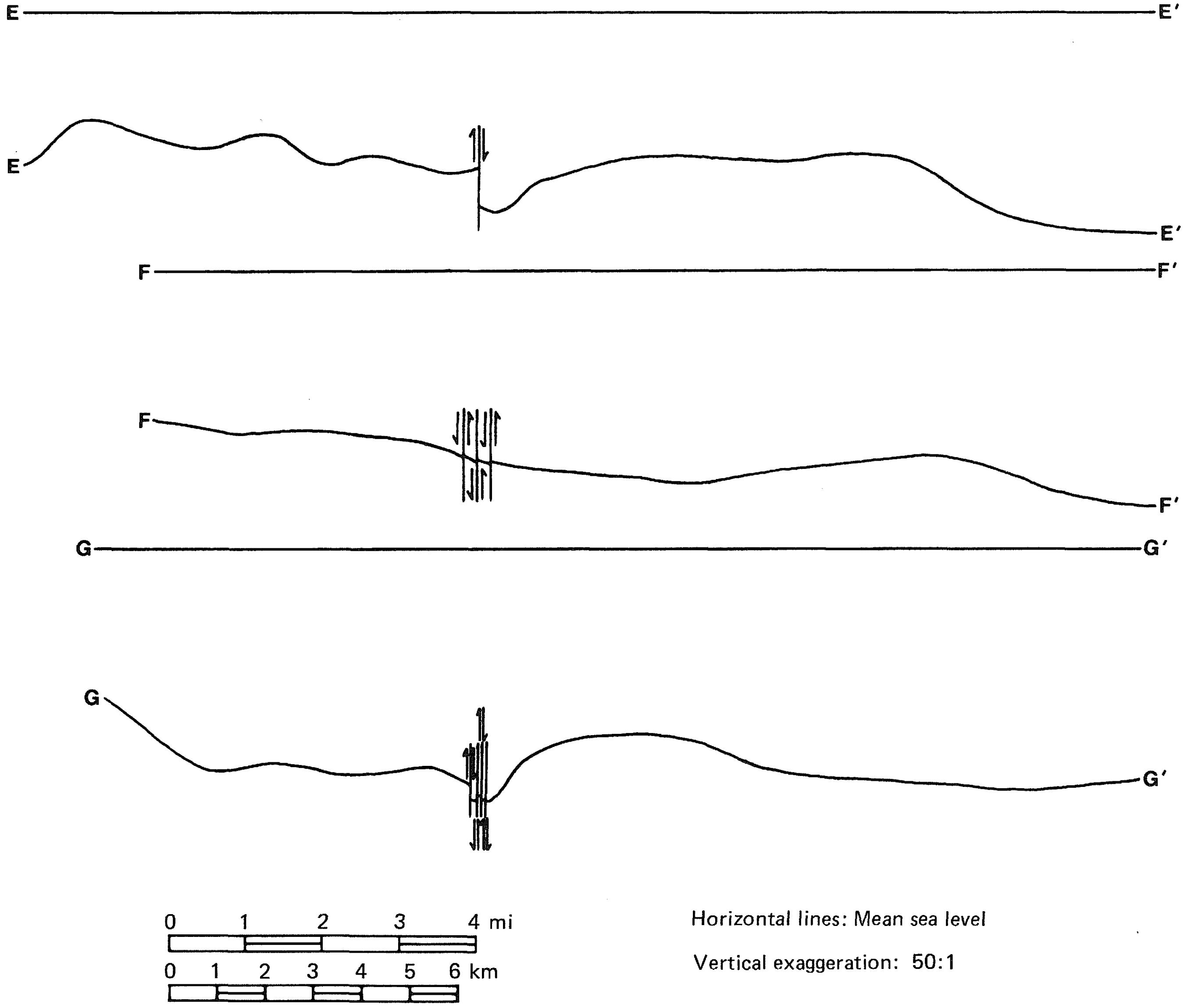

Figure 28. Cross sections of the Herrin (No. 6) Coal through the Rend Lake Fault System in southern Illinois. Locations of cross sections are shown in figure 25.

On the basis of these four subsurface maps it is evident that the folding in the area is not the result of Rend Lake faulting. A cross-sectional summary of structural development is shown in figure 33; it shows that the folding developed long before faulting occurred. Nevertheless, because of the close correspondence in location between the folding and the fault system, there must be a genetic relationship.

One explanation for the faulting is that the thick sediments present in the syncline led to differential compaction and faulting; however, compactional or growth faulting would be expected to occur before the sediments were lithified, and field evidence is to the contrary.

The most likely explanation for the faulting, then, is the occurrence of differential uplift and subsidence. Unlike folds caused by horizontal compression, warping caused by vertical differential uplift and subsidence creates extensional forces, which in the case of these gently dipping beds, is essentially horizontal. In the tectonically active period following deposition of the Shoal Creek Limestone, differential uplift and subsidence increased in rate, especially on the west-flanking anticline. This led to the formation of the Rend Lake Fault System. This interpretation corresponds with the field evidence, which indicates that incremental movements took place over a long period of time. An east-west extension gave rise to north-striking normal faults that dip randomly to the east and the west.

It is possible that the structural development of the area is related to deep-seated basement faulting. Indeed, it is difficult to explain such localized vertical movements of shallow strata otherwise. Slow pre-Pennsylvanian faulting of the basement with downthrow to the west would have

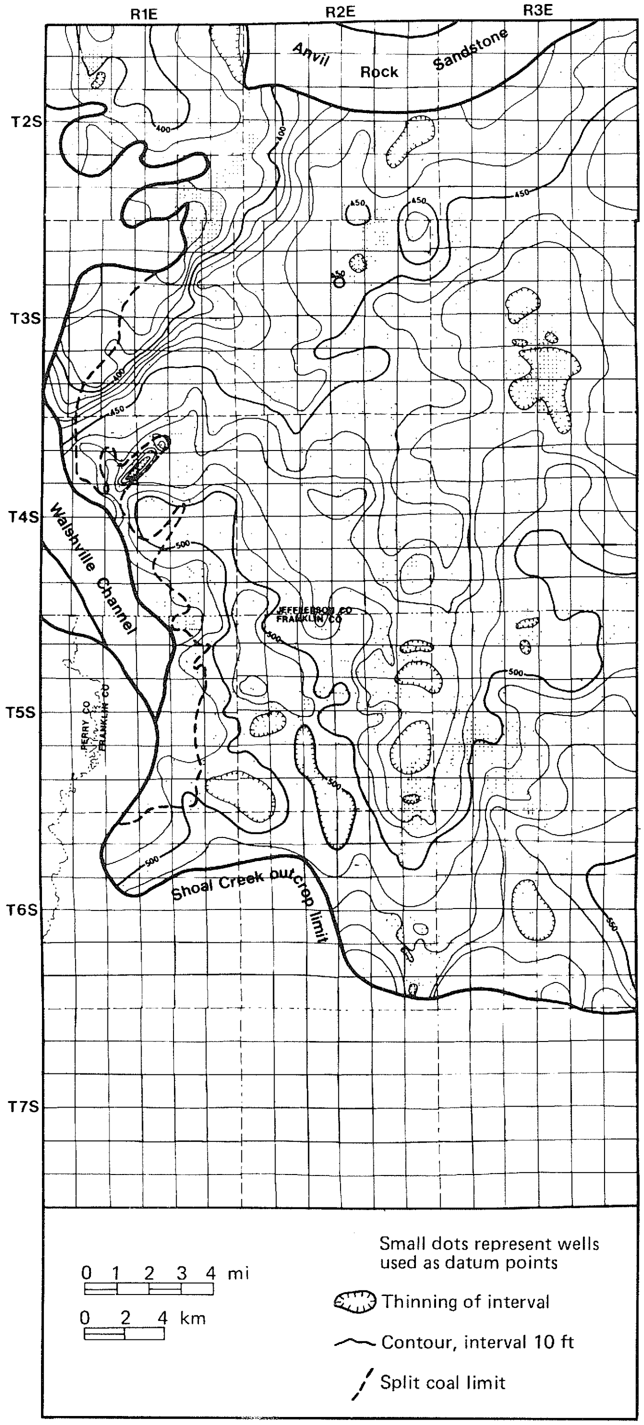

Figure 29. Interval between the Herrin (No. 6) Coal Member of the Carbondale Formation and the Shoal Creek Limestone Member of the Bond Formation. The interval is thinned significantly along the north-trending anticline east of the Rend Lake Fault System—evidence that the anticline was rising during the time between deposition of the Herrin Coal and deposition of the Shoal Creek Limestone.

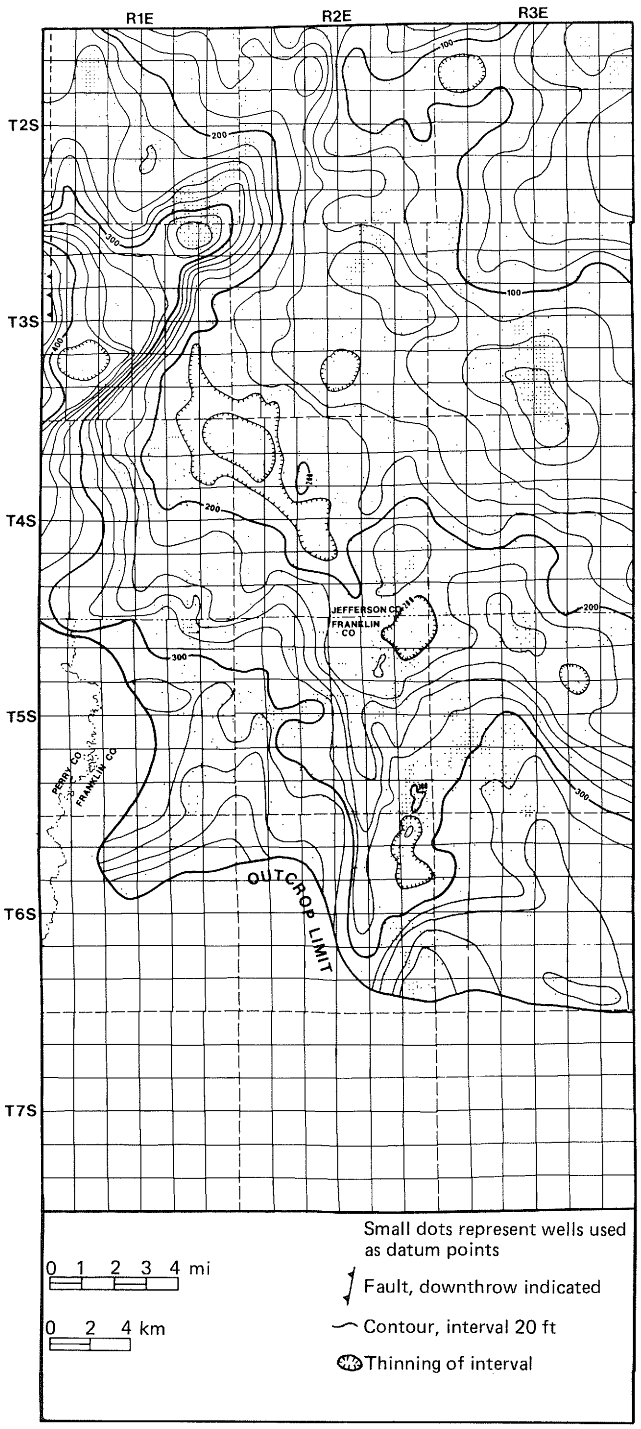

Figure 30. Structure map of the base of the Shoal Creek Limestone Member, Bond Formation. The central syncline and the anticline to its west are reflected by the contours, as is the southern portion of the east-flanking anticline; therefore, folding must have continued after the Shoal Creek Limestone was deposited.

been reflected at the surface by thickness variations and warping of the sediments, similar to that shown in figure 33 for the Walche Limestone Member. A reversal of movement later in time and an increase in strain rate after lithification of the sediments could have led to the brittle Rend Lake deformation. Conclusions regarding basement movement are beyond the limits of this study, however, because no detailed gravity or magnetic studies have been done in this area.

A north-south trending fault is present in the northwest corner of T. 3 S., R. 1 E. (fig. 30). On the basis of drill hole data, we determined that this fault has a throw of approximately 200 feet down to the west. This fault represents a southern continuation of the Centralia Fault Zone (Nieto and Donath, 1976; Brownfield, 1954), which has been crossed by several mines farther north in Marion County. Located just east of the western north-south-trending branch of the Du Quoin Monocline, the Centralia Fault zone consists of several parallel normal faults with a net displacement down to the west. A similar fault zone is present in mines farther south in Perry County. The faults there also lie on the flank of the Du Quoin Monocline. All of these faults are probably parts of a continuous zone of faulting along the length of the Du Quoin Monocline, and all are probably the result of differential uplift and subsidence. For this reason it is unlikely that the Centralia Fault Zone is a continuation of the Rend Lake Fault System, as suggested by Nieto and Donath (1976). Such a hypothesis would require a drastic change in strike of the fault zone in the lower half of T. 3 S., R. 1 E.

The exact course and extent of the Rend Lake Fault System northward into unmined areas is unknown. On the basis of our structure maps of the Herrin (No. 6) Coal and the Shoal Creek Limestone, the system appears to continue northwest to Sec. 23, T. 3 S., R. 1 E. Whether it continues any farther is conjectural. North of this point the anticline and syncline, which mark the trend of the fault

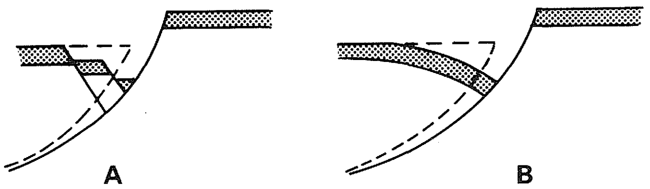

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Figure 31. Example of how reverse drag may be produced (from Hamblin, 1935). Normal movement along a curved fault plane would tend to pull the blocks apart as well as displace them vertically. Subsidence filling the incipient gap may develp antithetic faults (A) or reverse drag (B). This is an unlikely explanation of the parallelism of the Rend Lake Fault System and the shallow syncline to its east. Rend Lake faults are not consistently downthrown to the east, and they are not known to be curved in dip direction (except locally on a small scale).

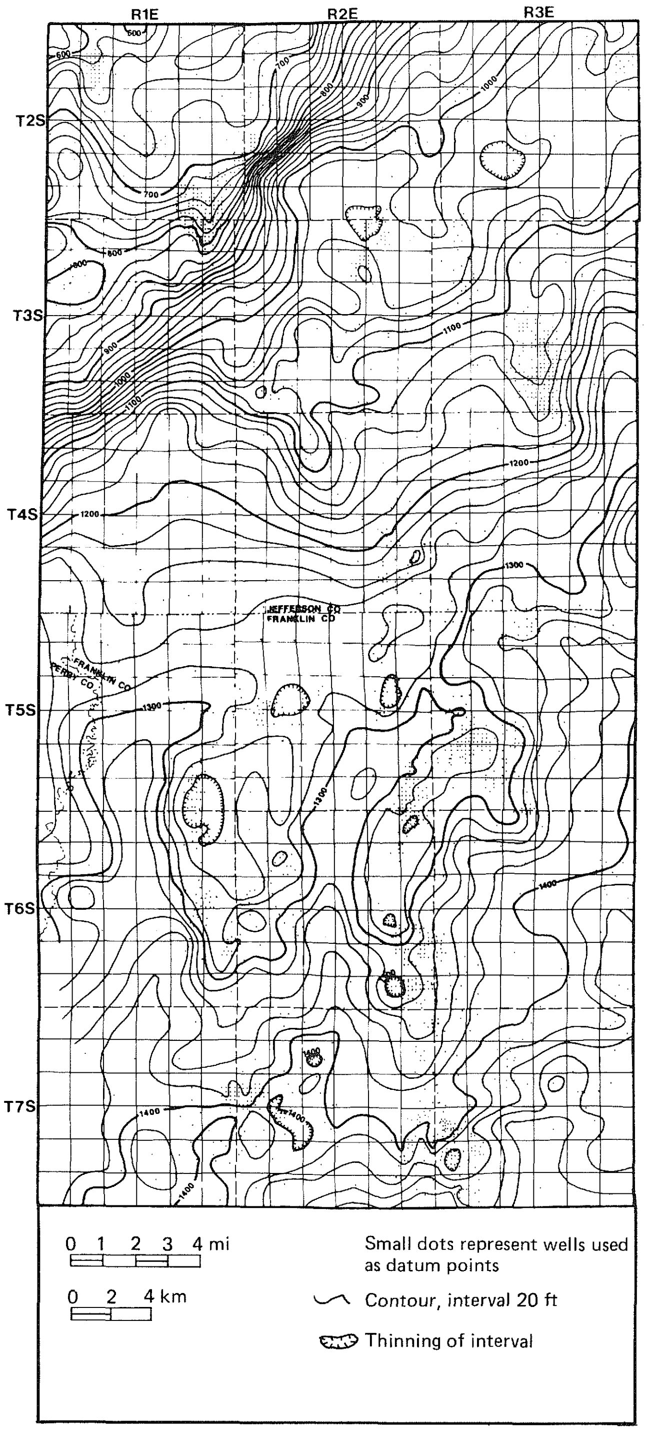

Figure 32. Interval between the Walche Limestone Member of the Menard Formation (Mississippian) and the Summum (No. 4) Coal Member of the Carbondale Formation (Pennsylvanian). The interval thins abruptly across the northeast-trending branch of the Du Quoin Monocline (northwest corner of map). The interval thickens directly below the central syncline of the Herrin (No. 6) Coal, and thins across the anticlines east and west of the syncline. This indicates that the structure of the area began to take shape prior to deposition of the Herrin Coal; therefore, the folding cannot be a result of Rend Lake faulting.

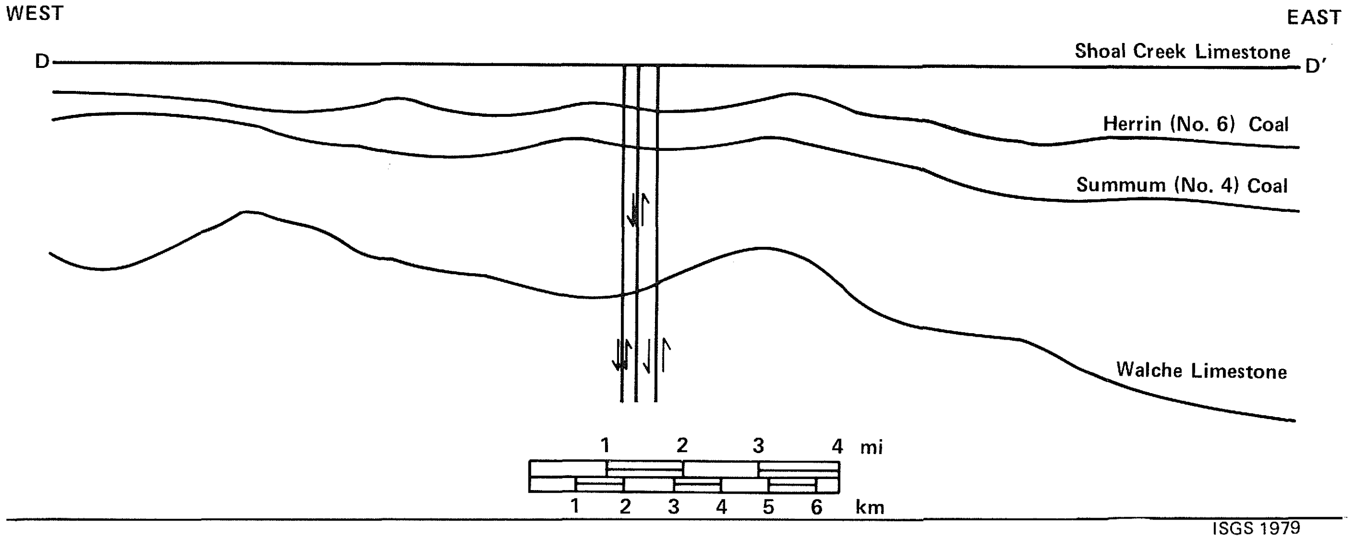

Figure 33. Profile of the Rend Lake Fault System with the Shoal Creek Limestone as datum. The line of profile is shown in figure 26. Vertical exaggeration of the structure is 50:1. The interval from the Walche Limestone to the Summum Coal, and from the Herrin Coal to the Shoal Creek Limestone, has been compressed to 75 percent. The interval from the Summum Coal to the Herrin Coal is compressed to 40 percent.

farther south, either terminate or are masked by the steep dip of the northeastern branch of the Du Quoin Monocline. It is interesting to note that small northeast-striking faults have been found in the extreme northwest portion of Freeman United Orient Mine No. 3, on the flank of and parallel to this branch of the Du Quoin Monocline. The northwest-striking Rend Lake faults probably die out as they approach this structure because of the change in the stress field.

As shown in figure A of plate 1, the Rend Lake Fault System curves to the east and decreases in width and vertical displacement as it approaches the Cottage Grove Fault System. North-south-trending Rend Lake faults are not known to exist in the body of the Cottage Grove Fault System. These observations imply that the Cottage Grove Fault System was at the boundary of the stress field responsible for the Rend Lake faulting, and/or Cottage Grove faults were able to adsorb the strain attendant with that stress field. The Rend Lake faulting, therefore, is contemporaneous with or postdates Cottage Grove faulting.

CONCLUSIONS

The following conclusions emerged from our investigation:

1. The Rend Lake Fault System is a zone of east-west extension that is very long in comparison to its modest displacements.
2. Although some of the rocks reacted to stress in a ductile fashion, this was a function of lithology, not incomplete lithification. There is no evidence of soft-sediment or growth faulting penecontemporaneous with sedimentation.
3. Movement across fault planes occurred sporadically in small increments over a long span of time.
4. Drag is the result of ductile stretching and bedding-plane slip prior to actual loss of cohesion across the fault planes.
5. Faulting is most likely the result of north-south-trending differential uplift and subsidence, which caused an east-west extensional stress. The differential vertical movements began prior to deposition of the Herrin (No. 6) Coal, resulting in stratigraphic thickness variations. These movements probably increased in rate after deposition of the Shoal Creek Limestone, resulting in the Rend Lake faults.
6. Faulting occurred after deposition of the Shoal Creek Limestone. No evidence exists that Pleistocene sediments are affected by faulting; hence, the Rend Lake Fault System's potential as a source of present-day seismicity is low.
7. The fault system appears to extend northwest at least to Sec. 23, T. 3 S., R. 1 E., beyond which it seems to terminate against the northeast-trending branch of the Du Quoin Monocline.

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