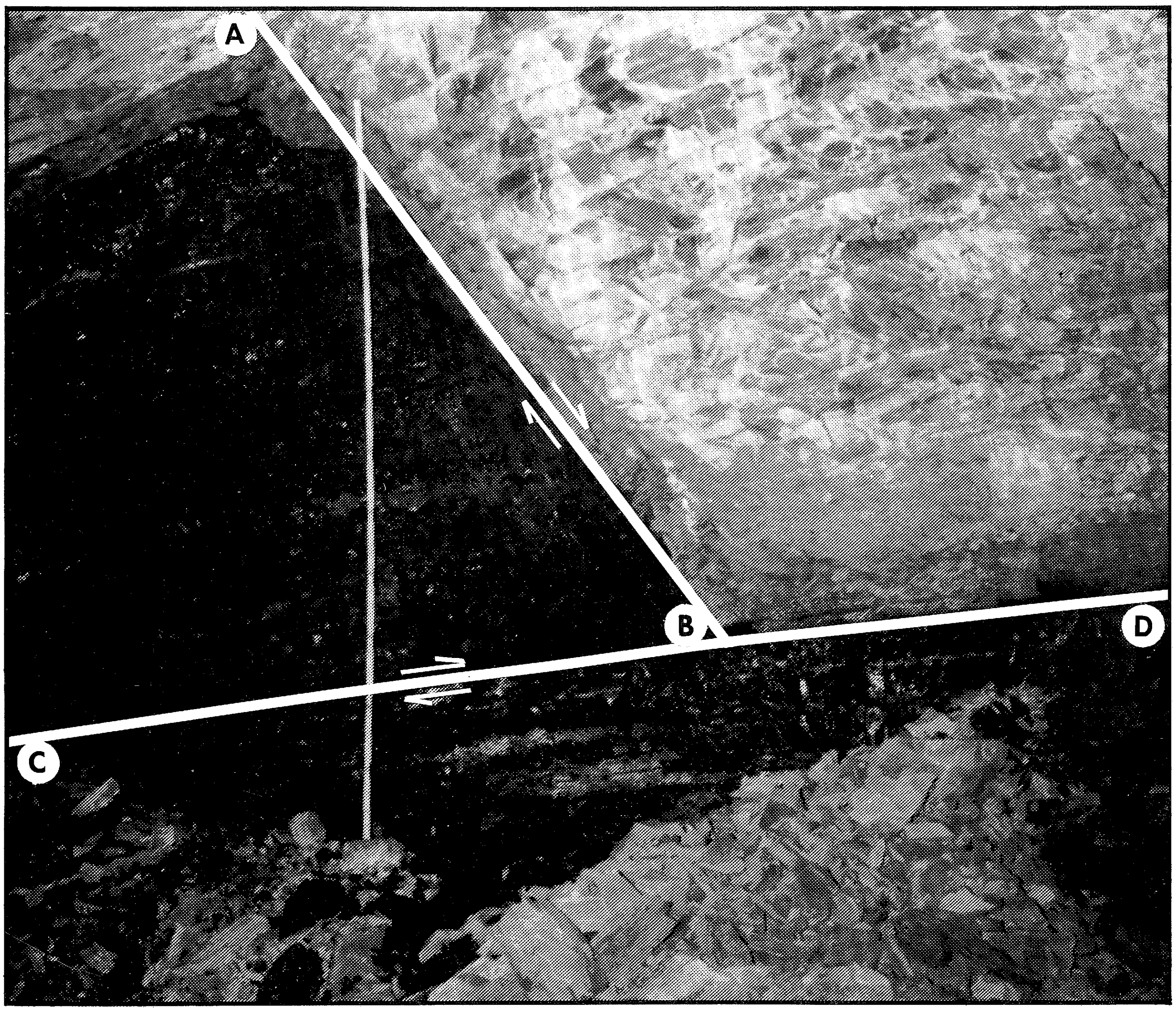
# FAULTS AND THEIR EFFECT ON COAL MINING IN ILLINOIS

W. John Nelson




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

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COVER PHOTO: Herrin (No. 6) Coal offset by a high-angle normal fault (AB) and a horizontal bedding fault (CD). Located in the Cottage Grove Fault System, at a mine in southern Illinois. Ruler is 6 feet long.

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# FAULTS AND THEIR EFFECT ON COAL MINING IN ILLINOIS

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# FAULTS AND THEIR EFFECT ON COAL MINING IN ILLINOIS


## ABSTRACT

Faults are fractures in the earth's crust along which movement (slippage) has occurred. They are one of many types of geologic disturbances that affect coal seams. Faults, which are common in coal seams of Illinois, have considerable effects on coal mining, such as: offsetting of the coal seams, creation of grades too steep for mining equipment to follow, weakening of roof and ribs, admission of water and gas into workings, and introduction of clay and other impurities into the coal.

Faults can be grouped into tectonic faults, which are caused by forces acting in hard rock deep within the earth, and nontectonic faults, which are formed by localized disturbance of incompletely lithified sediments. The presence of most tectonic faults can be predicted before mining begins, and their location can be determined by drilling, seismic exploration, and other means. Most nontectonic faults, in contrast, are too small to detect or predict much beyond the working face.

The major systems of tectonic faults in Illinois that influence coal mining are located in the southern part of the state. They include the Cottage Grove, Wabash Valley, and Rend Lake Fault Systems, the Dowell Fault Zone and Centralia Fault, the Shawneetown Fault Zone, and faults in the Eagle Valley Syncline. Smaller tectonic faults are known or may exist in other coal mining areas of the state. Many tectonic faults occur in regions where the rock layers are folded, but some exist in unfolded areas.

Nontectonic faults are found in every mine in the state, although they are more troublesome in some areas than in others. The major classes of nontectonic faults include compactional faults, clay-dike faults (associated with clay dikes), and gravitational slumps and slides. Many nontectonic faults are strongly controlled by lithologic patterns in the rocks above a coal seam. The relationships of nontectonic faults to lithology often can be mapped so that the presence of the faults can be predicted a short distance ahead of the face. Mining plans should be as flexible as possible to allow adaptation to local conditions in faulted areas.

## INTRODUCTION

Faults are responsible for many difficulties in coal mining in Illinois. They cause major losses in production; they increase the danger, difficulty, and expense of mining; and sometimes they force the abandonment of large blocks of coal reserves, or even of entire mines. Every coal mine in the state is affected to some degree by faults, and some of the most productive coal-mining areas are also the most heavily faulted. Therefore, a better understanding of faulting could be highly beneficial to the mining industry.

A fault, in geologic terms, is a break in the earth's crust along which slippage or displacement has occurred. Faults are only one of many types of geologic disturbances that can interrupt coal seams and interfere with mining operations. Unfortunately, many people who work in mining in Illinois and elsewhere possess a limited understanding of the variety of geologic disturbances that affect coal measures. Frequently, all discontinuities in the coal are labeled as "faults," and no attempt is made to identify the true nature or origin of the disturbances. Thus some structures that are not true faults are mistakenly treated as faults, which leads to improper mining procedure—often with enormous costs in lost production, wasted effort, and hazards to workers.

This report defines faults, describes their effects, explains how they can be identified and predicted, and suggests procedures to ensure optimum mining in faulted areas. The major fault systems in the coal fields of Illinois are presented in maps and text, and unmined areas where faults can be expected to occur are identified. Although this report is aimed primarily at the mine operator in Illinois, many of the principles presented are valid for other coal fields as well.

A glossary of terms related to faults is included in the back of this publication.

This report does not cover all the technical aspects of faulting or present all the details known about the various fault systems in Illinois. For more complete discussions of individual fault systems, the reader should consult the other published reports available on these systems. Among the more recent reports are: Nelson and Krausse (1981) on the Cottage Grove Fault System; Bristol and Treworgy (1979) on the Wabash Valley Fault System; and Keys and Nelson (1980) on the Rend Lake Fault System. Faults around Centralia are discussed by Brownfield (1954), and igneous dikes in Saline County are covered by Clegg (1955) and Clegg and Bradbury (1956). For a thorough discussion of clay-dike faults and clay dikes, the reader should consult Krausse et al. (1979). All of these reports are available either free or on loan from the Illinois State Geological Survery (ISGS). Among the many general textbooks on structural geology, Billings (1954), Hills (1963), and Spencer (1969) are suggested.

This report deals only with true geologic faults (the results of slippage along fractures in the earth). I am preparing a second report that will cover the other types of geologic disturbances in the coal seams of Illinois.

## FAULTING—BASIC TERMS AND CONCEPTS

### Definition of faulting

A fault is defined as any break or fracture in the earth's crust along which slippage has occurred. The slippage may range from a barely perceptible amount to many miles. Faults produce displacement of rock layers; a coal seam that has been faulted will be broken, and the broken pieces will have moved relative to one another. The movement may be up and down, lateral, or any combination of the two.

Joints are fractures along which no slippage has occurred. Joints are found in almost all hard, brittle rocks, and are especially pronounced in coal and black shale. Some of the joints in coal are frequently called cleat. Joints can have significant effects on coal mining, but since they do not produce slippage, they are not faults and will not be considered any further in this report. Some features of joints are covered in Krausse et al. (1979); joints also will be discussed in my upcoming paper on disturbances in coal seams not related to faulting.

### Nomenclature of faults

The surface of a fault, along which slippage has occurred, is known as the fault surface. A fault surface may be curved, but commonly it is planar or nearly so; then it is termed a fault plane (fig. 1). Fault planes can have any orientation, ranging from horizontal to vertical. The orientation of a fault plane is described in terms of strike and dip (fig. 1). The strike is the trend of a horizontal line in the plane of the fault; that is, it is the direction shown by the fault on a map (horizontal faults do not have a strike). The dip is the angle the fault plane makes with a horizontal surface. Faults with a dip of 0 to 45° often are called low-angle faults; those dipping 45° to vertical are high-angle faults.

On a fault with an inclined plane, the block above the fault is called the hanging wall, and the block below is known as the footwall (fig. 1). These terms are derived from mining practice, and refer to the fact that in an entry (tunnel) intersected by a fault, the miner would have his feet on the footwall, and the hanging wall would overhang him.

The term slip denotes the relative displacement of formerly adjacent points on opposite sides of a fault surface (fig. 1). The total amount of slip, measured along the fault surface in the direction of movement, is the net slip. The net slip can be resolved into two components: strike-slip (horizontal, parallel to strike) and dip-slip (parallel to the dip of the fault plane). Two additional terms used to describe displacement of faults are throw and heave (fig. 1).

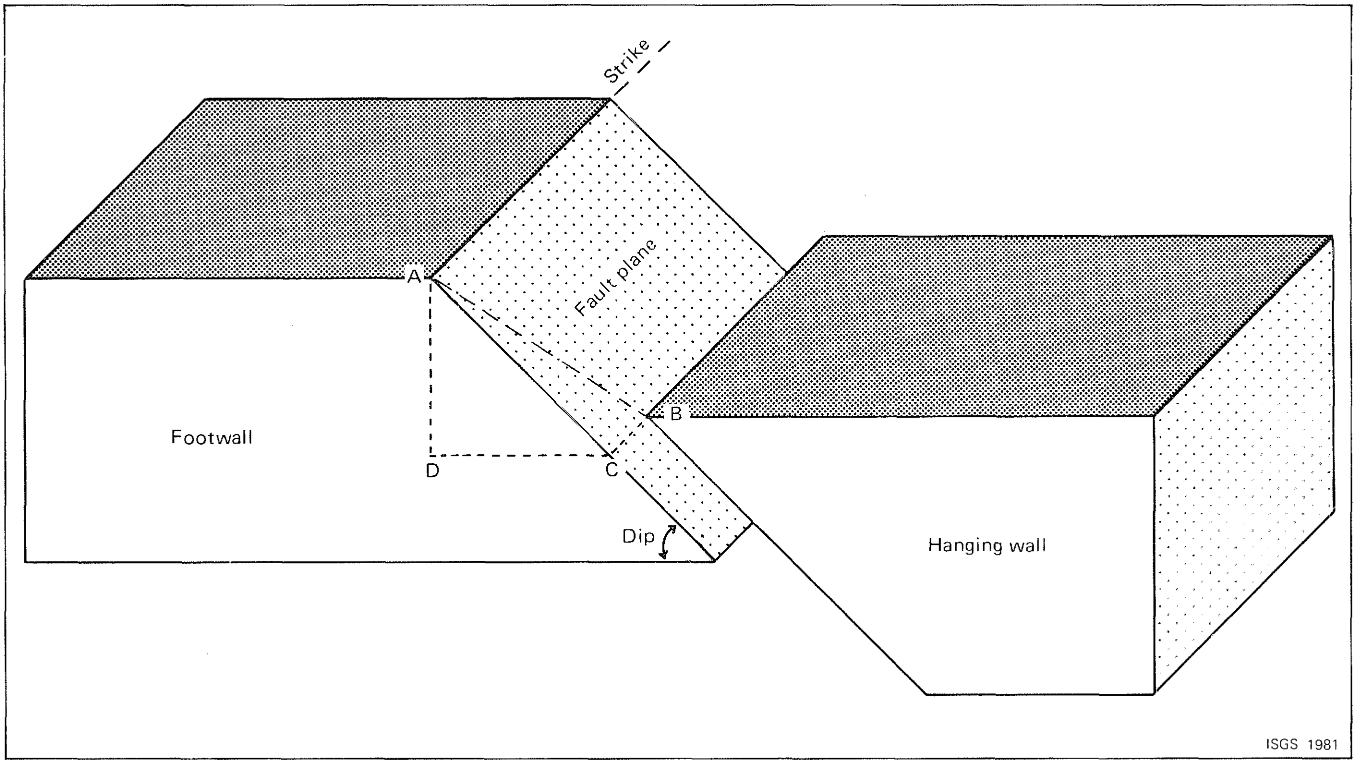



Figure 1. Where A and B are points that were adjacent prior to faulting, AB = net slip, BC = strike slip, AC = dip slip, AD = throw, DC = heave.

Throw is the vertical component of separation of two formerly adjacent points, and heave is the horizontal component of separation for the same two points. Throw and heave are measured along planes perpendicular to the strike of the fault.

**Types of faults**

Faults can be classified according to the geometric orientation of the fault plane and the direction of movement (fig. 2). The fault plane in a normal fault (fig. 2A) is inclined to the vertical and the hanging wall has moved downward relative to the footwall. Normal faults indicate an extension of the earth's crust perpendicular to the strike of the fault plane. Tension causes the rock layers to rupture, and the hanging wall moves downward under the influence of gravity. For this reason normal faults are sometimes termed gravity faults.

A reverse fault (fig. 2B) has an inclined plane along which the hanging wall has moved upward relative to the footwall. Reverse faults are generally caused by compression of the earth's crust. Sometimes they are termed thrust faults, particularly when the dip of the fault plane is shallow.

A fault with a vertical plane and vertical movement is technically neither a normal fault nor a reverse fault. In most cases the dip of the fault plane will deviate from 90°. It is not uncommon for the same fault to be geometrically normal in one place, and reverse in another.

A strike-slip fault is a fault on which the primary direction of movement is horizontal along a vertical or inclined fault plane (fig. 2C). The movement may be further defined as right-lateral or left-lateral. If, to an observer standing along the fault and looking along its strike, the right-hand block has moved toward him, it is a right-lateral fault. If the left-hand block has moved toward him, it is a left-lateral fault.

Strike-slip faults are caused by wrenching action about a vertical axis in the crust of the earth, and are sometimes called wrench faults. Many of the world's largest and best-known faults, such as the San Andreas Fault in California, are strike-slip faults.

In many cases a fault shows components of both strike-slip and dip-slip movement. Such faults are called oblique-slip faults (fig. 1). Careful examination of the fault occasionally allows a determination of the relative proportion of horizontal and vertical movement.

In layered rocks, movement can occur along bedding planes in the rock to produce a bedding fault (fig. 2D). Movement along bedding planes may occur within one rock unit, such as a coal seam, or at the boundary between two rock units. Bedding faults are often difficult to recognize because there is no apparent offsetting of the layers. A thin zone of crushed or broken rock or coal along the fault surface may be the only indication of a bedding fault. Bedding faults can turn into thrust faults or normal faults that cut across bedding.

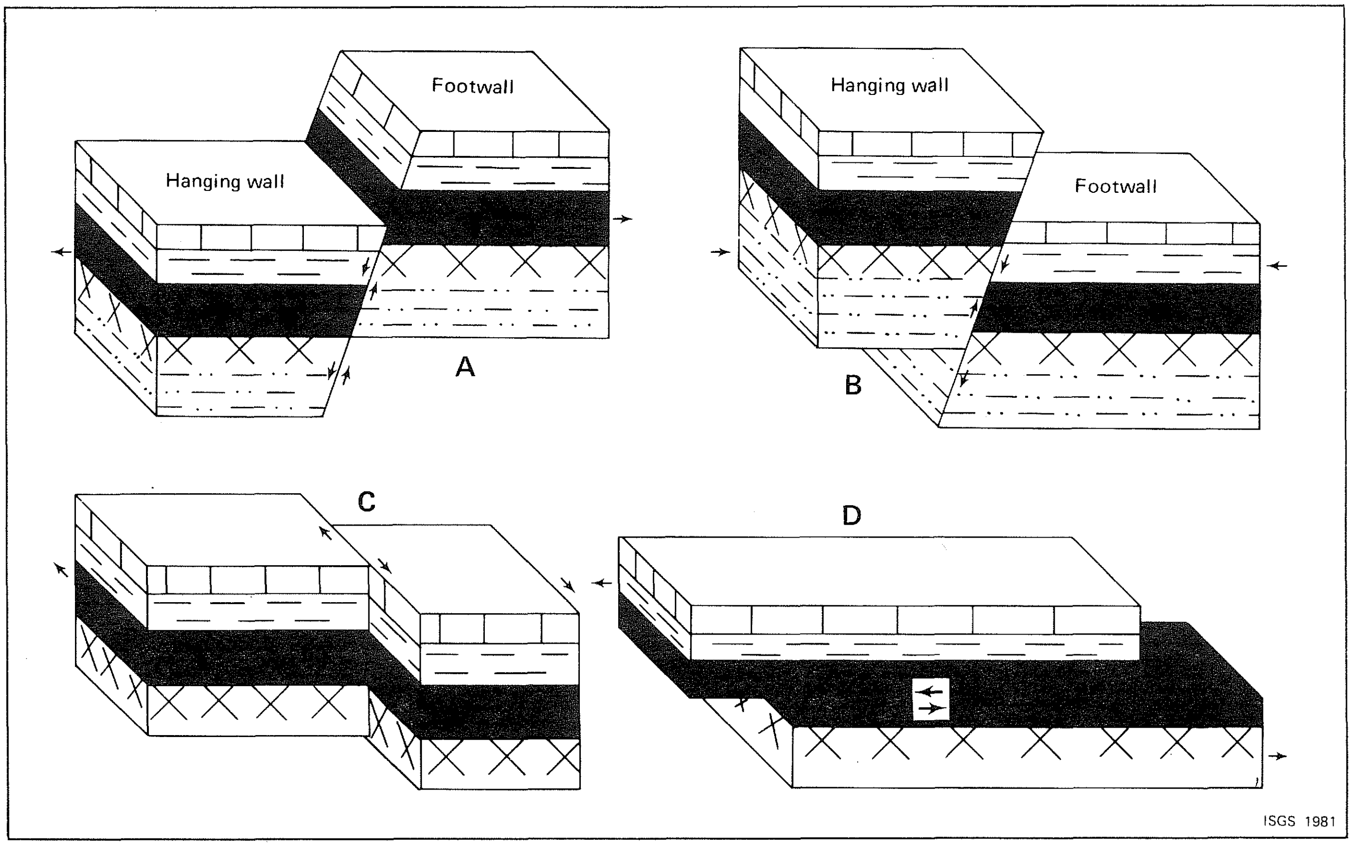



Figure 2. Types of faults. (A) Normal fault; (B) reverse fault; (C) strike-slip (wrench) fault (this example is a right-lateral fault); (D) bedding fault.

Faults seldom occur singly. Many large faults are expressed as fault zones, which are composed of numerous small faults and fractures that penetrate a zone of broken rock. Fault zones vary from a few feet to hundreds of feet in width. On a larger scale are fault systems, which are composed of many faults or fault zones. Some fault systems consist of a series of similar, parallel faults. Examples in Illinois include the Rend Lake Fault System and the Wabash Valley Fault System, both of which consist of many parallel high-angle normal faults. Other fault systems are more complex, and include faults that show a variety of orientations, magnitudes, and types of movement. The Cottage Grove Fault System in southern Illinois is an example of a complicated fault system. It includes a fairly continuous, large master fault that strikes roughly east-west, which is flanked by many smaller subsidiary faults, most of which strike northwest-southeast. Normal, reverse, strike-slip, oblique-slip, and bedding faults have all been recognized within the Cottage Grove Fault System.

**Features of faults**

Some features are characteristically found along fault planes and may be useful in determining the direction and amount of slip. Slickensides (figs. 3A and 3B) are polished surfaces with grooves or striations that are caused by the friction of movement. Slickensides may be obliterated by minor adjustments of movement along a fault, and so may record a minor, final movement that differs from the net slip. On some faults larger parallel furrows may occur, with amplitudes ranging from inches to feet. Such furrows are known as mullion. Large-scale mullion are not as easily erased by later movement as are slickensides, but they are rare on faults in Illinois.

Fault breccia (fig. 4) consists of angular fragments of rock set in a matrix of finely ground material found along a fault surface. Gouge consists of pulverized rock, usually with a claylike consistency, found in the same setting. Gouge and breccia are the result of grinding of rock between the walls of the fault as movement occurs. Large faults generally have wide zones of gouge or breccia or both. In many cases minerals have filled open spaces between fragments in the gouge zone, as well as fractures in the rocks bordering the fault zone. Calcite and quartz are the most common minerals in fault zones in Illinois, but in many parts of the world, valuable ore minerals are found within fault zones. Much of the fluorspar mined in southern Illinois occurs as fillings along faults.

Friction along a fault surface may cause the rock layers adjacent to the fault to be bent or folded in the direction of net slip. Such folding of the rocks abutting a fault is

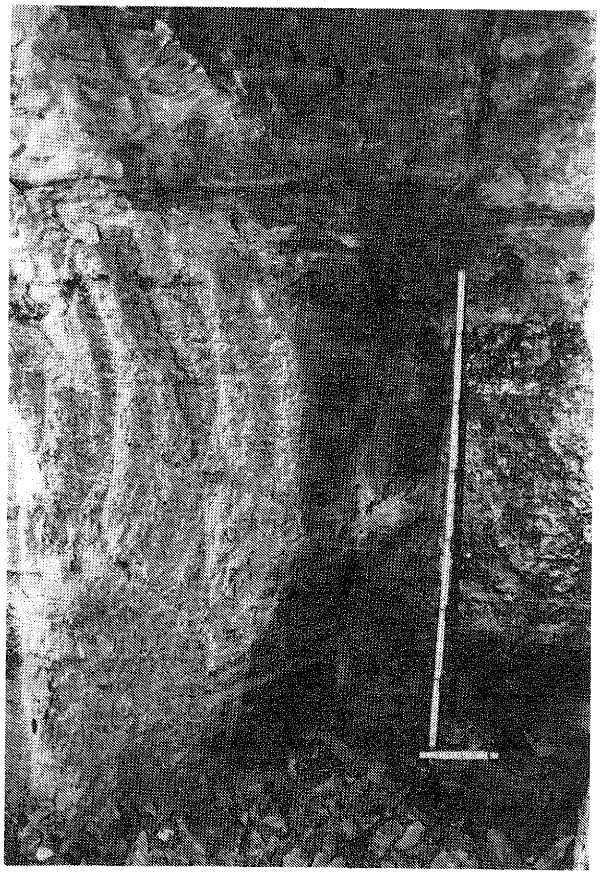


Figure 3A. Vertical fracture in coal to left of ruler shows horizontal slickensides and small-scale mullion, indicating strike-slip movement.

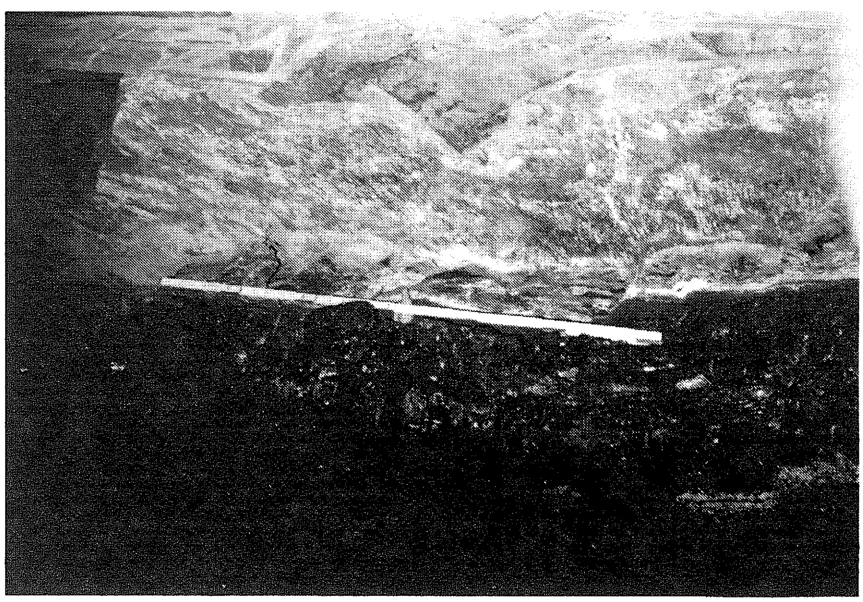


Figure 3B. Slickensides on lower surface of shale show that a bedding fault exists at the contact of coal and roof.


Figure 4. Breccia—sample from Rend Lake Fault System shows angular fragments of dark limestone in a matrix of white, crystalline calcite.

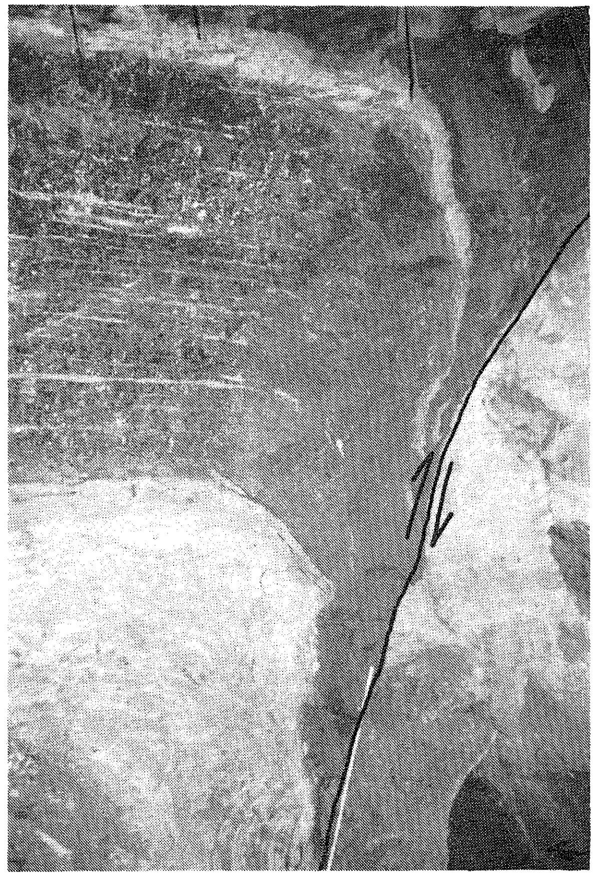


Figure 5. Reverse fault in which the hanging wall (left) moved up relative to the footwall, and the coal was bent downward along the fault plane, resulting in drag. (From Nelson and Krausse, 1981.)

called drag, and can be a useful indicator of the direction of slip (fig. 5). Not all faults display drag; however, in some faults the rocks may be sheared off quite cleanly. Coal is often sheared without drag because it is so brittle. Many normal faults show no drag because the blocks are being pulled away from each other by extensional forces, and so the friction is less than on reverse (compressional) faults. Furthermore, on some small normal faults the layers may be bent opposite the direction of slip, forming what is called false drag. Nonetheless, where drag is present it provides one of the most reliable indicators of the direction of slip.

**Origin of faults**

Faults can have their origins in a variety of processes, and have been classified according to many different criteria. For the purposes of this report faults are divided into two broad categories: tectonic faults and nontectonic faults. Tectonic faults are formed by forces acting over large areas, and mostly affect rocks that are fully hardened. Usually tectonic faults can be projected into unmined areas. Nontectonic faults are formed when stresses affect sediments while they are being transformed into rock; these faults are difficult to predict ahead of the working face.

Several characteristics are useful in recognizing tectonic faults and distinguishing them from nontectonic faults (table 1). Tectonic faults occur in well-defined systems that may extend for many miles along strike. They are usually not limited to any specific rock type, but cut across many layers, and some may penetrate the entire crust of the earth. Most tectonic fault systems consist of hundreds or thousands of individual fractures, with displacements ranging from a fraction of an inch to many miles (the largest in Illinois have displacements of a few thousand feet). Tectonic faults include all the types of faults we have discussed, including normal, reverse, strike-slip, oblique-slip, and bedding faults.

Tectonic faults are planar to slightly curved and generally follow straight courses, cutting across the boundaries between different rocks with little or no deviation. The faults are commonly composed of many parallel or en echelon fractures (fig. 6). Large tectonic faults may have wide zones of gouge and breccia, and the rocks adjacent to the fault may be brecciated. Drag is either absent or normal, with strata bent in the direction of net slip; false drag is rare.

TABLE 1. Characteristics of tectonic and nontectonic faults

| | Tectonic faults | Nontectonic faults |
|---|---|---|
| Occurrence | In well-defined systems | Highly variable |
| Length | Up to hundreds of miles | A few feet to thousands of feet, rarely miles |
| Displacement (net slip) | Up to many miles | Usually under 3 feet, rarely up to hundreds of feet |
| Fault surface | Planar to slightly curved | Often strongly curved both in strike and dip |
| Types of faults | Normal, reverse, strike-slip, oblique-slip, and bedding | Predominantly normal, some bedding faults, rarely reverse faults |
| Patterns on map | Generally form parallel or en echelon sets | Curving, follow boundaries between rock types |
| Gouge or breccia | Usually wide zones | Narrow zones or absent |
| Drag | Absent to well-developed normal drag | False drag may be developed |
| Place of origin | Consolidated rock, basement rocks[a] | Unconsolidated or partially consolidated sediments |
| Lithologic control | Generally cross lithologic boundaries with little or no deviation | Curving, tend to follow lithologic boundaries |
| Mode of origin | Regional stresses, often from deep within the earth; movement on tectonic faults can cause earthquakes | Gravitational stress, loading, and differential compaction; some may be triggered by earthquakes |
| Predictability | Often can be projected for miles into unmined areas; many can be located by drilling | Difficult to predict more than a few feet to tens of feet ahead of the working face; difficult to locate by drilling |

[a] Basement = Precambrian igneous and metamorphic rocks that underlie the layered sedimentary rocks. In Illinois the basement is 2,000 to 14,000 feet below the surface (Willman et al., 1975).

Tectonic faults develop in response to tectonic stresses, which are major forces in the interior of the earth—the sort of forces that are responsible for building mountains. Tectonic stresses are the primary cause of earthquakes in most parts of the world. This is not to say, however, that all tectonic faults present a danger of earthquakes, since many of these faults were formed millions of years ago and are no longer active. None of the tectonic fault systems that penetrate coal-bearing strata in Illinois are known to be active today.

Tectonic faults known to exist in the coal fields of Illinois are concentrated in the southern part of the state, and include the Rend Lake, Cottage Grove, and Wabash Valley Fault Systems and the Shawneetown Fault Zone, among others.

Nontectonic faults do not occur in systems that can be traced continuously through large areas; rather, their occurrence and distribution are controlled by local factors. Nontectonic faults are very common and widespread, and are found in every coal mine in Illinois. They are not necessarily small faults. Some can be traced along strike for thousands of feet and may have net slips measured in tens to hundreds of feet. The vast majority of nontectonic faults in the coal-bearing strata of Illinois, however, are relatively small, with lengths of a few tens to hundreds of feet and net slips ranging from a few inches to several feet.

In contrast to tectonic faults, which are relatively straight and planar, most nontectonic faults are curved in strike or dip, or both. Nontectonic faults are usually confined to a single bed or stratum, such as the coal seam or a bed of shale in the roof. The great majority of nontectonic faults in Illinois are normal faults, which locally become bedding faults. Reverse faults are rare, and strike-slip faults of nontectonic origin are not known to exist in the state. Usually, nontectonic faults have little or no gouge and breccia, although the surfaces of some are coated with calcite, pyrite, and other minerals. Drag may develop, often as false drag opposite to the direction of slip.

Most nontectonic faults develop in unconsolidated or partially consolidated sediments, and not in hard rock. Some nontectonic faults result from gravitational stresses caused by loading of sediments. Other nontectonic faults result from differences in the rates of compaction of various sediments such as peat, mud, and sand. Other processes that may produce nontectonic faults are: expulsion

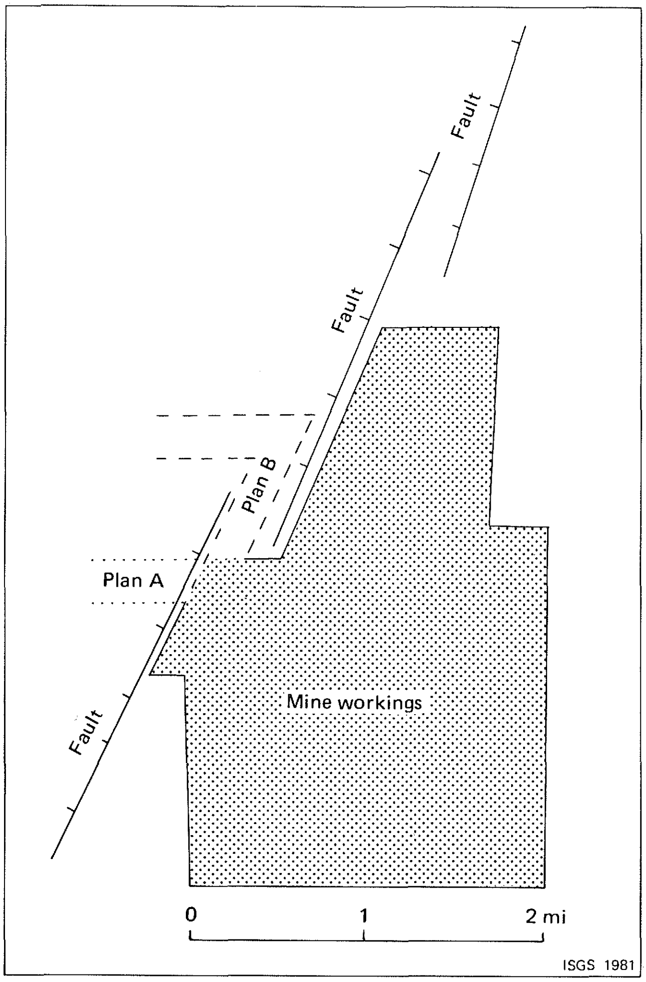



Figure 6. Faults forming an en echelon pattern. The mine workings above are to be extended west of the fault zone. If plan A is followed—driving straight through the fault—much rock must be mined and the haulageways must be graded. To compensate, plan A minimizes exposure to unstable roof in the fault zone. In plan B the entries are turned parallel to the faults and driven through the gap between two en echelon faults, and no grading in rock is necessary. However, many small fractures parallel with the faults and the entries are likely to be present, and may render roof control difficult.

of water from peat and other sediment, collapse of caverns in limestone, migration of salt and clay under overburden pressure, and shaking of the ground by earth tremors caused by slippage along tectonic faults.

## EFFECTS OF FAULTS ON COAL MINING

Faults have a number of effects, almost always undesirable, on coal mining. These effects include: (1) physical displacement of coal seams, which may make them difficult or impractical to mine; (2) reducing the stability of roof and ribs in underground workings; (3) opening of pathways for the influx of water and gas into underground workings; and (4) introduction of impurities, including clay and various forms of mineral matter, into coal seams.

### Displacement of coal seams

Faults in Illinois displace and offset coal seams by as much as several hundred feet vertically. In strip mining through a faulted zone, the operator may find the coal seam has been eroded at the surface in upthrown blocks, or is too deep for profitable recovery in downthrown blocks. In underground workings, large faults necessitate mining through rock, which is very abusive to equipment designed for mining in coal. Because haulage roads and belt lines must be kept within a specified gradient, large volumes of rock may have to be blasted, removed, and disposed of, either to the surface or to old workings. Faults frequently force the operator to change the layout of his mine, and leave behind blocks of coal that cannot be reached without excessive cost.

Another source of difficulty is steeply dipping or pitching coal in faulted areas. For example, along the Cottage Grove Fault System in southern Illinois, inclinations exceeding 20° have been encountered in several places. Mining equipment used in Illinois is designed for operation in flat-lying seams; shuttle cars, mantrips, and other vehicles have great difficulty on slopes steeper than 15°, and standard, smooth conveyor belts will not work when tilted above 18°. Several sizable blocks of coal have been left unmined because of steep dips along the Cottage Grove Fault System.

### Weakening of roof in underground mines

Any fault or fracture tends to decrease the stability of the roof and ribs in underground coal mines, and produces added danger to workers, decreased production of coal, and increased expense for supports and for cleaning of falls. Faults are natural planes of separation in rock. The slickensided "slip" with barely perceptible displacement can be as hazardous as the major fault with a displacement measured in tens of feet.

Certain configurations of faults relative to the mine opening are especially dangerous. One of the worst is the "coffin cover" (fig. 7A), where two faults intersect above the middle of the entry. The wedge-shaped block of rock below the junction of the faults is likely to fall as soon as the coal is removed. Almost as hazardous is the situation where a fault strikes along one rib line, and dips away from the entry (fig. 7B). This leaves the footwall as a cantilever, prone to break near the opposite rib. A fall may be prevented by placing cribs or timbers under the footwall, and by bolting through the fault to tie the footwall to the hanging wall. The opposite situation, where a fault along the rib dips toward the center of the entry (fig. 7C), is less dangerous because the weight of the roof is evenly supported by both pillars.

The closely spaced fractures associated with many tectonic fault systems present special problems for roof control. When the roof is adjacent to large faults, it frequently contains many parallel vertical or steeply dipping fractures, which may be spaced less than an inch apart. Such fractures can make roof control extremely difficult, especially if a weak rock, such as shale or thinly laminated sandstone, overlies the coal. In many cases two intersecting sets of fractures are present. Along major dip-slip faults, one set of fractures often trends parallel to, and another set perpendicular to the main faults. Strike-slip faults are usually accompanied by two sets of fractures striking obliquely to the master fault.

In some areas of Illinois the roof exhibits a preferential weakness in one direction that may be related to adjacent fault systems, even though no slip planes may be visible in the roof. Along the north-trending Rend Lake Fault System in Franklin and Jefferson Counties (fig. 8), north-south headings in mines are more prone to roof failure than are east-west headings. This phenomenon occurs all along the fault zone, and in some cases the effect has been noted more than 5 miles (8 km) east of the known faults. The effect seems to be more pronounced east of the Rend Lake Fault System than west of it, and is most intense immediately adjacent to the faults. Few of the roof failures can be attributed to any visible north-trending fractures in roof or coal. Rather, the instability usually is first shown by development of a "kink zone," or general line of roof sag along the center line of the heading. The "kink zone" appears soon after mining, and, if left unattended, leads to slabby breakage of the lower layers of rock (gutter falls), and eventually to massive failure of the main roof.

The difficulty resulting from this type of directional failure may be minimized by avoiding placement of the headings parallel to the direction of fractures or "kink zones." In a room-and-pillar operation, the operators should consider laying out the mine with main headings and panels at a 45° angle to the line of failure. In most of Illinois, mines have been laid out with headings trending north-south and east-west because property boundaries generally run in these directions. In areas where directional roof failures are a problem, this practice should be reevaluated.

**Influx of water and gas along faults**

Occasionally, difficulties are caused by the flow of water or flammable gases into underground mines along faults. Some faults provide natural pathways for the movement of fluids through the crust of the earth, but others act as barriers to the movement of water. Some seepage of gas and water has been reported along all the major faults in the coal fields of Illinois, but only locally have the volumes been great enough to hinder mining.

An example of water influx along a fault zone was recently reported in the Crown II Mine of Freeman United Coal Mining Company in Macoupin County (Nelson and

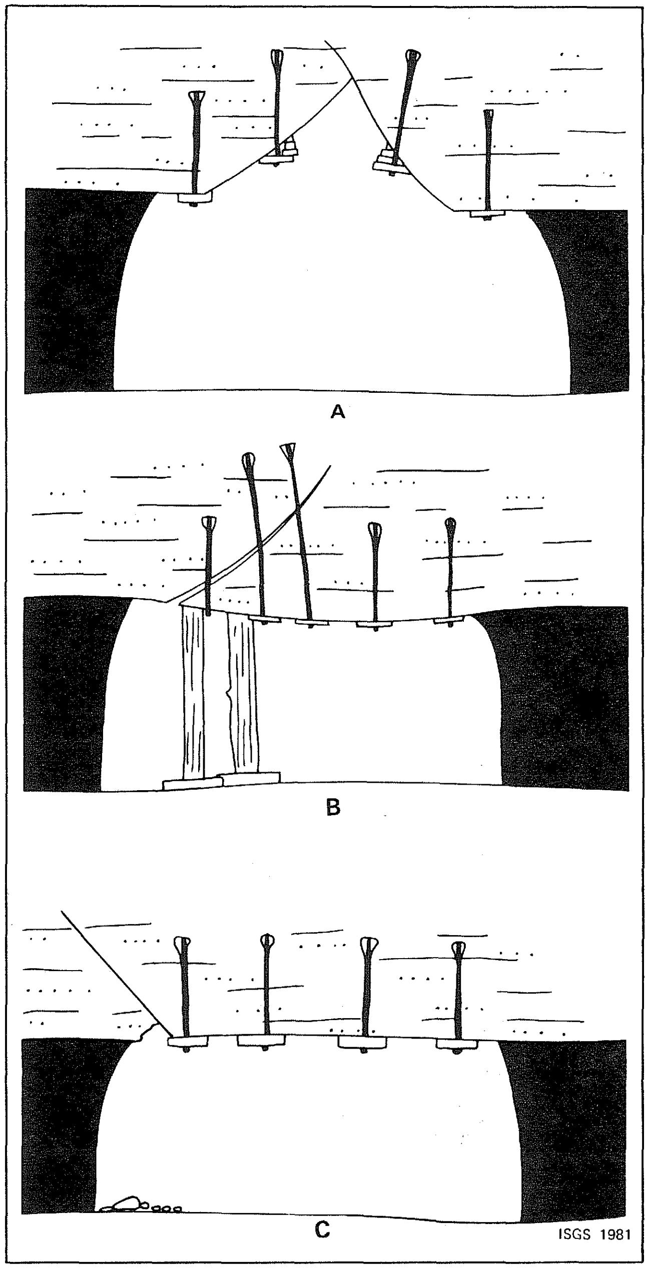



Figure 7. Configurations of faults dangerous to mining. (A) "Coffin cover" pattern, which occurs when two faults intersect above the center of the opening, is very dangerous. The wedge of rock below the faults is likely to fall before roof supports can be placed. (B) Fault near one rib that dips toward pillar leaves the footwall supported only on the far rib, and prone to failure. Prompt bolting through the fault or timbering or both may prevent a fall. (C) A fault near one rib that dips toward the entry is much less likely to produce a roof fall than A or B. The weight of the roof is evenly supported over the pillars, so normal bolting should suffice, although small slabs of rock may break away along the fault.

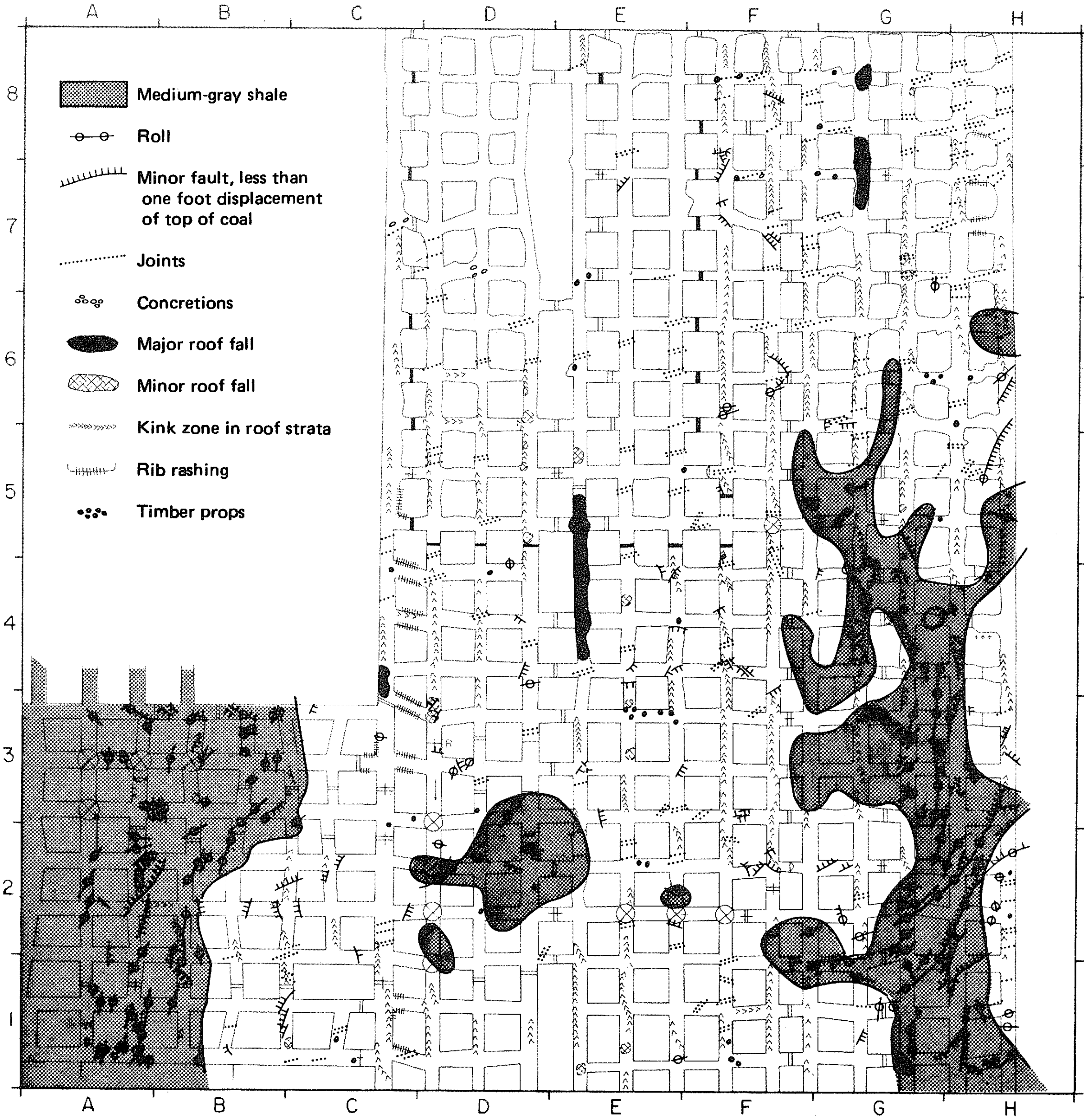



Figure 8. Portion of the Orient No. 6 Mine, Freeman United Coal Mining Company, about 1000 feet (300 m) east of the Rend Lake Fault System. Although few faults were observed in the study area, roof falls and "kink zones" dominantly extend north-south parallel with the faults. (From Krausse et al., 1979.)

Nance, 1980). The main fault is a left-lateral, strike-slip fracture of small displacement, trending east-west, and probably of tectonic origin. On both sides of the main fault are a large number of open fractures that trend northeast-southwest and penetrate water-bearing sandstone above the coal. The fractures are most intense near the main fault, but some extend more than 1,000 feet away from the main fault. Water and locally small amounts of gas enter the mine along the strike-slip fault and along the northeast-southwest fractures. The volume of water is not great, but is difficult to pump because the flow is widely dispersed through the mine rather than being concentrated in one place, according to Nelson and Nance.

Minor influxes of natural gas and crude oil have been observed in several coal mines, especially along the Cottage Grove and Wabash Valley Fault Systems in southern Illinois. The presence of oil provides a clue that some of the gas may be coming from underlying Mississippian or older strata, which the faults are known to penetrate (Bristol and Treworgy, 1979). Some gas may have originated in various coal beds cut by the faults. In at least one case, a sudden outburst of methane from a fault reached explosive concentration and forced evacuation of the working face until supplementary ventilation could be established.

### Impurities in coal

Various impurities detrimental to coal mining and coal quality are introduced into coal seams along faults. The most common unwanted materials are gouge and breccia, sand, clay, pyrite and other sulfides, calcite, and quartz. These minerals increase the ash and sulfur contents of the coal and may cause accelerated wear and tear on mining equipment.

Some faults are pathways for water. Water can carry large amounts of clay and dissolved mineral matter and deposit these materials in the coal seam. Deposits on tectonic faults in Illinois are normally limited to a thin film of clay or growth of pyrite, calcite, or quartz crystals along fractures. The deposits are usually inconspicuous and widely dispersed, so they do not have much effect on the overall quality of coal shipped from a mine. The clay dikes associated with some nontectonic faults, however, can be a major source of unwanted clay in the coal.

Occasionally, zones of highly crushed or pulverized coal are encountered in a faulted area. Mining such coal produces large amounts of dust and fine "slack." The dust is an environmental hazard, but the "slack" is not as great a problem today as it was in the days when the main demand was for lump and stoker coal.

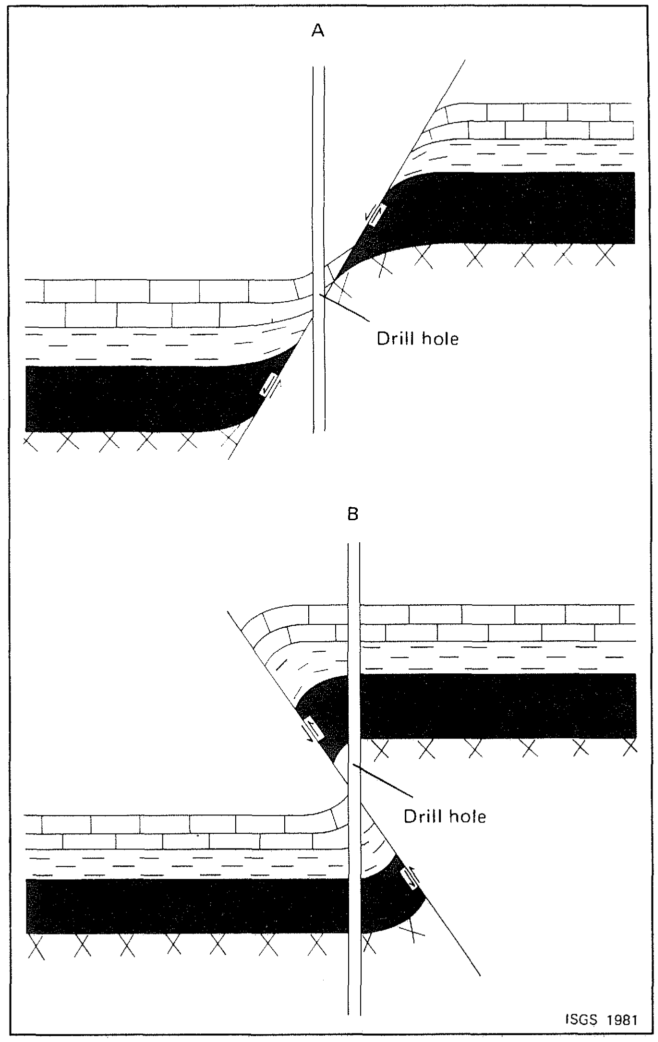



Figure 9. In a normal fault (A), drag is in the direction of movement, and the drill hole from the surface passes through missing strata (in this case the coal bed). In a reverse fault (B), drag is again in the direction of movement, and the drill hole from the surface encounters repeated strata.

## RECOGNIZING AND PREDICTING FAULTS

To deal effectively with the problems caused by faults in mines, one must know how to recognize faults and how to determine their orientation and amount of displacement. Methods to locate and predict faults include direct observation, mapping and analysis of related structural geologic features, drilling of test holes, and the application of geophysical (seismic) techniques.

### Recognizing faults in mines

A problem arises when a fault is encountered unexpectedly in a mine, and the operator needs to know in what direction and how far the coal seam has been displaced. In many cases this can be determined by a careful examination of the fault and the rocks it penetrates in the area. No special training in geology is needed to recognize many of the clues that faults leave about the direction and amount of slip. Drag is often a useful indicator of the direction of slip (figs. 5 and 9). Some faults show false drag, but such faults are rarely large enough to completely offset a coal seam. A clean-cut fault with no drag is more likely to be a normal fault than a reverse fault. In faults where the indications of drag are inconsistent or contradictory, one should suspect there to be a large component of strike-slip.

Another feature to look for is slices—narrow slivers of coal or rock in the zone of a large fault. A fault with slices actually consists of multiple, roughly parallel fault surfaces. Slices will usually be thrown in the same direction as the net slip of the fault; for example, the presence of an upthrown slice of coal indicates that the seam is probably upthrown across the main fault zone. Again, observation of slices may not be reliable on a strike-slip or oblique-slip fault.

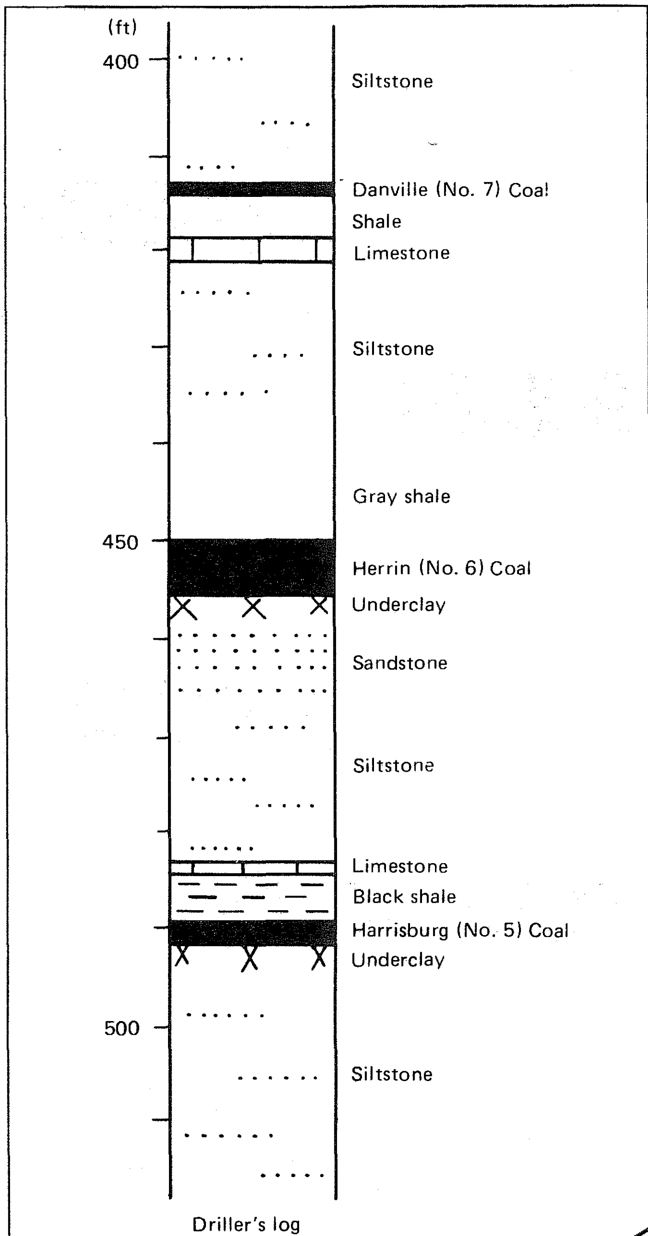
More valuable clues are slickensides and mullion, especially the latter. On a slickensided surface the "smoothness test" is occasionally helpful in determining the direction of slip. This test involves rubbing the palm of the hand along the fault plane parallel with the slickensides, first in one direction and then in the other. The surface will feel smoother when the hand is moved in the direction of slippage than when it is rubbed in the opposite direction. This effect is caused by sharp tiny ridges that develop on a fault surface in the direction of movement. The "smoothness test" must be used with caution because it reveals the final slip, and not necessarily the major or net slip of the fault.

On a large fault the direction and amount of displacement can often be determined from examination of the rocks on the far side of the fault. To examine these rocks, one must first excavate through the gouge, breccia, and slices into unbroken rock (not always easy or advisable from the standpoint of safety). The strata at the far side of the fault are then compared with those from nearby exploratory cores, roof falls, overcasts, and so on, to determine whether they belong to the roof or the floor of the seam (fig. 10).

Knowledge of what has been previously experienced with faults in a mine or in a district can be helpful in answering questions. For example, in the Rend Lake Fault System, all the known major faults are normal faults; therefore, on a large fault of this system one can confidently expect to find the coal downthrown on the hanging wall. The same is true in the case of large nontectonic faults. Virtually all such faults known in Illinois are normal faults, with the hanging wall downthrown.

### Recognizing faults when drilling

When the methods described above have failed, coal companies usually drill to locate faults and determine their displacement. Drilling is done from within the mine to find the coal. Test borings from the surface facilitate the detection of faults suspected to lie ahead of the working face. Faults also may be predicted through well-planned, carefully analyzed exploratory drilling.



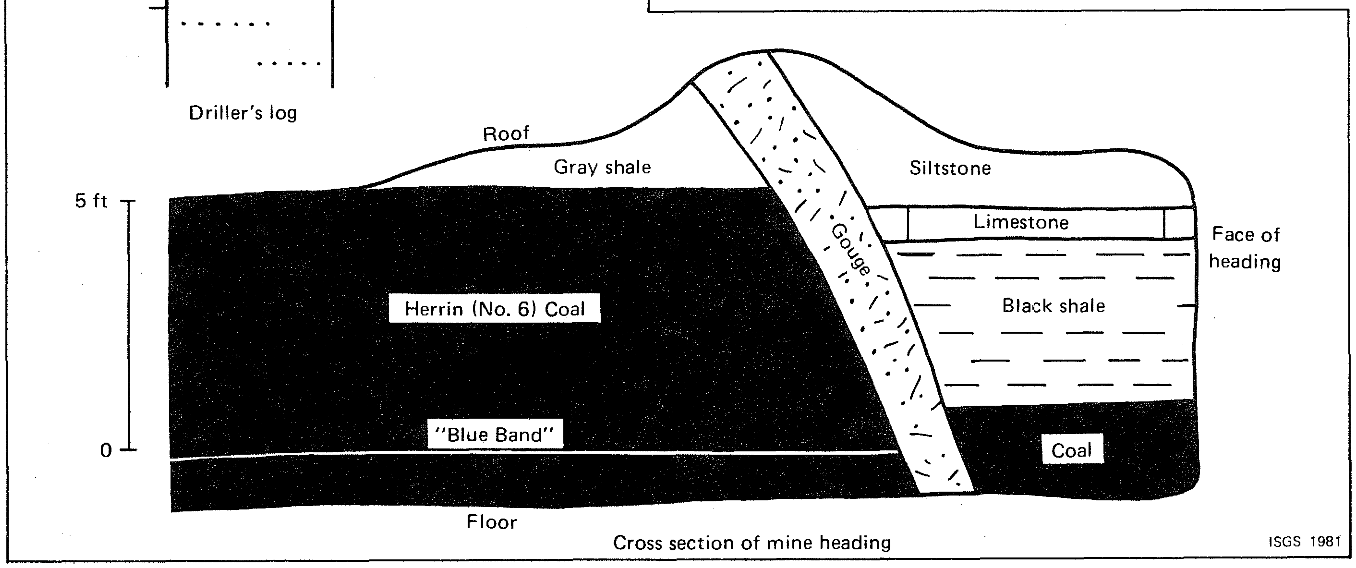




Figure 10. Determining the throw of a fault by comparing strata. A fault has been encountered on a heading of a mine in the Herrin (No. 6) Coal. After driving through the gouge zone left to right, coal is found on the far side of the fault. This coal cannot be the No. 6, however, because it is overlain by black shale and limestone, whereas the No. 6 Coal has a roof of gray shale. Comparison with the log of a nearby drill hole (left) shows that the coal across the fault is probably the Harrisburg (No. 5). The fault must be a reverse fault, and the No. 6 Coal has been upthrown about 35 feet.

On cores obtained through drilling, the presence of faults is indicated by such features as slickensided surfaces, zones of gouge or breccia, and intensely fractured and mineralized rock. The broken rock in a fault zone often is not recovered during coring, but the displacement of the fault can still be determined if geophysical logs or an accurate driller's log for the hole are available. Assuming vertical drill holes and roughly horizontal strata, as is usually the case in Illinois, normal faults are indicated by missing strata, and reverse faults by repeated strata in the log (fig. 9). The vertical separation on the fault is the same as the amount of missing or repeated section. When making the determinations, reliable marker beds such as coals, black shales, or limestones should be used, rather than gray shales or sandstones, which tend to be discontinuous or variable in thickness.

Recognition of faults between adjacent drill holes requires knowledge of the structural conditions likely to be found in the area under investigation. A large difference in the elevation of a coal bed between two holes does not always indicate the presence of a fault. Along the Cottage Grove Fault System in southern Illinois the strata may be folded; dips of 10° to 20° are not uncommon. A difference of 50 feet in the elevation of a coal bed between two holes 500 feet apart may reflect folding, faulting, or a combination of the two. In contrast, within the Rend Lake or Wabash Valley Fault Systems, the rock layers are seldom significantly tilted or folded between faults, so a difference of 50 feet in elevation within 500 feet of lateral distance may safely be attributed to a fault.

Most mining companies in Illinois plot faults on their maps as a single solid line; those who make and use structural maps must realize that only a few faults in nature can be portrayed accurately in this manner. In many cases a fault zone consists of a series of closely spaced parallel slices in which the coal is downthrown in stepwise fashion. Another common pattern in Illinois is a set of faults, staggered in en echelon position along strike (fig. 6). Mine entries sometimes can be driven through gaps in the line if the actual extent of the faults is known.

### Seismic exploration for faults

Techniques of reflective seismology have long been used by the oil and gas industry to delineate subsurface structures, but such methods have only recently been applied to the search for coal. The results of recent experiments in seismic exploration for coal have been promising. Researchers have claimed that not only can depth, continuity, and sometimes thickness of seams be determined, but also that faults, channels, major splits, and mined-out areas can be located.

Conventional oil-field seismology, usually designed for exploration at depths of several thousand feet, lacks adequate resolution for work in coal. Modifications of equipment, techniques, and data processing must be made for oil-field seismology to be suitable for coal. These modifications include using less intense sources of energy, spacing the geophones more closely, using filters to reduce noise, using higher frequencies of sampling, and improving the processing of data (Peng, 1978; Lepper and Ruskey, 1976; and Serres and Wiles, 1977).

In one experiment, the U.S. Bureau of Mines (USBM) accurately located two normal faults by seismic methods in a mine in Colorado. At a mine in southern Ohio, a sand-filled channel was identified on a seismic profile and its presence was subsequently confirmed by drilling. In the USBM tests, the maximum resolution was about 16 feet (5 m), but recent refinements in equipment and techniques should allow a resolution of 3 feet (1 m) (Lepper and Ruskey, 1976). In comparison, the smallest faults detectable by standard oil-field seismology are about 20 feet (Howard Schwalb, 1979, personal communication).

The Consolidation Coal Company has made several tests on its properties of a system using vibroseismic sources and analog recording. At an underground mine in Illinois, a sandstone-filled channel and a neighboring mined-out area were located seismically; these locations were confirmed by drilling. Similar features were located by the same method at two mines in Pennsylvania. The seismic data could also be used to distinguish areas of thin or missing coal from areas of normally developed coal (Coon et al., 1979).

The greatest advantage of seismic exploration over drilling is that seismic testing provides a continuous profile, whereas drilling provides only point data. By combining seismic studies with conventional coring in an exploratory program, coal companies can increase their supply of data and cut costs by reducing the number of holes that must be drilled (Daly, 1979).

A seismic method for locating faults and other irregularities in coal seams within a mine has been developed recently in Czechoslovakia (Stas, 1976). The method involves firing several small explosive charges at various locations in the mine, at the surface or in drill holes, and monitoring the impulses from the shots on receivers placed in the mine around the area to be investigated. Two methods of operation are available: one using direct radiation of shock waves from the firing base to the receivers, and the other involving reflection of the waves off of faults or other obstructions situated ahead of or alongside the firing base and receiver. The radiation method can be applied at distances up to 2,600 feet or even higher, under favorable conditions. The reflective method is successful to roughly half that distance. Stas claims that either method can be used to locate faults whose displacement is as little as 30 percent of the height of the coal seam. According to Stas, the system has been used with considerable success in a number of Polish and Czechoslovakian coal mines.

## MINING IN FAULTED AREAS

Before any mining is attempted in a faulted area, the location, direction, extent, and amount of displacement of the faults must be determined as accurately as possible. The money spent on exploration can be recovered many times over by the reduction in mining expenses.

Where a large fault or fault zone must be crossed, the best procedure generally is to drive the headings at right angles to the faults to cross the fault zone in the shortest possible distance. This minimizes the amount of rock to be excavated. Roof control can be improved by leaving larger pillars than are normally left, and, insofar as possible, by avoiding driving headings parallel with faults and fractures.

Good procedure in mining through major faults is illustrated in several mines in southern Illinois (fig. 11). The faults, which are part of the Rend Lake Fault System, trend nearly north-south and have throws of 20 to 45 feet. The headings that cross the faults extend east-west. The entries of a set of mains were mined in coal up to the fault surface before the crossing was attempted. The belt and haulage entries were then driven through the fault zone, grading to the required angle. Intake and return-air entries were usually not graded, but were connected across the faults by means of vertical or steeply inclined raises. The use of raises allowed maximum recovery of coal while mining the minimum amount of rock. The least number of entries needed to maintain ventilation were driven through the fault zone.

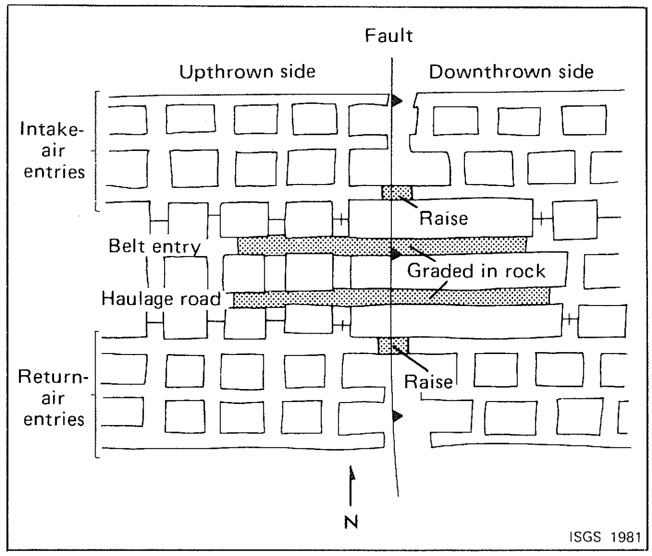



Figure 11. Mining through a large fault, as seen in many mines along the Rend Lake Fault System. Mining advanced from left to right.

The main entries and panels of most mines in Illinois are laid out due north, south, east, and west, to minimize the loss of coal around the boundaries of properties, which also generally run north, south, east, and west. Mining directly to the points of the compass works well in the Rend Lake Fault System, but in other parts of the state, faults do not run parallel with property lines. For example, the Wabash Valley Faults of southeastern Illinois strike dominantly north-northeast, whereas the faults in the Cottage Grove Fault System of southern Illinois show a wide variety of orientations, northwesterly being the most common. Mines within these fault systems are usually designed so that entries and panels run parallel and perpendicular to the major faults.

Roof stability almost always suffers when mine openings follow faults or fracture zones; for this reason, mining directly along any fractures or faults should be avoided. The main entries close to major faults should not be advanced parallel with the faults. Large faults are invariably accompanied by numerous smaller parallel faults and fractures that appear in the entries. Often, the fractures are not easily seen on the fresh face, and only become apparent some time later, after the roof has already fallen.

The placement and angling of crosscuts is important in faulted areas. Figure 12 shows desirable and undesirable layouts of pillars for mining a set of headings through a series of small faults at right angles. Mining the usual square grid (fig. 12A) is a poor practice because faults can cut across several intersections and crosscuts, producing roof failure. One plan is to stagger the pillars (fig. 12B), which reduces the length of heading that can be affected by a single fault, and produces only three-way intersections, which are easier to support than four-way intersections. As an alternative, the crosscuts may be driven at an angle to the direction of the faults. Angling the crosscuts minimizes the span of mine opening that can be crossed by a fault. Possibly the best plan is to both stagger the pillars and angle the crosscuts (fig. 12C).

The same principles apply where entries cross a set of faults at an oblique angle (fig. 13). If the crosscuts are to be angled, they should be turned perpendicular to the faults rather than parallel to them. Staggering the crosscuts can be helpful, provided that care is taken to ensure that the faults do not cut across intersections.

Where faults are numerous or trend in many directions, as is the case with many nontectonic faults, mining along faults cannot be completely avoided. When this occurs, working crews should inspect the roof carefully for faults, and install extra supports as required. Several suggestions on bolting and timbering in faulted areas are provided in figure 7.

## TECTONIC FAULTS IN THE COAL FIELDS OF ILLINOIS

Several major systems or zones of tectonic faults occur in southern Illinois and significantly influence coal mining there (fig. 14). These include the Cottage Grove, Wabash Valley, and Rend Lake Fault Systems, the Shawneetown and Dowell Fault Zones, and the Centralia Fault. Smaller unnamed faults also are numerous in southern Illinois. Whereas no major tectonic faults are known in the coal-bearing strata north of Marion and Wabash Counties, a

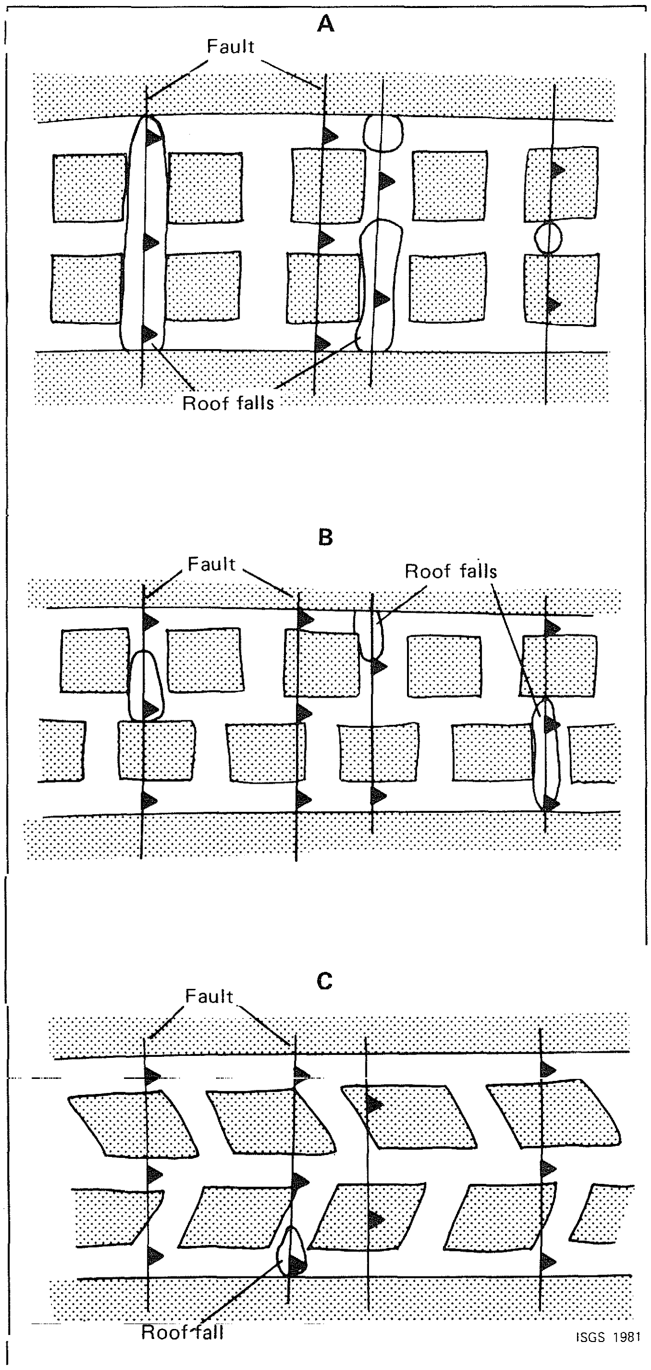



Figure 12. Placement and angling of crosscuts in a faulted area, where faults cross mine headings at right angles. (A) Pillars laid on square grid—large roof falls occur where faults follow crosscuts and intersections. (B) Staggered pillars—faults cannot follow mine openings for so long a distance, so large falls are less likely to occur than in A. (C) Staggered pillar and angled crosscuts—probably the best layout for this situation.

number of small faults of possible tectonic origin have been encountered.

**Cottage Grove Fault System**

More coal mining has occurred along the Cottage Grove Fault System than along any other fault system in Illinois. At the present, four underground mines and two surface mines are active within the faulted area, and large reserves of coal remain within the Cottage Grove Fault System in Saline, Williamson, and Jackson Counties.

The Cottage Grove Fault System extends westward from extreme eastern Saline County to at least as far as northwestern Jackson County—a distance of 75 miles (fig. 15). The width of the zone ranges from 2 to 10 miles and averages 4 to 5 miles. The largest fault of the system, designated as the master fault, trends west to northwest and has as much as 200 feet of vertical displacement. The direction of throw is not consistent: in some places the north side is downthrown, elsewhere the south side is downthrown. In several areas the master fault splits into two or more roughly parallel branches. The master fault apparently is discontinuous, and has little or no vertical offset in at least three places along its trend. The master fault consists of high-angle normal and reverse faults, probably with a large component of strike-slip movement (Nelson and Krausse, 1981).

Numerous northwest-trending subsidiary faults diverge from the north and south sides of the master fault and extend as far as 7 miles. Displacements range from a few inches to more than 50 feet and generally, but not always, increase toward the master fault. Most subsidiary faults are high-angle normal faults, but a few show reverse or oblique-slip movement. In most cases, large subsidiary faults are accompanied by numerous smaller parallel faults and fractures, often forming an en echelon arrangement.

In Saline County and extreme eastern Williamson County, numerous dikes of igneous rock accompany the subsidiary faults and present a hindrance to mining. The largest dikes are as much as 300 feet wide and 4 miles long, but most are smaller (Kay, ISGS unpublished field notes). The material forming the dikes is a very hard rock known as mica-peridotite, which is difficult to cut or blast. Frequently the coal on both sides of the dikes was altered to coke by the heat of the igneous rock that intruded the coal (Clegg, 1955; Clegg and Bradbury, 1956). The width of the coked zone ranges from a few inches to many feet. The coked coal is usually mineralized and has little value as a fuel.

Another factor complicating mining along the Cottage Grove Fault System is the presence of steep dips in the coal close to the master fault. Inclinations of 15° to 20° are common; in the abandoned Old Ben Mine No. 15 in Williamson County, the Herrin Coal reportedly dipped at 45° close to the fault. Several sizable blocks of coal have been left unmined because of severe dips. The steep tilts

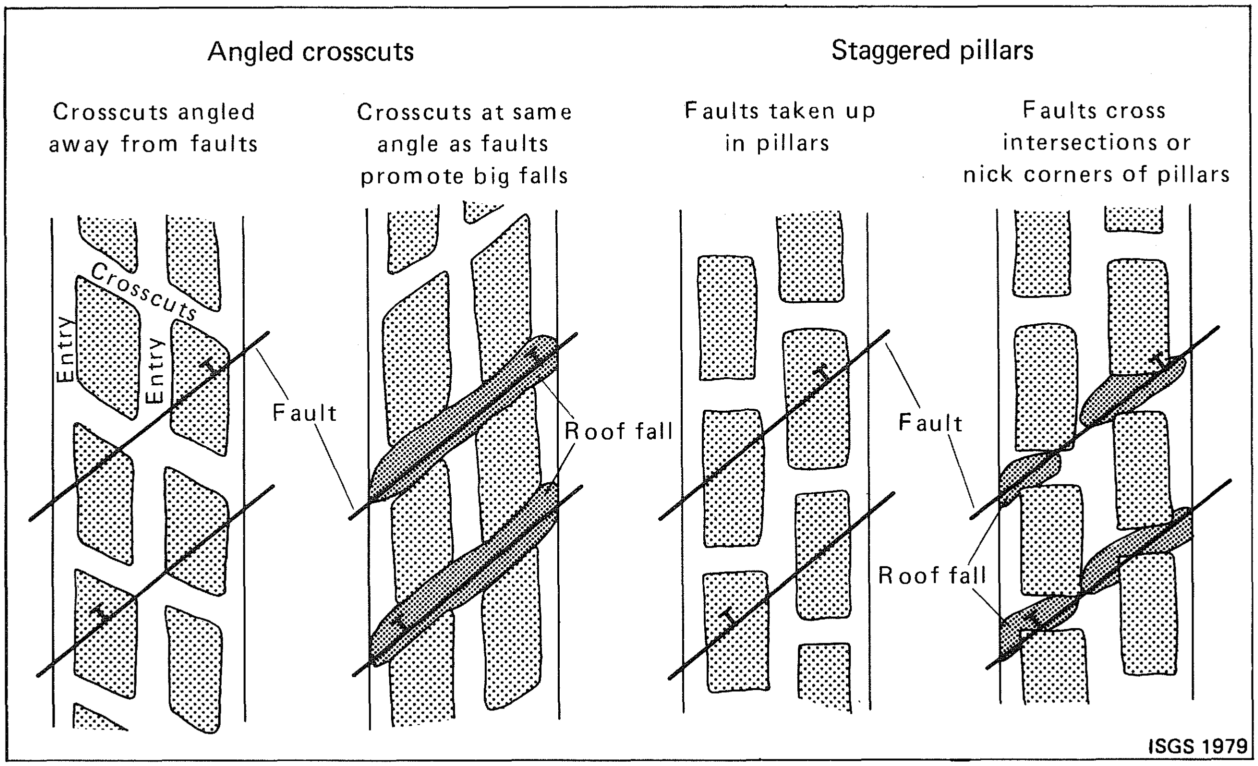



Figure 13. Placement and angling of crosscuts in faulted area where faults cross mine headings at oblique angles (from Krausse et al., 1979).

also make the calculation of reserves and projection of mining plans from drill-hole data a difficult task. Unless drill holes are closely spaced, one cannot be sure whether differences in elevation between adjacent holes indicate faults or merely inclined coal seams.

Disruptions to mining caused by faults can be minimized with careful exploration. Figure 16 illustrates an effective drilling program that prepared the way for mining through a segment of the master fault at the Orient No. 4 Mine in Williamson County.

**Wabash Valley Fault System**

The Wabash Valley Fault System lies in southeastern Illinois. Although large reserves of coal are known to exist in this area (particularly in the Springfield [No. 5] Coal Member), there has been little coal mining to date. The fault system is known primarily from drill-hole data and from exposures in the two underground mines currently active in the fault zone (Bristol and Treworgy, 1979).

The Wabash Valley Fault System in Illinois extends northeast from just north of the Shawneetown Fault Zone in Gallatin County to Mt. Carmel in Wabash County. The easternmost faults cross into Indiana. The system is about 60 miles long and about 15 miles wide, and consists of numerous subparallel faults that generally are en echelon. Twelve individual faults have been named (fig. 17).

The individual faults are up to several miles long and have vertical displacements ranging up to 480 feet in the Herrin (No. 6) Coal. All the known faults are high-angle normal faults, with angles of dip that range from 50° to 85°. Faulted strata exposed in the coal mines display little drag, but beds in the fault zone may be tilted. This fault zone consists of several large faults and numerous minor faults and fractures that weaken the roof. In the immediate vicinity of the fault zone, water seepage has never been observed; however, an increase in surface moisture was apparent.

The larger faults of the system can be located readily by coal-test drilling. At the Eagle No. 2 Mine of Peabody Coal Company in Gallatin County, drilling disclosed the presence of a large fault trending slightly east of north and lying just west of the slope bottom. The displacement on the fault, as indicated by drilling, decreased from about 80 feet west of the slope to about 20 feet at a point 3 miles farther north. A set of entries was driven across the fault where the throw was 20 feet to gain access to the coal west of the fault. Since the location and size of the fault were accurately known, mining through it was not difficult (fig. 18).

Individual faults of the Wabash Valley System typically overlap one another in en echelon fashion. The Mt. Carmel and New Harmony Faults overlap within the Wabash Mine of Amax Coal Company in Wabash County (fig. 19). Three east-trending cross-faults were encountered in the mine between the overlapping segments of the two large faults. The cross-faults were normal faults whose north sides were downthrown 6 to 8 feet on each fault.

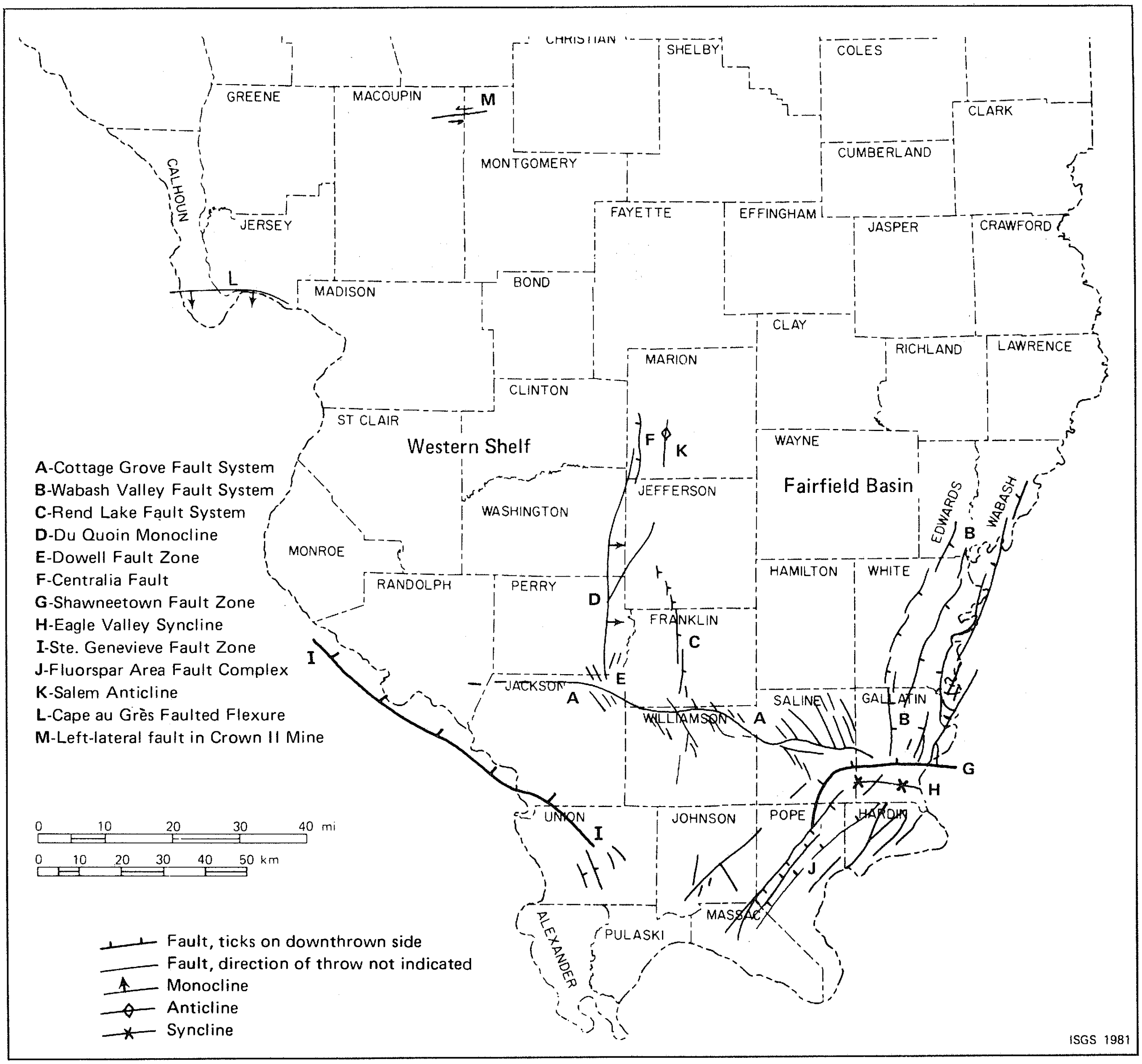



Figure 14. Faults and related structures in southern Illinois (compiled by Janis D. Treworgy, 1979).

Considerable difficulty was encountered as mining advanced through the cross-faults. Extensive grading was required to achieve a gradient compatible with the mining equipment. The efforts of grading the entries and handling and disposing of excessive amounts of gob resulted in a loss of production.

### Rend Lake Fault System

The Rend Lake Fault System (fig. 20), described in detail by Keys and Nelson (1980), occurs in an area where the Herrin (No. 6) Coal Member is being mined extensively and where mining is likely to continue. The fault system is well known from numerous exposures in underground mines, and locally from closely spaced test holes drilled by coal companies.

The Rend Lake Fault System extends northward from northern Williamson County into Jefferson County, where it curves toward the northwest. In the south it splits and dies out among the faults of the Cottage Grove System. To the north, the subsurface data indicate that the Rend Lake Fault System probably terminates on the flank of the Du Quoin Monocline. The known length of the fault system is about 24 miles and the width varies from roughly 100 feet to over half a mile.

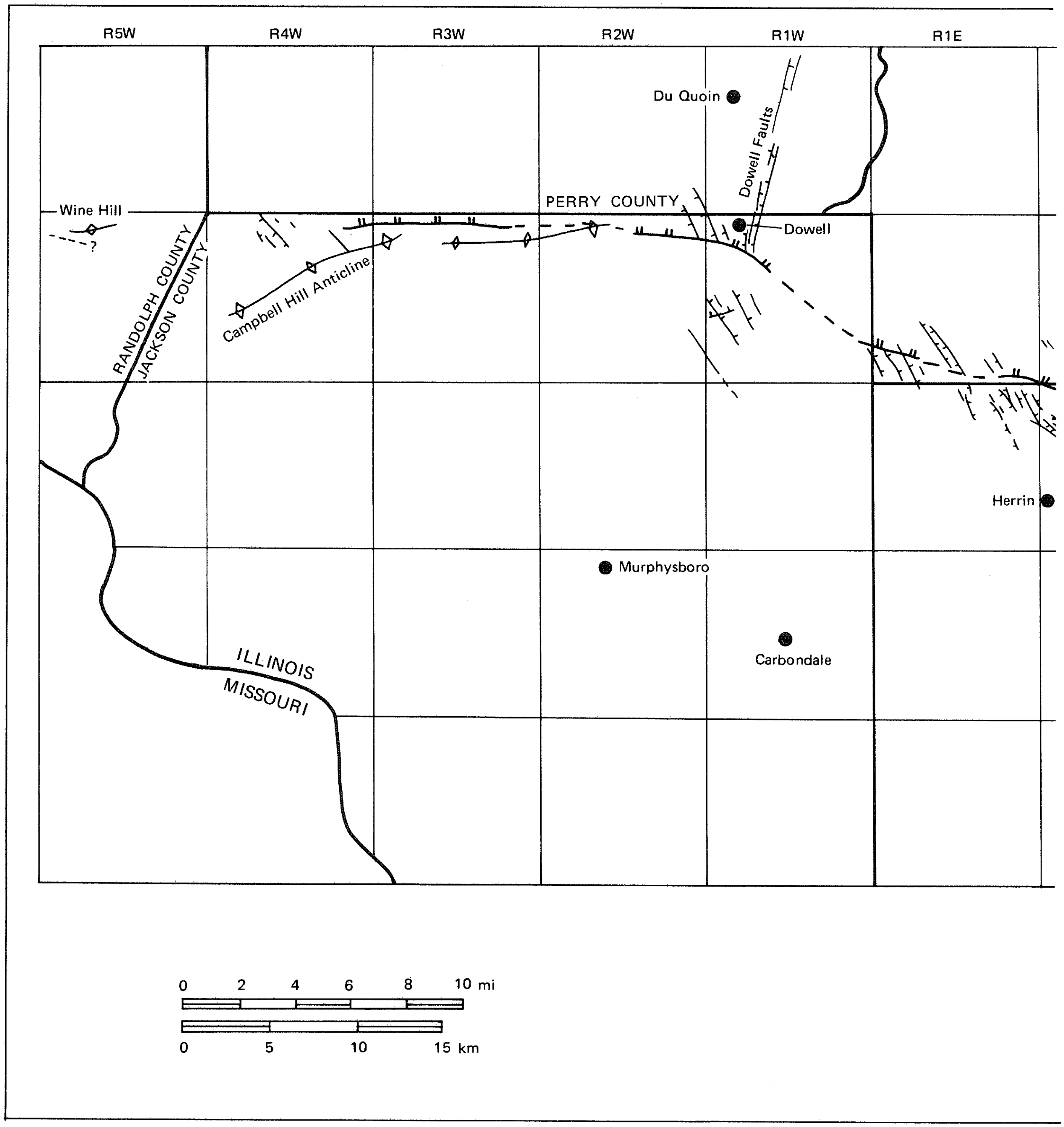
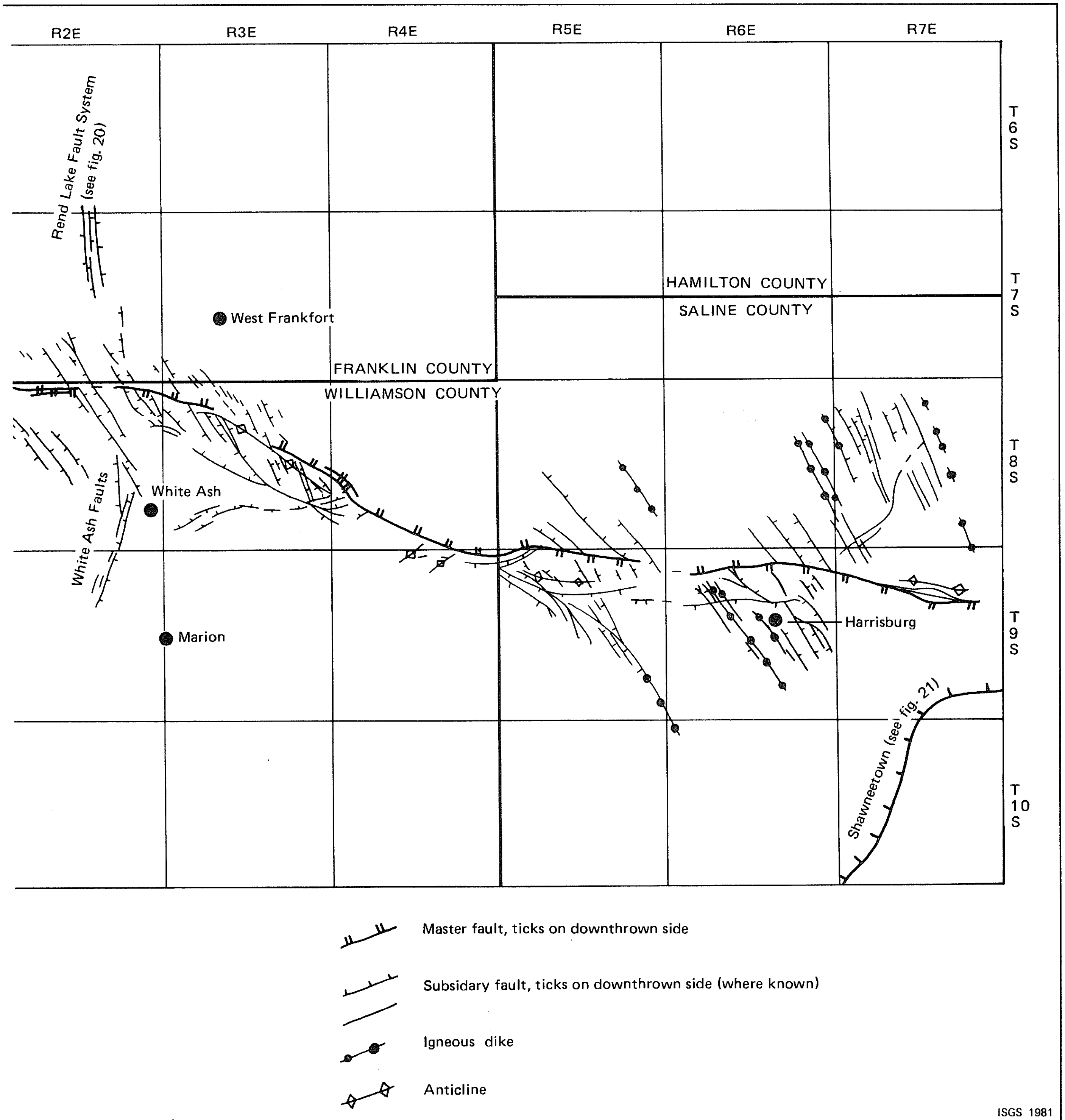



Figure 15. The Cottage Grove Fault System.



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 (see fig. 20)
West Frankfort
HAMILTON COUNTY
SALINE COUNTY
FRANKLIN COUNTY
WILLIAMSON COUNTY
White Ash
White Ash Faults
Marion
Harrisburg
Shawneetown (see fig. 21)
Master fault, ticks on downthrown side
Subsidary fault, ticks on downthrown side (where known)
Igneous dike
Anticline
ISGS 1981

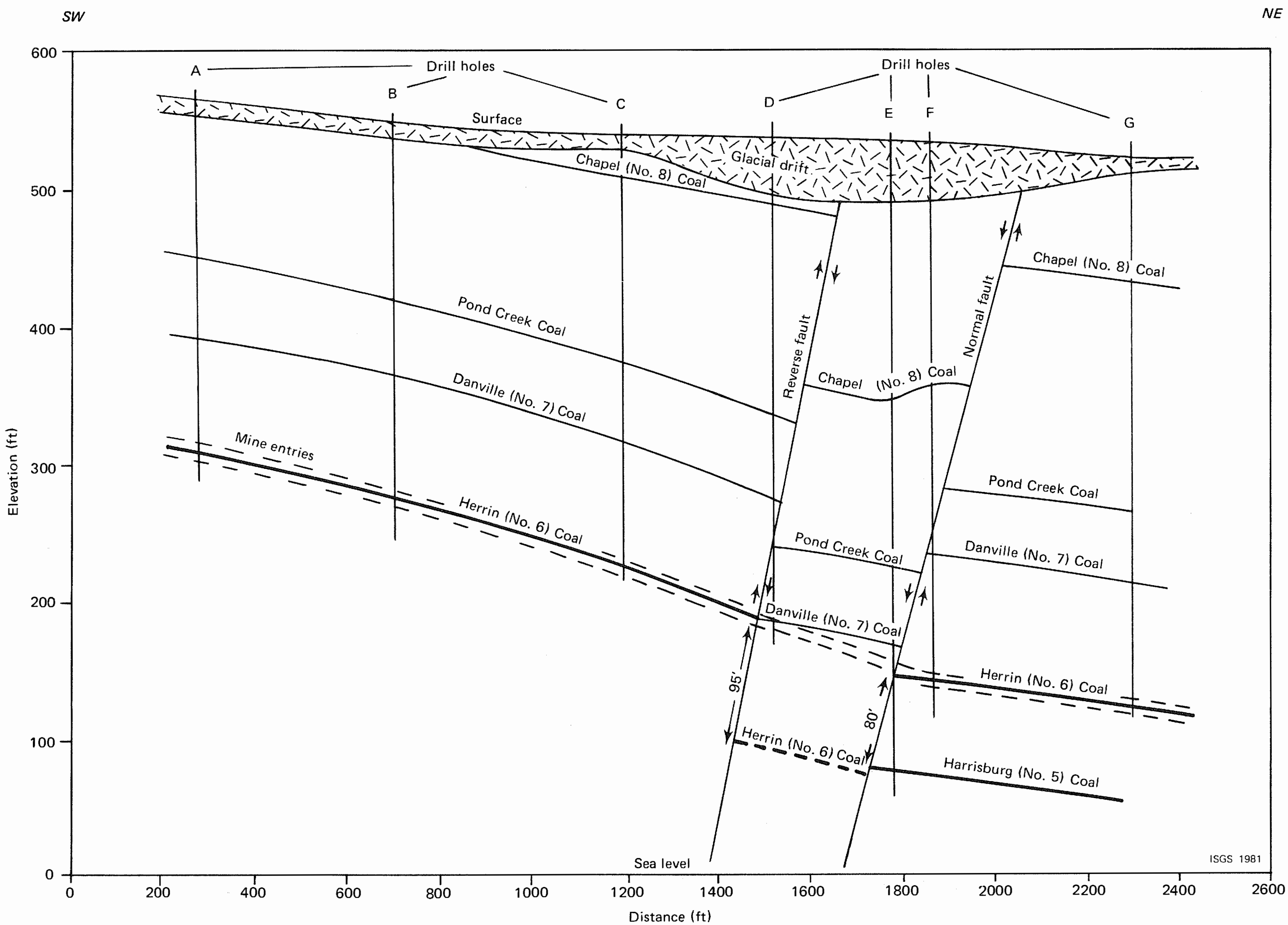



Figure 16. Cross section of part of the Cottage Grove Fault System in Orient No. 4 Mine, Freeman United Coal Mining Co., Williamson County, showing how faults were located by drilling. Drill hole D penetrated a reverse fault and cut the Danville (No. 7) Coal twice. Holes E and F went through a normal fault and showed a missing section. Accurate interpretation of the structure enabled the company to grade entries through the fault zone with minimum expense (adapted from Nelson and Krausse, 1981).

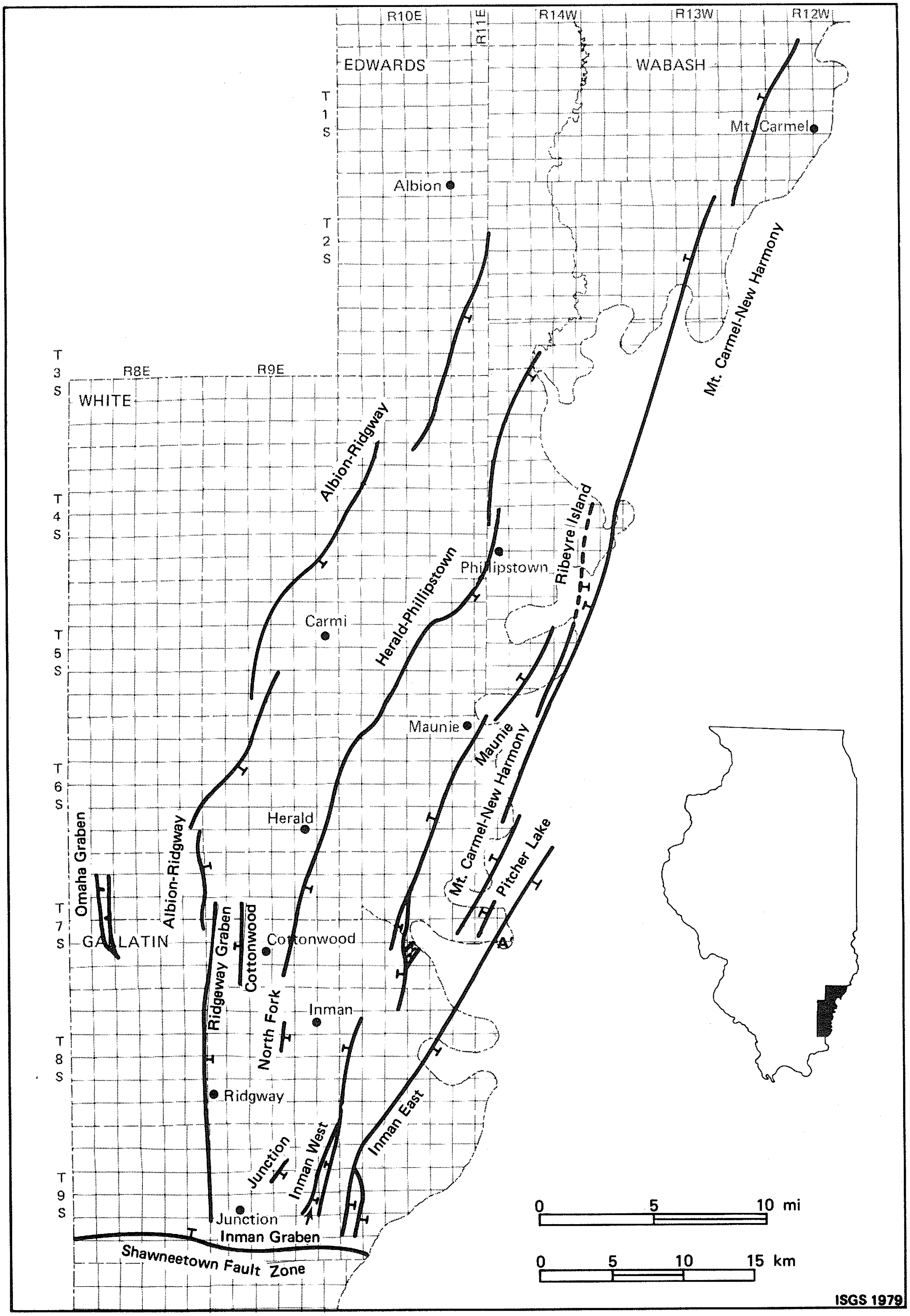



Figure 17. Major structures of the Wabash Valley Fault System (from Bristol and Treworgy, 1979; and Bristol, 1975). Faults are plotted as they occur in the Herrin (No. 6) Coal, and downthrown sides are indicated.

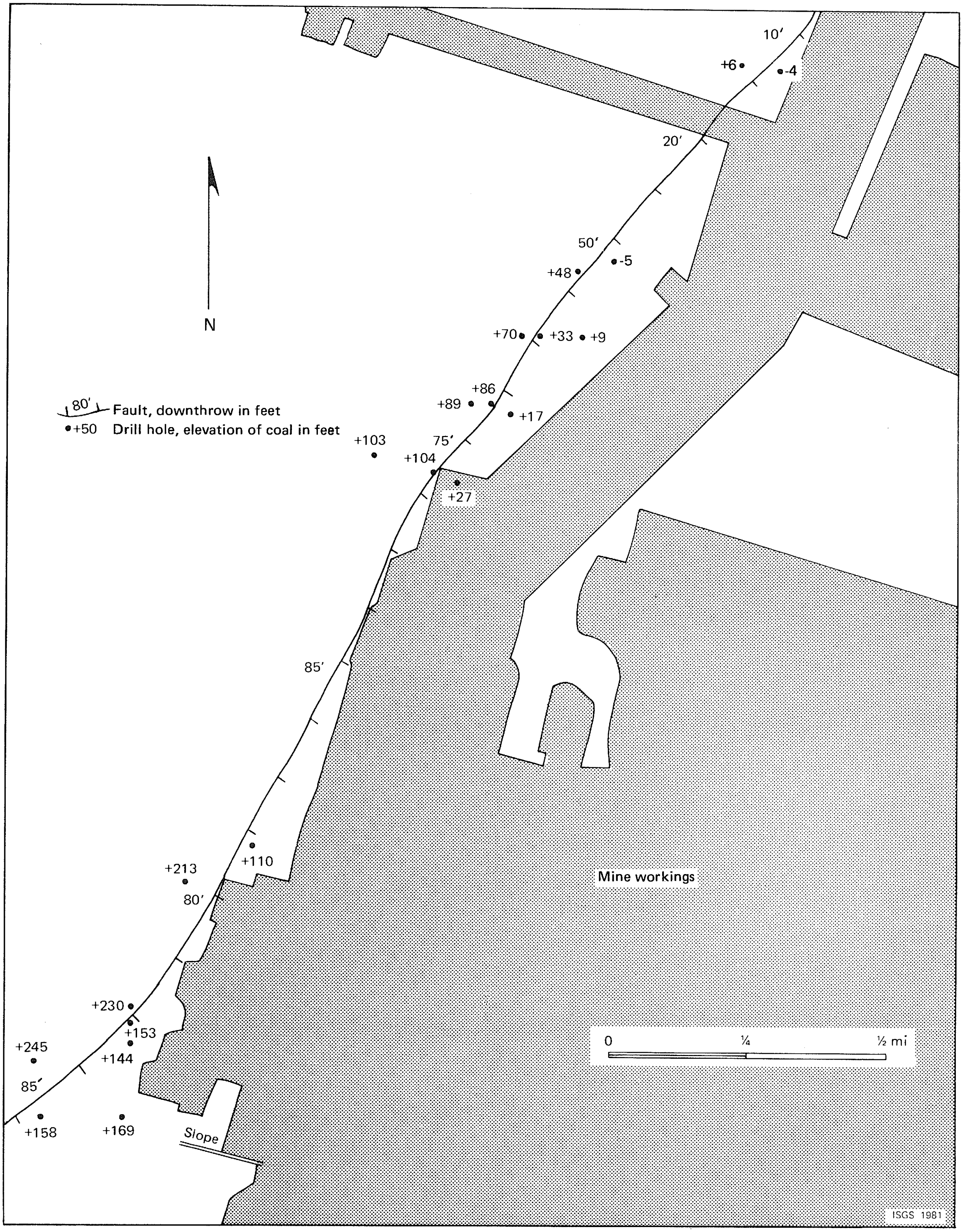



Figure 18. Portion of Eagle No. 2 Mine of Peabody Coal Company in Gallatin County. Mining layout was adjusted to accommodate a fault mapped from drill-hole data. Mine entries were driven across the fault near its north end, where throw diminishes.

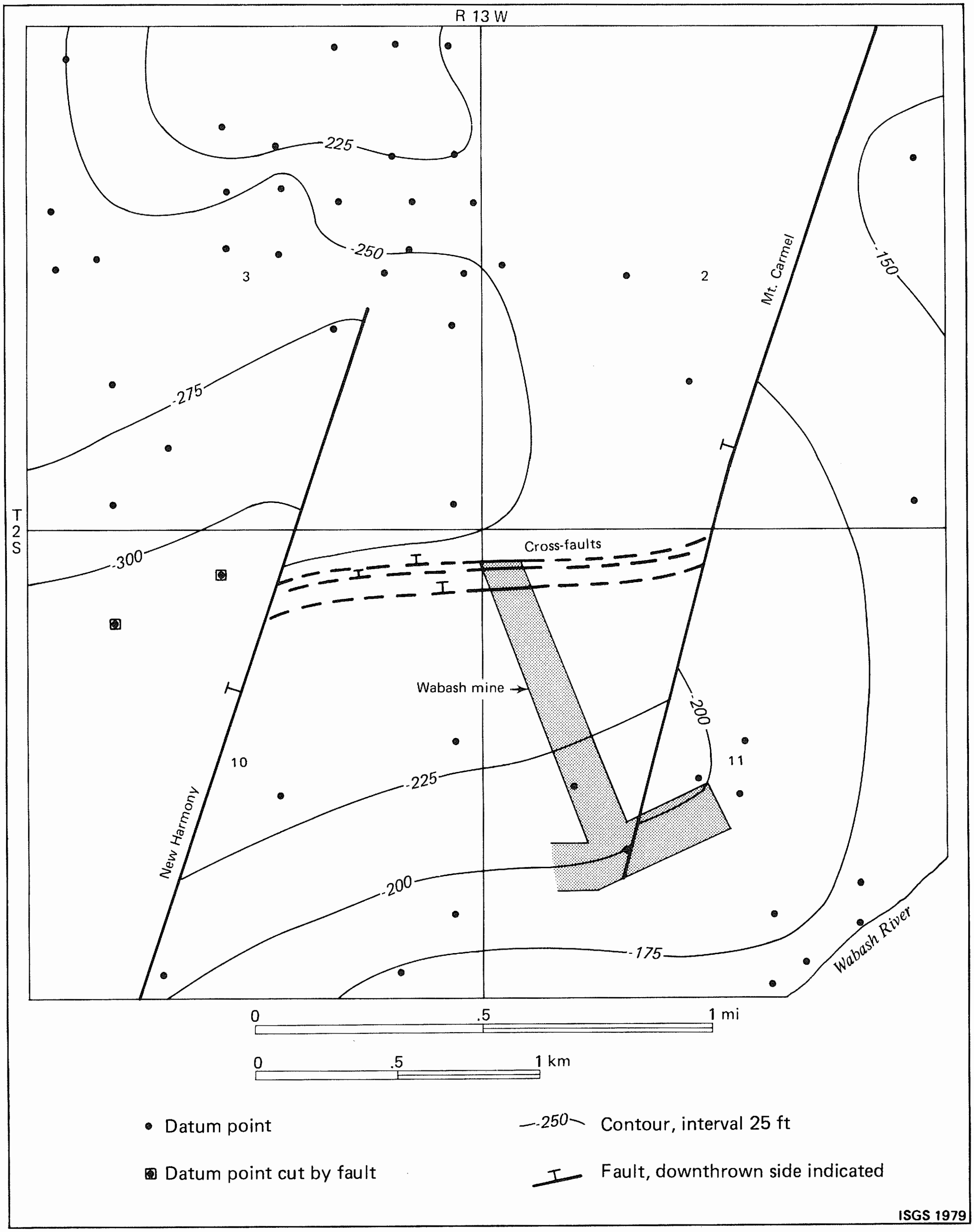



Figure 19. Detailed structure of the top of the Herrin (No. 6) Coal in Wabash County, illustrating the presence of cross faults, as observed in the Wabash Mine of Amax Coal Company in the overlapping area of two major fault segments of the Mt. Carmel-New Harmony Fault. Datum mean sea level (from Bristol and Treworgy, 1979).

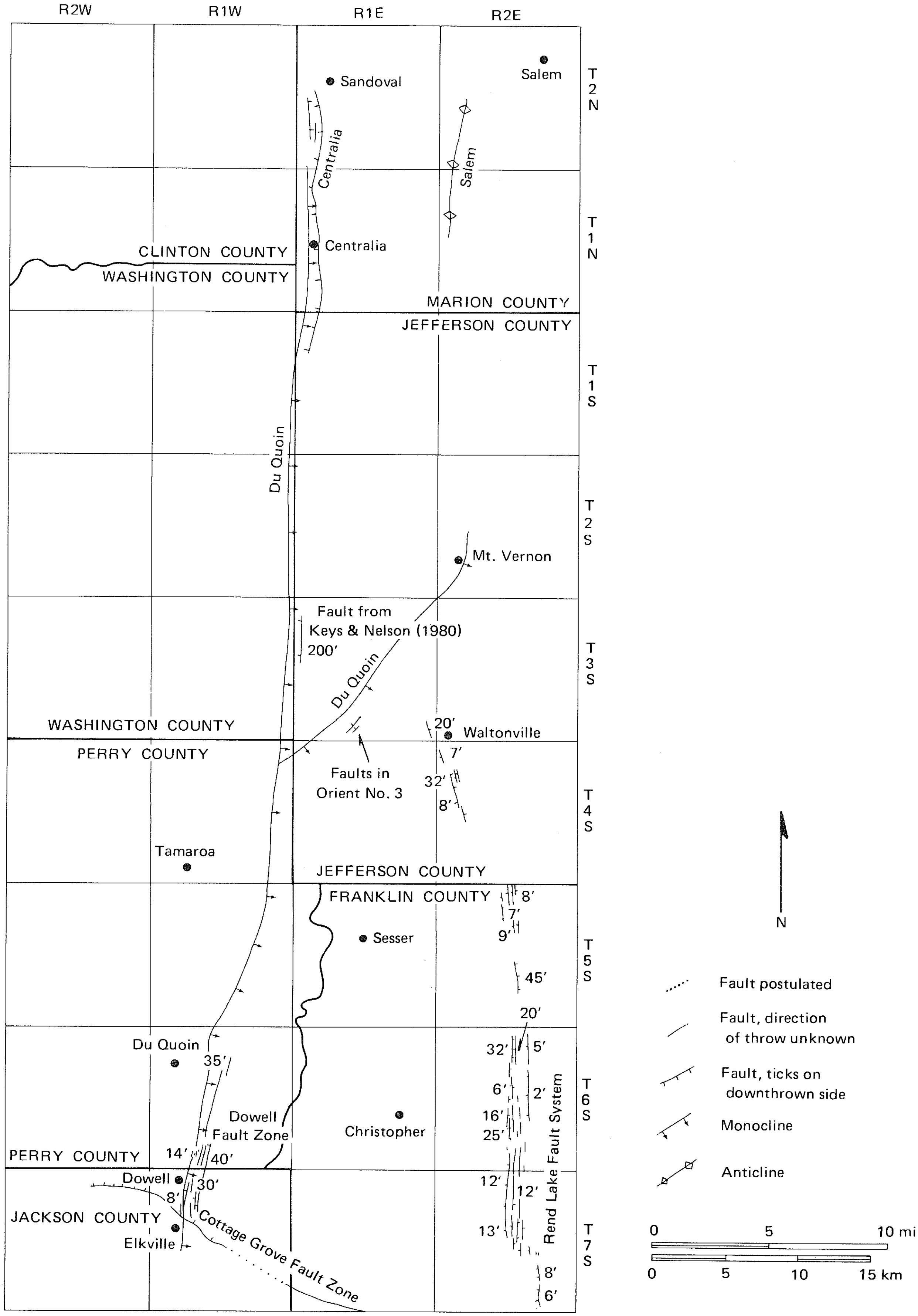



Figure 20. Rend Lake Fault System, Du Quoin Monocline, Dowell Fault Zone, Centralia Fault, and related structures (throw of some faults shown in feet).

Individual faults of the system are nearly all normal faults, although a few small reverse faults have been noted. The longest faults can be traced for 3 or 4 miles, but most are much shorter. The largest known displacement on a single fault is 45 feet, at Old Ben Mine No. 26. No consistent direction of displacement is evident; the throws are about equally divided in direction between down to the east and down to the west.

An en echelon arrangement of faults is very common, especially in Jefferson County, where the strike of the system curves from northerly to northwesterly. Many of the larger faults in figure 20 probably consist of several closely spaced staggered faults that cannot be distinguished at this scale.

In general, the wider the fault system is, the greater the number of faults and the smaller their displacement. For example, in Old Ben Mine No. 26, a single fault with 45 feet of throw was encountered, accompanied by only a few fractures of insignificant displacement. Extensive grading of belt and track entries was required to cross the fault. In contrast, northward in Old Ben Mine No. 21, the fault system is approximately half a mile wide and includes dozens of faults having displacements ranging from a few inches to a maximum of 10 feet. Little grading was necessary in Mine No. 21, but extra measures of roof control were needed to support the fractured rock.

Projecting the Rend Lake Fault System into unmined areas is relatively easy because the system is narrow and fairly straight. Locating individual faults by drilling, however, can be difficult because of the generally small displacements.

### Du Quoin Monocline, Dowell Fault Zone, and Centralia Fault

The Du Quoin Monocline, the Dowell Fault Zone, and the Centralia Fault (fig. 20) extend northward from northeastern Jackson County as far as southwestern Marion County. These three structures are closely related to each other, and for the purposes of this report they are regarded as a continuous structural entity.

The Du Quoin Monocline is a large steplike flexure whose eastern side is downdropped. The Herrin Coal drops as much as 300 feet within a mile across the monocline. The average gradient on the east-dipping flank is about 2 to 3 percent; only locally does it exceed 5 percent. Several underground mines in southeastern Perry County formerly operated on the flank of the monocline and apparently experienced no difficulties from the dip of the coal.

The monocline, as mapped in the Herrin Coal, splits into two branches near the southeastern corner of Washington County. The western branch continues due northward and gradually dissipates in western Marion County near Sandoval. The eastern segment strikes northeastward, then returns to a northerly heading and bears toward the Salem Anticline (Keys and Nelson, 1980).

The Dowell Fault Zone is a series of faults that lies along the eastern flank of the Du Quoin Monocline in northeastern Jackson and southeastern Perry Counties. The fault zone is named for the village of Dowell (Nelson and Krausse, 1981) and is known from exposures in several abandoned underground mines, as first described by Fisher (1925). This fault zone consists of high-angle normal faults with displacements of up to 40 feet. Along most of the faults the western block is downthrown opposite the dip of the Du Quoin Monocline; however, on some of the faults the eastern block is downthrown. The faults have not been traced north of the mined-out area in Sec. 10, T. 6 S., R. 1 W., but they are small enough to be difficult to detect by drilling.

The Centralia Fault is known from exposures in underground mines and from subsurface data near Centralia, in Marion County. Like the Dowell Fault Zone, the Centralia Fault strikes northward and follows the eastern flank of the Du Quoin Monocline. The Centralia Fault consists of one or more high-angle normal faults whose major displacements are down to the west. The maximum vertical separation, as shown by data from drilling, may be as much as 200 feet (Brownfield, 1954).

Keys and Nelson (1980) mapped a fault directly in line with the Centralia Fault but farther south, in T. 3 S., R. 1 E., Jefferson County. This fault, as indicated by data from drill holes, has a displacement of approximately 200 feet down to the west in the Shoal Creek Limestone Member (which lies approximately 350 feet above the Herrin Coal). The Herrin Coal is absent at this location, having been replaced by sandstone in the Walshville channel (Smith and Stall, 1975).

A series of small faults has been encountered in the Orient No. 3 Mine in Sec. 33, T. 3 S., R. 1 E., Jefferson County, where the Herrin Coal is being mined along the northeast-trending branch of the Du Quoin Monocline. The small faults strike N 15° to 35° E, roughly parallel with the contours of the monocline. All are high-angle normal faults that lie parallel to each other or are staggered en echelon. Their displacements are so small (less than 1 foot) that miners did not even notice the faults initially. However, the presence of these faults signals that possibly larger faults will be found elsewhere along this northeast-trending branch of the monocline.

In summary, high-angle normal faults have been encountered wherever coal has been mined along the east flank of the Du Quoin Monocline. The close association of faults with the monocline indicates that the two are genetically related and suggests that similar faults exist in the unmined areas along the monocline. Specifically, faults can be expected along a continuous line from Du Quoin to Centralia. The main zone of faulting would probably lie near the foot of the monocline and the major displacements would be down to the west. Similarly, faults may also occur along the northeast-trending segment of the monocline in Jefferson County, and northward toward Salem.

**The Shawneetown Fault Zone**

Although the Shawneetown Fault has not yet been encountered in coal mining operations, the fault zone is described here because of its importance in the structural framework of southern Illinois (fig. 21). The Shawneetown Fault Zone joins a major system of faults known as the Rough Creek Fault System in western Kentucky. From a point just south of Old Shawneetown in Gallatin County, the fault zone strikes westward for about 15 miles into eastern Saline County, where it turns abruptly toward the southwest. The Shawneetown has the largest displacement of any known fault zone in Illinois; the strata north of the fault zone are downthrown more than 1000 feet in places, and displacement of individual faults may be as great as 3500 feet (Cote, Reinertsen, and Killey, 1969). The fault zone is prominently expressed at the surface by the northern scarp of the Shawnee Hills. The resistant lower Pennsylvanian sandstones and Mississippian limestones south of the fault zone rise above the more easily eroded middle Pennsylvanian shales north of the fault zone.

**Faults in the Eagle Valley Syncline**

The Eagle Valley Syncline is an east-trending downwarp of the coal-bearing strata south of the Shawneetown Fault Zone in Gallatin County (fig. 21). The structure extends into western Kentucky, where it is known as the Moorman Syncline. In Illinois the syncline is roughly 15 miles long and 6 miles wide at its broadest point. Several coal seams have been mined in the Eagle Valley Syncline. Most mining has been by surface methods, but some underground coal has been mined, mainly in the Springfield (No. 5) Coal.

Many northeast-trending faults of large displacement have been mapped in the fluorspar-mining district immediately south of the Eagle Valley Syncline. At least one of these faults, the Grindstaff Fault (fig. 21), extends northward into the syncline. As shown in a map compiled by Butts (1925), the Grindstaff Fault is almost 7 miles long and follows a heading of N 25°E across the entire syncline. Strata southeast of the fault are downthrown as much as 100 feet in places. Butts also mapped several smaller northeast-trending faults, but he did not show these faults in detail.

A series of faults has been encountered recently in surface (strip) mines of Peabody Coal Company, in the northern part of T. 10 S., R. 8 E., Gallatin County. The faults trend generally east-west and dip at shallow angles that are usually less than 45°. Some of the faults are nearly horizontal (e.g., bedding-plane faults). Normal faults are the most common type of faults here; they have throws ranging from 10 to 30 feet or more. These normal faults hinder mining because the coal is usually too deep for economic recovery on the downthrown side. Thrust faults (low-angle reverse faults) are also present in the strip mines, and some have displacements of more than 100 feet. Locally, the coal seam is thrust over itself and in effect doubled in the pit (fig. 9). In one instance, the coal seam was tripled where two thrust faults were present.

The origin of these faults and their relationship to other structures in Eagle Valley is not certain. They are eroded at the base of a Pennsylvanian channel-fill sandstone on the highwall and must have formed during Pennsylvanian time soon after the Herrin Coal was deposited. Probably they are not tectonic faults, but rather are the result of slumping of partially lithified sediments.

**Faults in southeastern Saline County**

A number of northeast-trending faults have been observed in strip mines in southeastern Saline County, mainly in T. 10 S., R. 6 E. Little is known of their extent and distribution because there are few exposures. The faults are high-angle normal faults that display little drag. Displacements on many of the faults exceed 50 feet and in some cases may reach 100 feet or more. About half of the faults dip to the northwest and the other half dip to the southeast.

The best mapped line of faulting crosses the J. J. Track Mine (Brown Brothers Excavating) in Sec. 19, 20, and 30, T. 10 S., R. 6 E., and the Jader Fuel Co. Mine No. 1 in Sec. 10 (fig. 21) These faults are directly in line with the McCormick Fault, a large fault that has been mapped from surface exposures to the southwest in Johnson and Pope Counties.

A different style of faulting has been encountered in several underground mines in southern Saline and southeastern Williamson Counties. The faults in these mines consist of bundles of north-trending, low-angle reverse (thrust) faults. The coal and associated strata seldom show more than a few feet of heave, but these faults are highly detrimental to roof stability. They have created such difficult roof conditions that in several cases no attempt was made to mine through them. The low-angle slickensided surfaces of these faults create easy planes of separation for large masses of roof rock. These problems are often compounded by the water entering along the fractured zones, which softens the shales. Because of the small displacements of the faults, they cannot be projected by drilling, and are not always recognized even when encountered during mining.

**Other tectonic faults in Illinois**

Because of the degree of control available from oil-test borings in most of Illinois, it seems unlikely that any fault systems of the magnitude of the Wabash Valley or Cottage Grove Fault Systems still remain undiscovered. Nevertheless, many smaller tectonic faults probably exist in the Illinois Basin, and may be encountered in future mining operations.

A number of northwest-trending high-angle normal faults have been observed in underground mines in Christian,

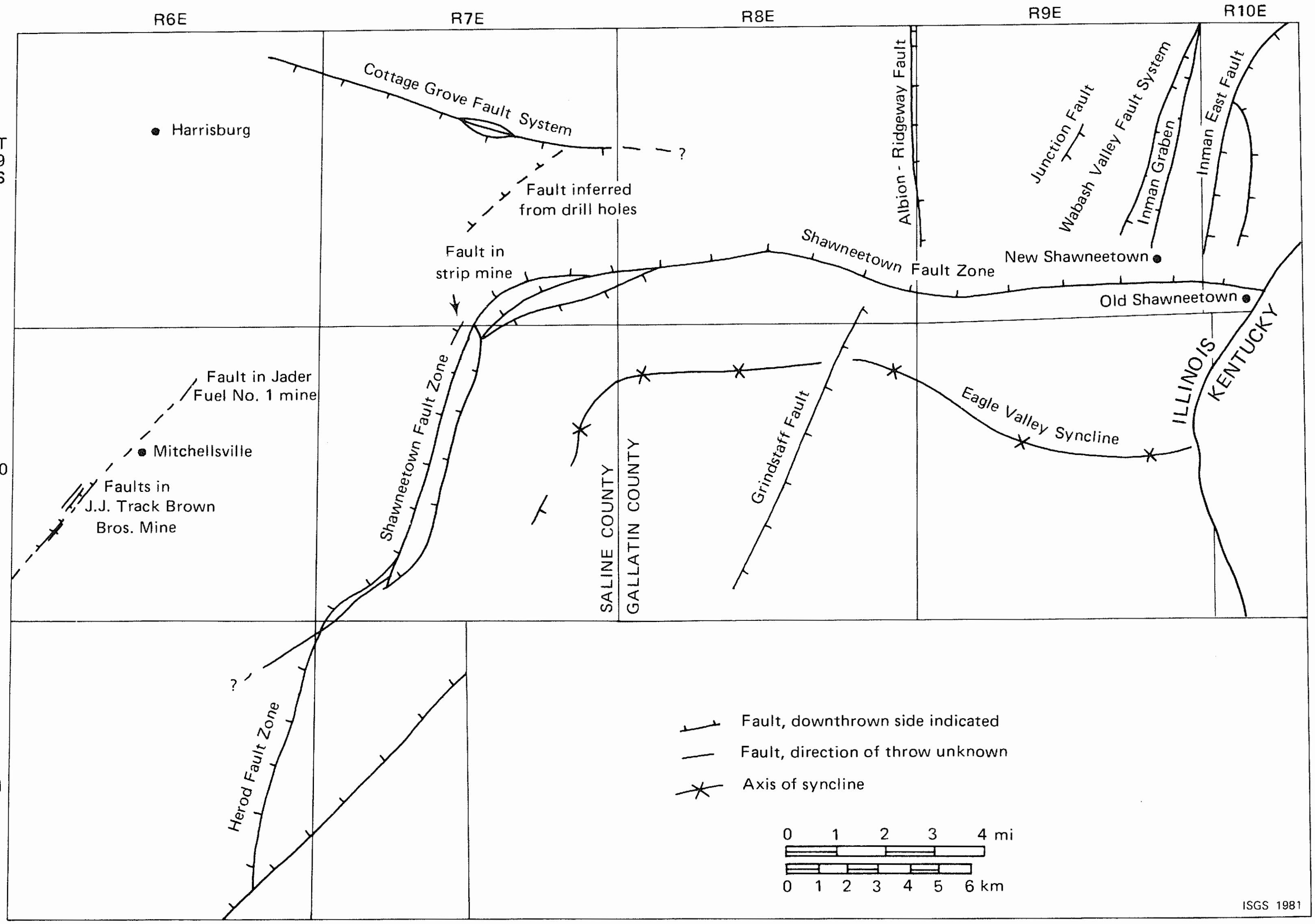



Figure 21. Shawneetown Fault Zone, Eagle Valley Syncline, and associated structures (from Smith [1957], Baxter et al., [1967], and personal observation of author).

Macoupin, Montgomery, and Sangamon Counties of central Illinois. The faults are very straight along strike and show both northeasterly and southwesterly dips. One such fault in Christian County extends at least 6 miles through two mines and shows as much as 15 feet of throw in the Herrin (No. 6) Coal. The continuation of the fault beyond the mined-out area has been confirmed both by drilling and by high-resolution seismic surveys. Another fault in the Crown II Mine of Freeman United Coal Mining Company, in northeastern Macoupin County, has as much as 7 feet of throw and continues for 3,000 feet; neither end has been found. Similar faults of smaller displacement were mapped at the Crown I Mine, about 5 miles east of Crown II Mine in Montgomery County. Yet another northwest-trending normal fault was reported by Simon and Harrison (ISGS, unpublished field notes) in the Farrand Coal Company's mine on the east side of Springfield, Sangamon County. The coal was downthrown 14 feet to the southwest along this fault.

The presence of so many similar faults over so large a region indicates that the faults are the product of regional tectonic stresses; however, the overall distribution of the faults and their relationship to the regional structure have not yet been determined.

A different type of fault was reported by Eadie and Gartner (ISGS, unpublished field notes) at the Eddy Coal Company mine north of Springfield. The notes describe a faulted zone trending north-south and dipping 60° to the west. Eadie and Gartner wrote that the fault had 12 to 18 inches of strike-slip displacement; how they determined this is not mentioned. Faults of this type were reported to occur frequently on the west side of the mine and apparently were randomly distributed.

The best documented example of a small tectonic fault in central Illinois is the zone of strike-slip faulting recently identified in the Crown II mine of Freeman United Coal Mining Company (fig. 22). The coal in this mine is flat lying, and the strike-slip fault shows left-lateral displacement. It runs east-west and shows a maximum dip-slip of about 4 feet. The strike-slip, as indicated by the offsetting of lenses of shale above the coal, varies from about 15 to about 70 feet. Innumerable northeast-trending extensional fractures, which tend to increase in number and intensity toward the fault, are associated with the fault. These fractures cause local problems of roof instability and admit water into the mine. Thus this fault has a structure similar to that of the Cottage Grove Fault System (fig. 15), but is much smaller in scale and has the opposite direction of displacement (Nelson and Nance, 1980).

This fault at Crown II has been mapped along strike for about 2 miles, but its termination at either end has not been found. According to ISGS unpublished mine notes, an area of intense fracturing similar to that observed along the fault in Crown II was encountered in the extreme northern part of the now abandoned Crown I Mine. The fractures in Crown I lie directly on line with the fault in Crown II and are about 5 miles to the east. These facts imply that the fault is continuous between the two mines, and thus is at least 7 miles long.

Although the fault in Crown II is fairly long and has significant effects on mining, the coal seam shows only small vertical offset in most places. Perhaps other faults of this nature have been encountered in underground workings and were not recognized.

Possibly, faults may exist in unmined areas of the Illinois Basin. Faults are likely to be found in association with any of the large folds (anticlines and synclines) in the basin. We have already noted the occurrence of faults along the Du Quoin Monocline. Other structures that may have associated faults include the La Salle and Clay City Anticlinal Belts, and the Salem and Louden Anticlines (fig. 23).

## NONTECTONIC FAULTS IN COAL-BEARING STRATA OF ILLINOIS

Tectonic faults in Illinois and elsewhere are confined to well-defined zones or systems, and often can be mapped with a fair degree of confidence before mining begins. In contrast, nontectonic faults are present throughout the coal-bearing rocks of Illinois, and probably no mine is free of them. The small size and lack of continuity of these faults makes them difficult or impossible to detect during exploration; nevertheless, their occurrence and distribution are not random. Various types of nontectonic faults in Illinois are closely restricted by area, and, on a small scale, their distribution is often highly dependent upon local variations in the coal seam or roof rock. In recent years the ISGS has become actively involved in mapping nontectonic faults in underground mines and learning their geologic affinities. Results of this work have been presented by Krausse et al. (1979), Krausse and Damberger (in preparation), and Nelson and Ledvina (1979).

Nontectonic faults can be divided into a number of categories, based on their form and presumed modes of origin. These include compactional faults, clay-dike faults, and gravitational slumps and slides.

### Compactional faults

Most sediments undergo considerable compaction as they are changed into rock, and different sediments compact at widely varying rates and amounts. Plant matter that becomes coal is assumed to undergo at least a tenfold reduction in thickness during coalification. Muds commonly lose 50 percent or more of their volume when they become shale; on the other hand, well-sorted sand undergoes little compaction. Apparently, therefore, any irregularities in a sedimentary sequence will produce stresses during compaction, and these stresses are often relieved by the development of compactional faults.

Small compactional faults are encountered in every mine and are known to miners as "slips." Slips may have

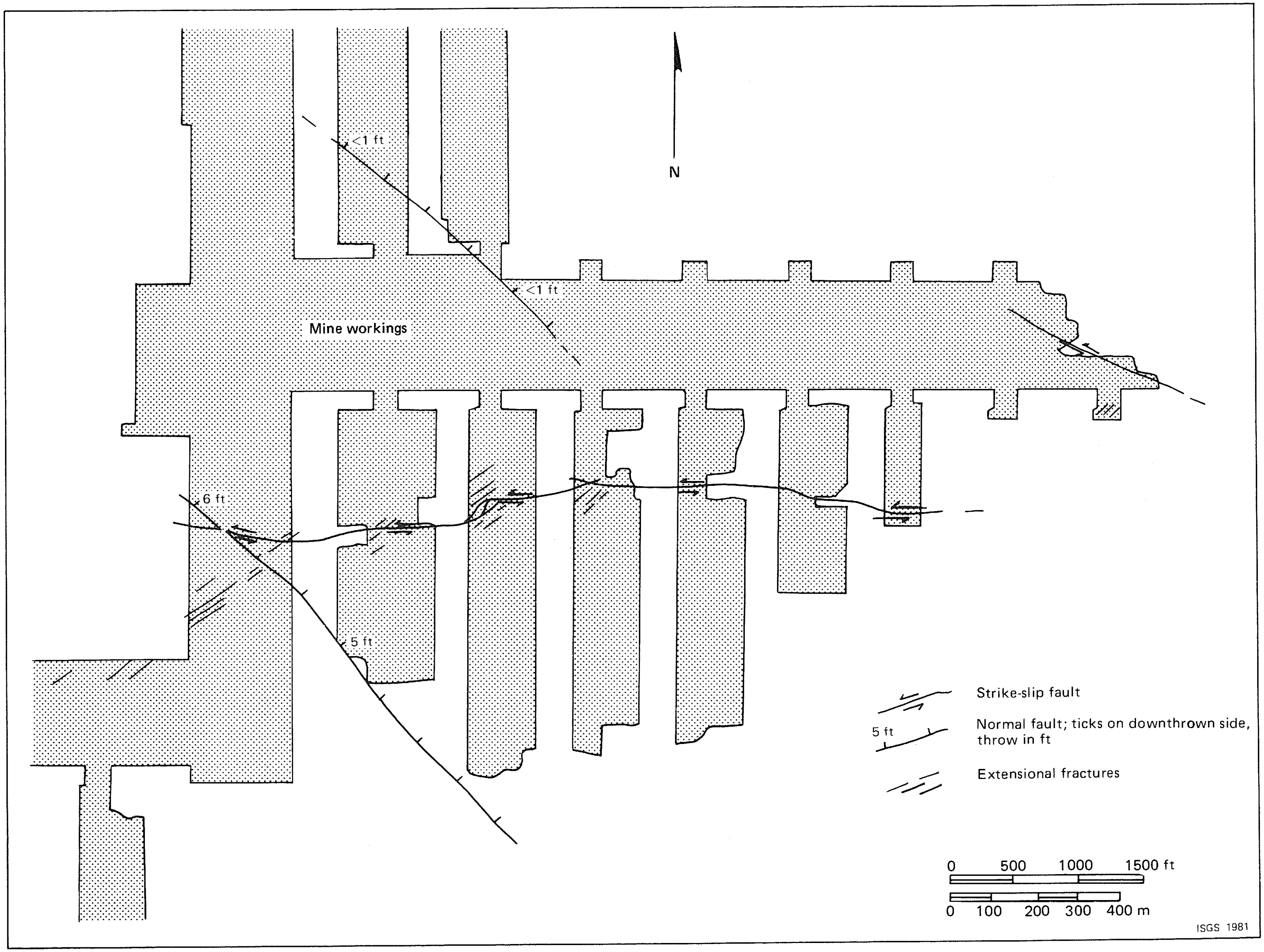



Figure 22. Crown II Mine of Freeman United Coal Mining Co. Faults and related features are shown.

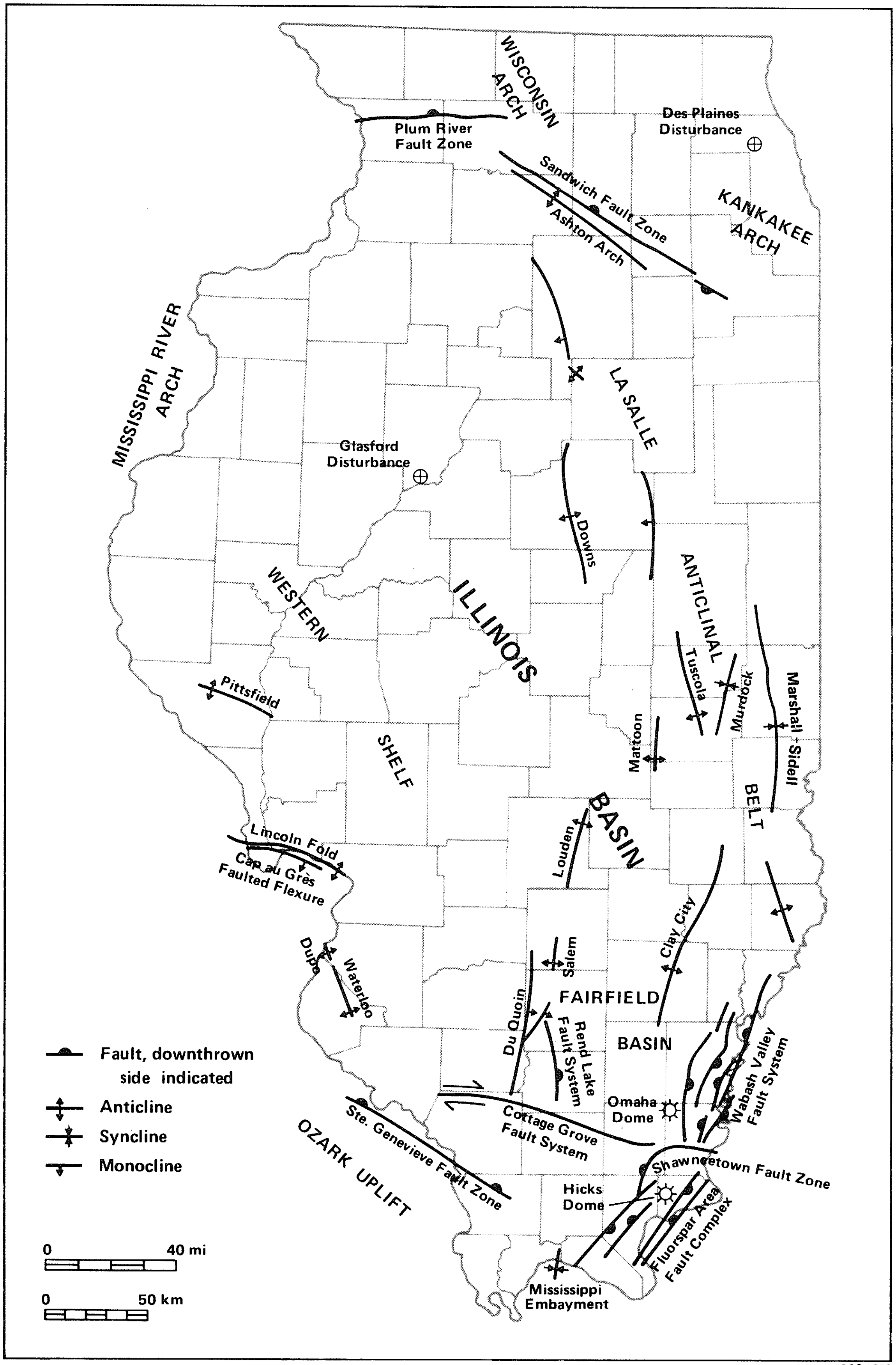



Figure 23. Geologic structures of Illinois (compiled by Janis D. Treworgy, 1979).

little or no apparent displacement but are well-known hazards because their slickensided surfaces allow separation of pieces of roof.

The presence of compactional faults often can be related to an irregularity in the coal or the overlying rocks; for example, the large concretions in black shale are usually surrounded by a set of faults (fig. 24). Concretions are composed of hard rock—usually limestone, pyrite, or siderite—that grew in place within the black mud before it was compacted into shale. As the mud compacted around this hard body, the mud yielded partially by folding and partially by slippage around the edges of the concretion.

Another common setting for compactional faults is within "rolls" (fig. 25), which are protusions of sediment from the roof into the top of a coal seam. Rolls, which are common in areas where coal seams are overlain by gray shale, siltstone, or sandstone (Krausse et al., 1979), were formed before the coal and surrounding sediments were fully lithified. During compaction the peat was deformed around the lens-shaped body of sediment in the roll, in the same manner as black shale is deformed around a concretion. Many of the faults associated with rolls are large: hundreds of feet long with up to 3 feet or more of throw. The larger the roll, the larger the faults are likely to be. The faults usually dip away from the center of the roll and contribute to roof falls (Krausse et al., 1979).

Compactional faults are likely to be found wherever the rocks above the coal change abruptly in thickness or lithology. Channel sandstones above the coal are commonly accompanied by faults, as are areas where the immediate roof changes from shale to limestone, or from gray shale to black fissile shale. Faults in such areas normally strike parallel to the boundaries between the two types of rock. Mapping the lithologies and thicknesses of the roof strata may facilitate projecting the locations of faults a short distance ahead of the working face.

A common danger to miners is the "hidden slip," which is a fault that penetrates the roof but not the coal. Many hidden faults, however, can be detected by the careful observer because there are clues that indicate their presence. One of the best clues is a "goat beard" in the top coal or on the rib. A goat beard is a bundle of small vertical extensional fractures that is usually filled with calcite, pyrite, or other minerals (fig. 26). Goat beards occur at the lower ends of many compactional faults, clay-dike faults, and other normal faults. Another clue to a hidden fault is an abrupt deviation of cleat in the top coal. Cleat is normally straight and continuous, but frequently becomes curved or is interrupted near faults or other irregularities in the coal.

Leaving top coal in mine openings can be a hindrance to the detection of faults. Top coal can conceal both the fault and the condition (such as a change in the type of rock forming the roof) that led to the formation of the fault.

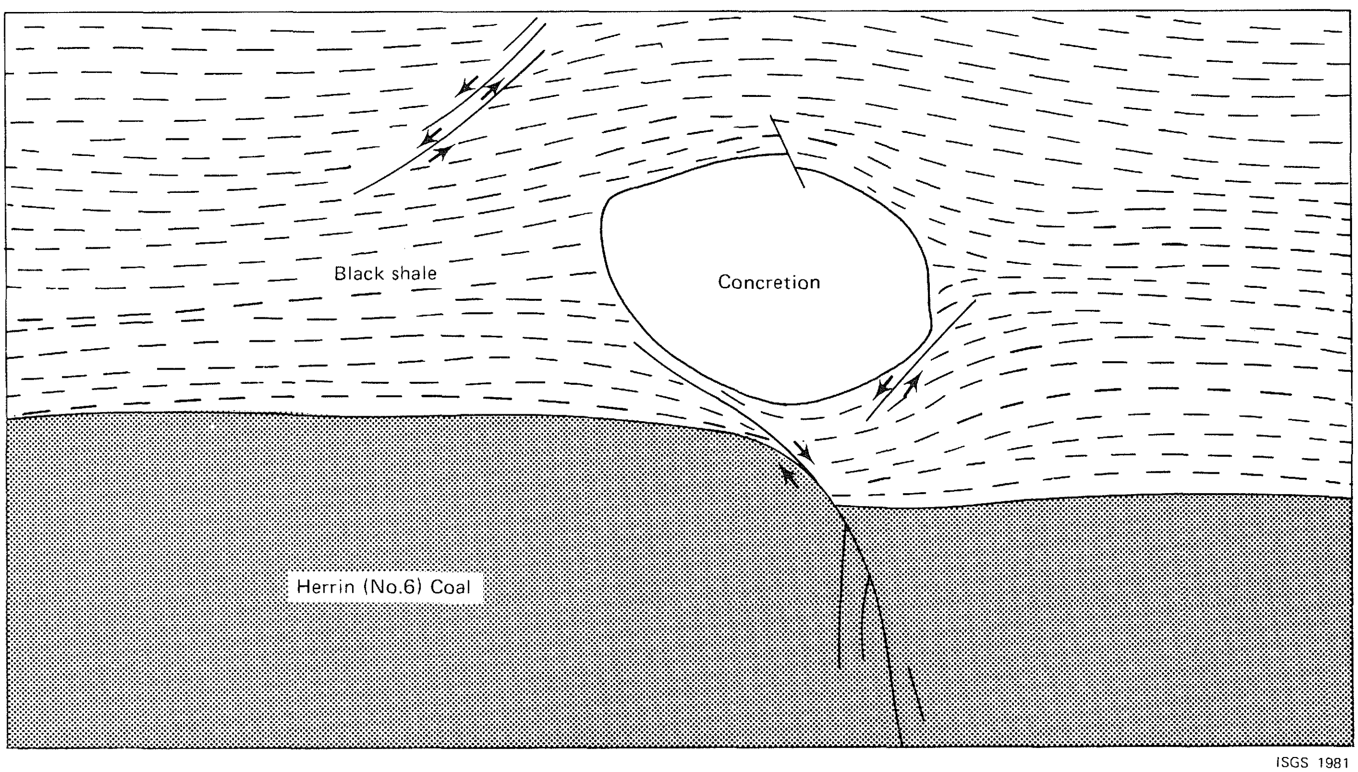



Figure 24. Concretion in black shale above the Herrin (No. 6) Coal. The layers of shale are bent around the concretion, indicating that the concretion grew and solidified before the shale was lithified. Compactional slips formed around the edges of the concretion and allowed it to separate from the roof.

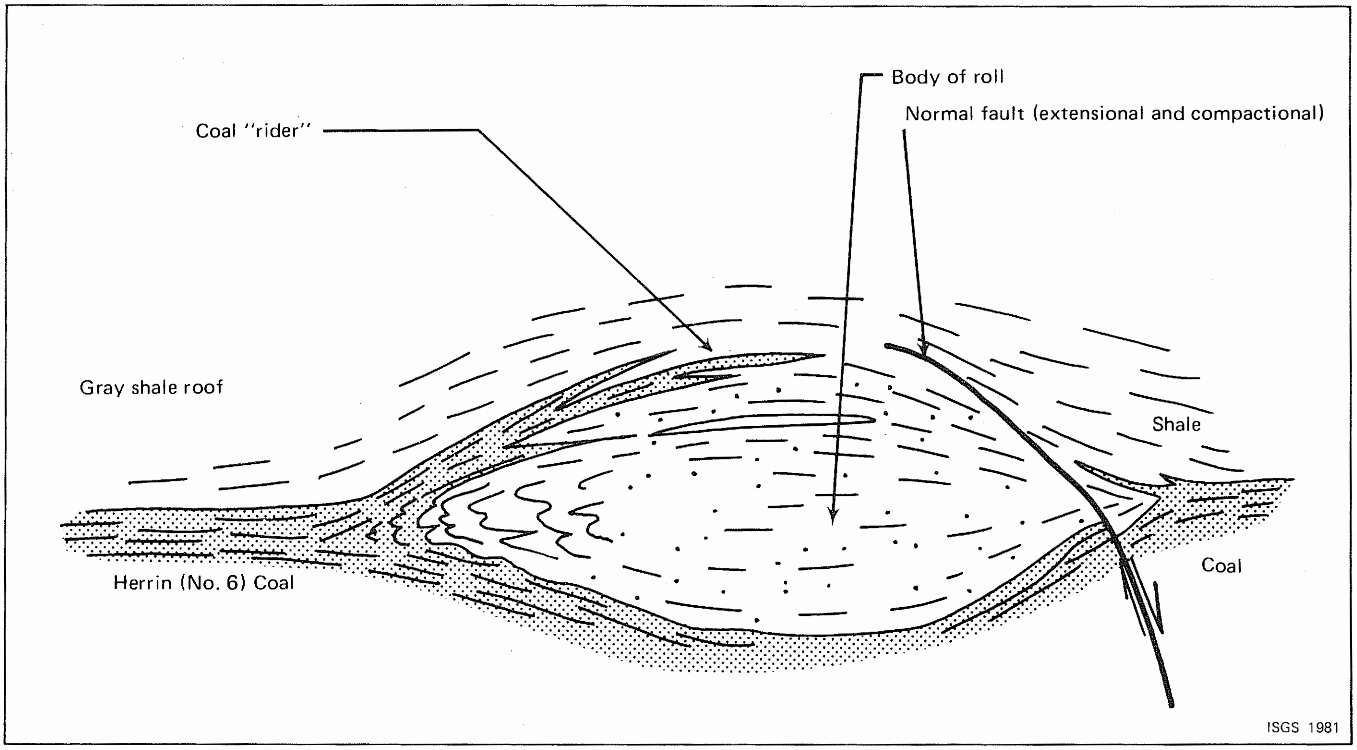



Figure 25. Sketch of a typical roll (from Krausse et al., 1979), showing a fault that formed as a result of differential compaction of shale and coal. The fault and the coal "riders" form intersecting planes of weakness in the roof, which may cause the body of the roll to fall.

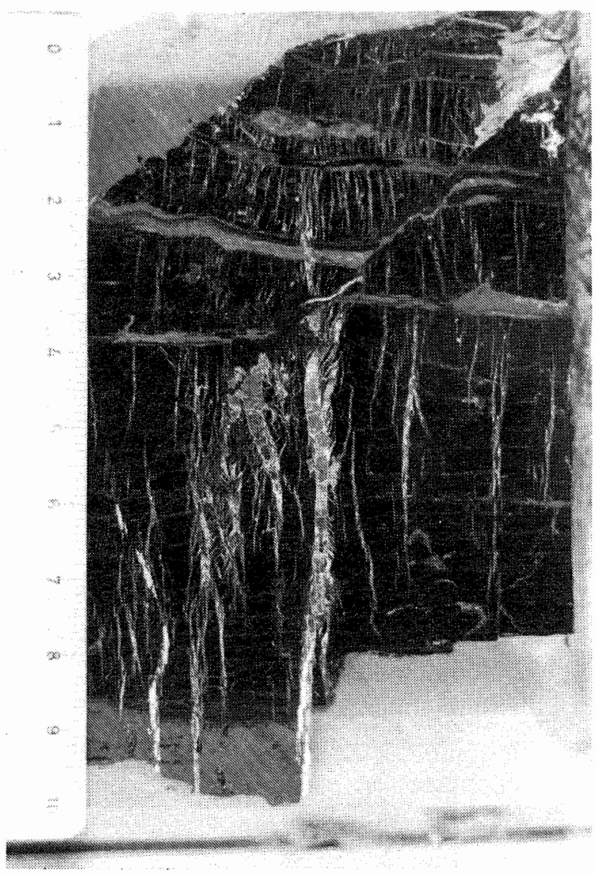


Figure 26. Mineralized "goat beards" at the lower end of a fault in the Herrin (No. 6) Coal. Scale at left is 10 cm (about 4 inches).

## Clay-dike faults

Clay-dike faults, first named by Krausse et al. (1979), are closely associated with clay dikes. Clay dikes are not faults in the proper sense of the word, but they bear mention because of their relationship with clay-dike faults. Clay dikes, also called "horsebacks" or clay veins, are irregular vertical or inclined intrusions of clay into coal seams and adjacent rocks (figs. 27 and 28). They range in width from less than an inch to several feet, and in length from a few feet to many hundreds of feet. Some penetrate the entire coal seam, whereas others affect only the upper layers of coal and lower layers of the roof. Where they are large or numerous or both, clay dikes adversely affect roof stability and contribute large amounts of rock to the coal mined.

Clay dikes and clay-dike faults were formed by horizontal stretching of the sedimentary layers before they were hardened to rock and coal. (What caused the stretching forces is being debated by geologists, and we shall not delve into this here.) The extensional stresses eventually led to rupturing of the coal-forming material. In some cases the ruptures formed were vertical or nearly vertical, and continued stretching pulled the walls of these fissures away from each other. Clay from above the seam moved in to fill the fissures, and clay dikes were formed (fig. 29). Other fractures in the coal-forming material were not vertical, but inclined. The walls of these fractures were not pulled away from each other, so little or no clay could intrude along the fractures. Instead, as the coal-forming material continued to be stretched, the walls of the inclined ruptures remained in contact with each other and slippage occurred, creating clay-dike faults (fig. 29).

All clay-dike faults are normal faults. Most clay-dike faults are small, with less than 2 feet of maximum throw. Most of these small faults affect only the upper portions of the coal seam and the lower layers of the roof. Larger clay-dike faults with 2 to 4 feet of throw are also numerous; most of these penetrate the entire thickness of the coal as well as some layers of the roof and floor. Still larger faults, some of which offset the entire thickness of the coal seam, are occasionally encountered. Krausse et al. (1979) reported a clay-dike fault with 18 feet of displacement, but this was exceptional.

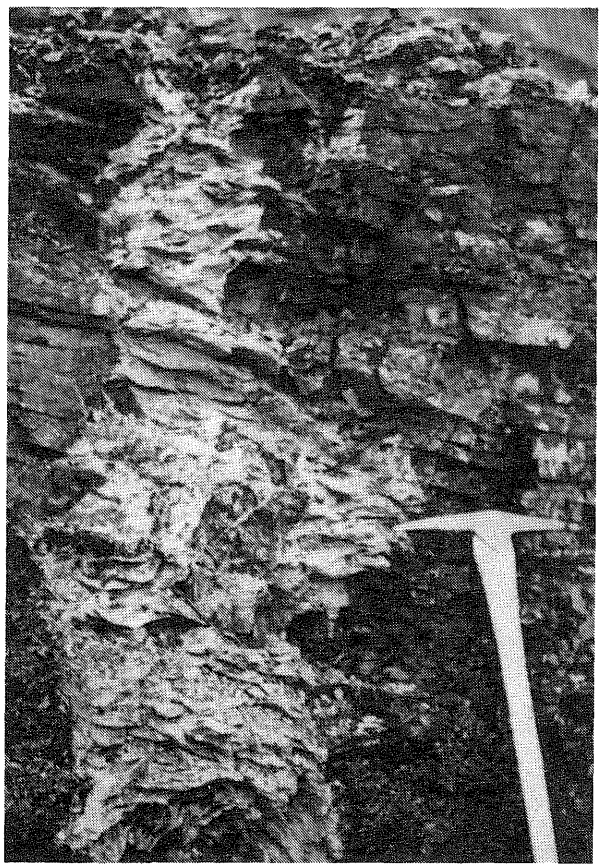


Figure 27. Clay dike in the Springfield (No. 5) Coal in a surface mine.

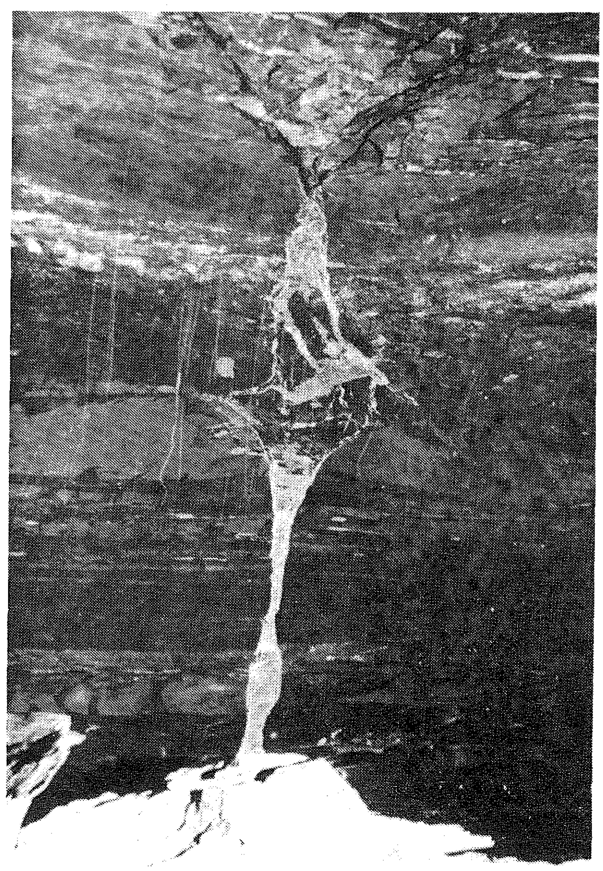


Figure 28. Vertical clay dike in black shale above the Springfield (No. 5) Coal in an underground mine. The V-shaped set of intersecting slips above the clay dike seriously weakened the roof and contributed to the fall at this location.

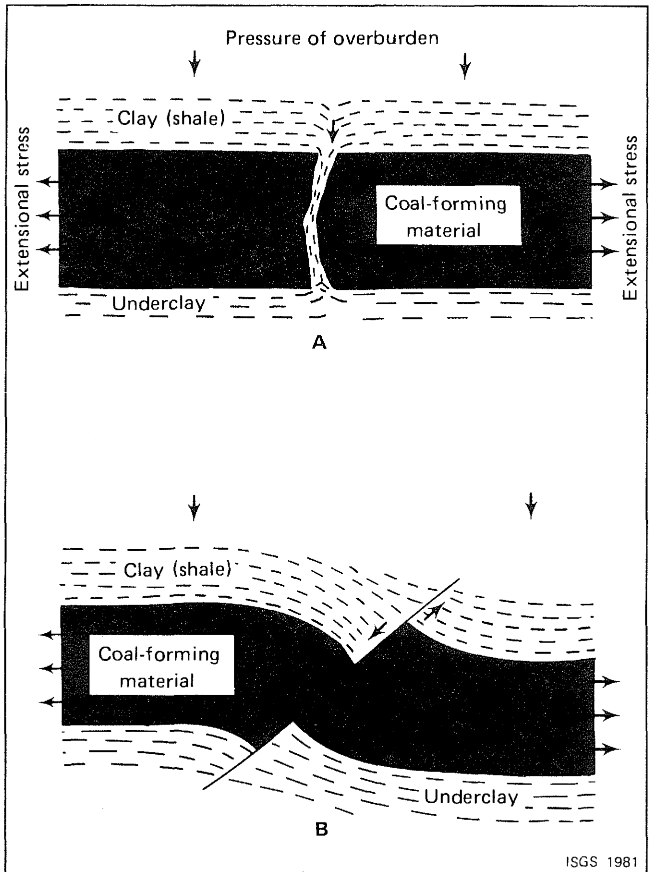



Figure 29. Origin of clay dikes (A) and clay-dike faults (B).

With most clay-dike faults that have less than 3 or 4 feet of throw, the maximum offset is observed near the contact of the coal with the roof (fig. 30). Larger clay-dike faults appear to maintain their throw through the roof, coal, and floor.

Clay-dike faults typically have moderate angles of dip—that is, roughly 35° to 55°. In many cases the upper portion of the fault in the roof flattens and may become horizontal, following bedding planes in the roof (fig. 30). The lower portions of the smaller faults steepen toward the vertical, and the faults die out amid a set of "goat beards" (fig. 26). Clay-dike faults with more than 2 or 3 feet of offset generally do not display this curvature along dip; rather, they tend to be planar and to dip consistently at 35° to 55°. This moderate angle of dip distinguishes them from tectonic normal faults, most of which dip at 60° or greater.

A common feature of clay-dike faults is the so-called "false drag," which is illustrated on the two right-hand faults in figure 30. False drag means the beds near the fault are bent opposite the direction of apparent movement, so that the layers tend to become perpendicular with the fault surface (compare figs. 9 and 30). False drag has the effect of increasing the apparent throw of the fault. Beds that are offset several feet at the fault surface may lie at nearly the same elevation when they are traced away from the fault. In contrast, tectonic normal faults produce real changes in elevation of beds on opposite sides of the faults. Geologists have not reached agreement on why some clay-dike faults have false drag.

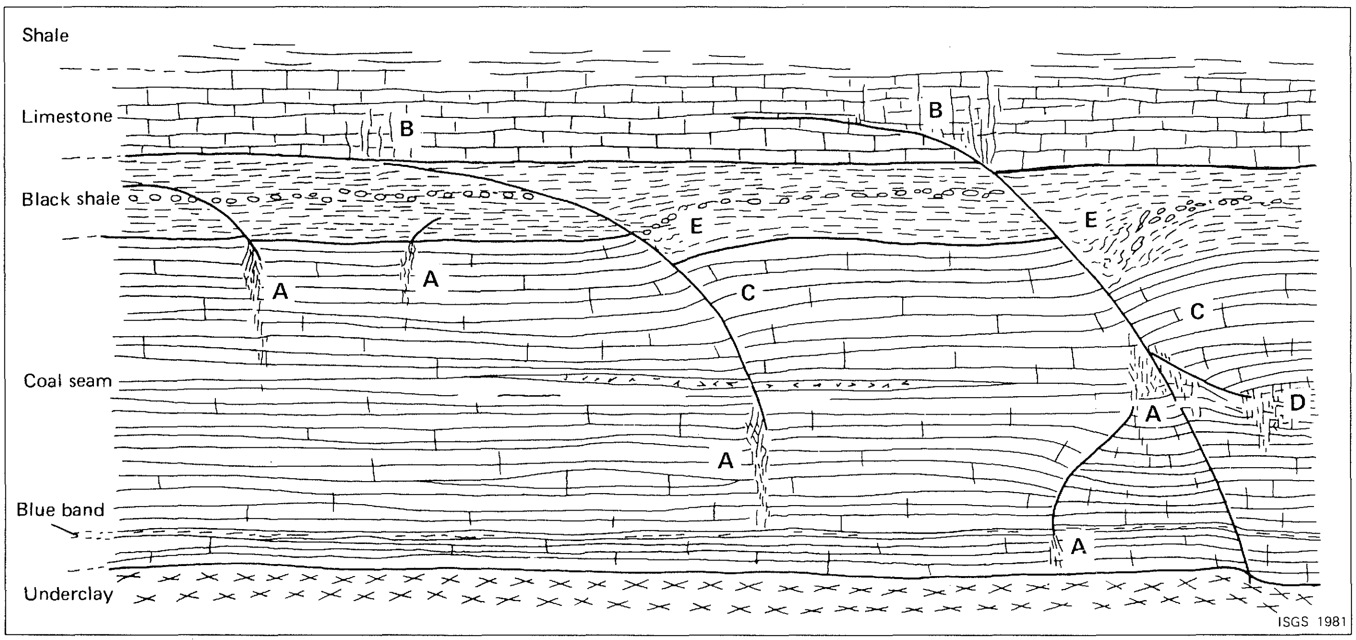



Figure 30. Clay-dike faults. Fault surfaces are curved and typically almost horizontal in the roof; they steepen downward, and become vertical at the base. Extension fractures (goat beards) are found at bases of faults (A) and also above some faults (B). False drag (C) is common; layers tend to be folded perpendicular to the fault surface. Convergent bedding (D) in coal may accompany small, low-angle fractures branching off the main fault. Shale on hanging wall (E) is thicker than shale on footwall, and its bedding is disturbed.

Detailed mapping of clay-dike faults in underground coal mines has disclosed that many of them can be traced for hundreds or even thousands of feet along strike. They may occur in parallel sets or swarms, but they are not linear, as are tectonic faults. Instead, they tend to be strongly curved along strike, and may form roughly circular patterns when plotted on a map. Krausse et al. (1979) reported that clay-dike faults, when mapped, commonly follow or run parallel with the boundaries between contrasting types of rock in the roof.

Clay-dike faults may or may not contain clay along the fault surface. All degrees of transition are found between faults with no clay, and true clay dikes. The same fault may have no clay at one place, a thin filling of clay at another place, and elsewhere may turn into a clay dike with a filling 1 foot or more in width.

Most clay-dike faults are not large enough to force changes in the layout of mines, but where the faults are numerous, it becomes difficult to avoid mining large amounts of rock from the roof or floor. To this rock is added the clay from fillings along the faults and from clay dikes. Like all faults, clay-dike faults tend to lessen the roof stability in underground mines. Areas where several faults intersect can be especially troublesome. Clay-dike faults do not appear to be responsible, however, for introducing water or gas into mine workings in Illinois.

Clay-dike faults and clay dikes have been observed in most of the minable coal seams in Illinois, including the New Burnside, Colchester (No. 2), Springfield (No. 5), Herrin (No. 6), and Danville (No. 7) Coal Members. Those in the Springfield and Herrin Coals in central and western Illinois have been studied the most thoroughly.

Clay dikes are most abundant in the Springfield (No. 5) Coal from Sangamon, Logan, and Menard Counties northward into Fulton and Peoria Counties. Damberger (1970, 1973) reported that nearly vertical clay dikes ranging from a few inches to about a foot wide are most typical of this area. Inclined clay dikes and clay-dike faults were reported to occur rarely in the Springfield Coal. In some of the underground mines of Sangamon and Logan Counties, however, clay dikes were numerous enough to seriously interfere with mining. Evidence of clay dikes frequently appears in cores drilled in these two counties. In Fulton and Peoria Counties, where the coal is being strip mined, there are enough clay dikes to add significantly to the waste separated in preparation plants.

Clay-dike faults, as well as clay dikes, are widely distributed in the Herrin (No. 6) Coal. They are common from St. Clair County northward to Macoupin and Montgomery Counties, and also are found in Vermilion County and in the northwestern region of the Illinois Basin Coal Field. They are rare or absent in mines east of the Du Quoin Monocline, in the deeper portion of the Illinois Basin. The factors that control the distribution of clay-dike faults in Illinois are not known.

#### Gravitational slumps and slides

Some faults in coal-bearing strata are caused by the effects of gravity on the sediments before they were lithified. Sediments deposited on sloping surfaces are subject to slumps, landslides (above or below water), and mud flows. Layers of mud or clay, under the pressure of overburden, can flow laterally or intrude the adjacent strata. Gravitational deformation is quite common in the rock above coal seams, and can contribute to unstable roof conditions.

An example of a gravitational structure that caused severe instability is the "shear body" at the Orient No. 6 Mine, described in detail by Krausse et al. (1979) and Nelson and Ledvina (1979). The shear body is an area about 1,800 feet long and several hundred feet wide in which the roof rock is intensely deformed (figs. 31 and 32). The lower boundary of the shear body is a series of faults that are horizontal in the center of the body and dip gently inward around the margins. These faults locally lie at the top of the coal but were not observed to penetrate the coal. The shale and siltstone in the shear body is crumpled and sheared in a manner that indicates sliding of soft sediments. Roof control within the shear body is very difficult because of the many slickensided surfaces within and below it.

Additional shear bodies have been mapped at the Orient No. 6 Mine. The origin of the shear bodies may be related to the loading of soft, rapidly deposited, water-saturated sediments. At the Orient No. 6 Mine, sandstone overlies 20 feet or more of shale above the coal. Since sand is denser than mud, a top-heavy situation was created. The sand may have slumped downward toward the coal as the mud and clay moved outward and upward to displace the sand (Nelson and Ledvina, 1979). Shear bodies may be common features where thick shale and sandstone overlie coal. The distorted and slickensided rock of a shear body should be easy to recognize in a core.

## RECOMMENDATIONS

The following are suggestions and recommendations aimed primarily at operators of underground mines, but also may be of value to operators of surface mines in faulted areas.

1. Faults and other geologic anomolies should be studied attentively and mapped, and all data about them should be recorded carefully. Faults and other features can be plotted directly onto mine maps as they are updated. For every fault, the direction of dip, the amount of apparent displacement, and the type of fault (e.g., normal, reverse) should be recorded. I recommend that any fault that is continuous for more than a couple of hundred feet should be plotted, even if its displacement is slight. In many cases a fault that seems insignificant in one part of a mine becomes large enough elsewhere to disrupt production. Mapmakers should be cautious about projecting faults as single straight or curved lines. Nearly all large faults in

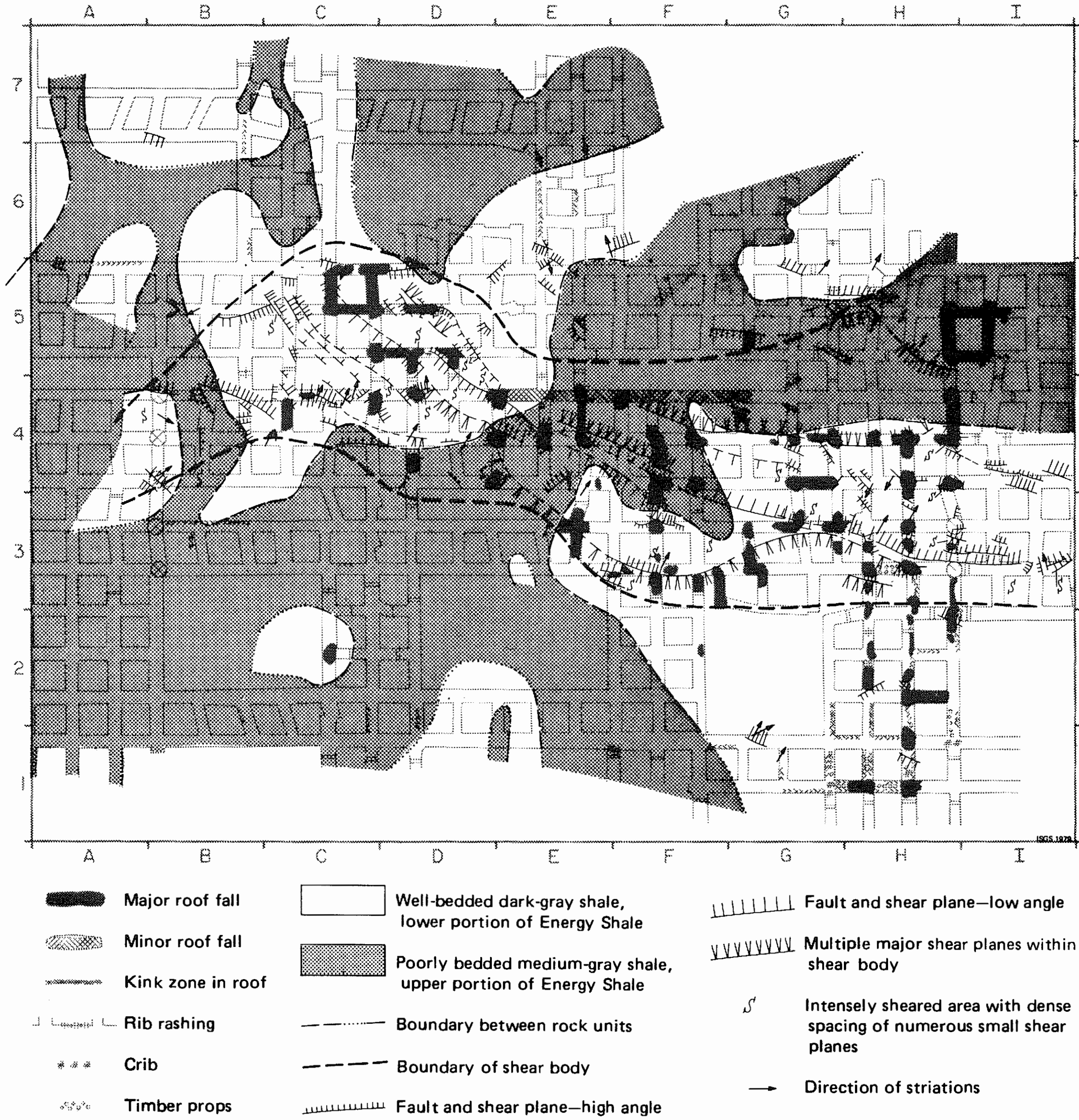



Figure 31. Portion of the Orient No. 6 Mine showing outline of the shear body (heavy dashed line). The shear body is a zone of intensively disturbed rock in the roof. Roof failures (dark gray) are numerous under the shear body.

Illinois are composed of multiple breaks, commonly arranged en echelon.

2. All data relating to faults on or near a coal property should be compiled. Sources of data include logs of drill holes, maps of mines, published reports and manuscripts, files of agencies such as the ISGS, and the recollections of people who worked in nearby mines.

3. Companies should keep abreast of the current technology for locating and predicting faults and other interruptions in coal seams. Many developments are being made in the application of seismic and other geophysical methods of exploration.

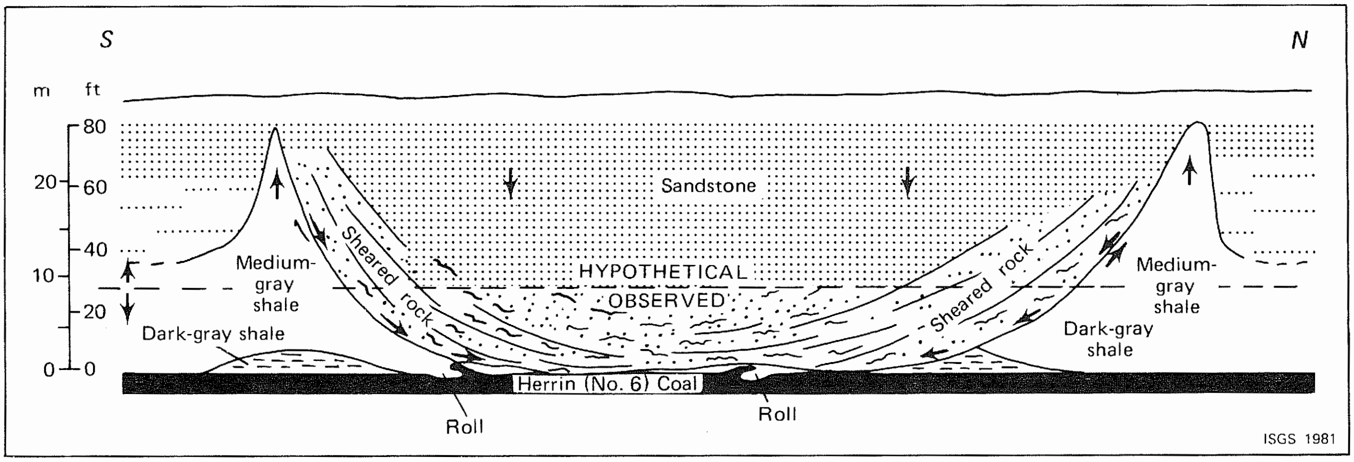



Figure 32. North-south cross section through the shear body at the Orient No. 6 Mine, illustrating Nelson and Ledvina's theory of the shear body's origin (1979). Thick sand was deposited rapidly above medium- and dark-gray mud. The sand was denser than the mud, and the pile of sediments became unstable. The sand may have pressed downward on the mud so that the mud squeezed outward and upward. This movement of sediments may have been responsible for the intensive faulting and disturbance observed in the shear body.

4. Mining plans should be flexible enough to cope with irregularities in the coal seam and in the roof. Simple changes in sizes or shapes of pillars can be beneficial in reducing roof failures caused by faults. On a larger scale, altering the orientations of entries and panels may improve efficiency and safety in faulted areas.

5. When faults are encountered unexpectedly, all possible courses of action should be explored. Sometimes large blocks of coal that could have been mined with little difficulty are abandoned simply because the operator did not understand the nature of faults. Many, if not most, lines of faulting have gaps across which mine entries can be driven. Operators should actively seek these gaps, using all the exploratory methods at their command.

## REFERENCES


Billings, M. P., 1954, Structural geology: Prentice-Hall, Inc., 2nd edition, 514 p.

Bristol, H. M., and J. D. Treworgy, 1979, The Wabash Valley Fault System in southeastern Illinois: Illinois State Geological Survey, Circular 509, 20 p.

Brownfield, R. L., 1954, Structural history of the Centralia area: Illinois State Geological Survey, Report of Investigations 172, 31 p.

Butts, Charles, 1925, Geology and mineral resources of the Equality-Shawneetown area (parts of Gallatin and Saline Counties): Illinois State Geological Survey, Bulletin 47, 76 p.

Clegg, K. E., 1955, Metamorphism of coal by peridotite dikes in southern Illinois: Illinois State Geological Survey, Report of Investigations 178, 18 p.

Clegg, K. E., and J. C. Bradbury, 1956, Igneous intrusive rocks in Illinois and their economic significance: Illinois State Geological Survey, Report of Investigations 197, 19 p.

Coon, J. B., J. T. Reed, W. L. Chapman, and D. E. Dunster, 1979, Surface seismic methods applied to coal-mining problems: Paper presented at AAPG annual convention, Houston, TX, April 1-4, 1979.

Cote, W. E., D. L. Reinertsen, and M. M. Killey, 1969, Field trip guide leaflet 1969 A and F, Equality Area: Illinois State Geological Survey.

Daly, T. E., 1979, High-resolution seismic methods in coal exploration: Paper presented at AAPG annual convention, Houston, TX, April 1-4, 1979.

Damberger, H. H., 1970, Clastic dikes and related impurities in Herrin (No. 6) and Springfield (No. 5) Coals of the Illinois Basin: *in* Depositional environments in parts of the Carbondale Formation—western and northern Illinois: Illinois State Geological Survey, Guidebook 8, p. 111-119.

Damberger, H. H., 1973, Physical properties of the Illinois Herrin (No. 6) Coal before burial, as inferred from earthquake-induced disturbances: Compte Rendu, Seventh International Congress of Carboniferous Stratigraphy and Geology, v. 2, p. 341-350.

Fisher, D. J., 1925, Structure of Herrin (No. 6) Coal near Du Quoin: Illinois State Geological Survey, Report of Investigations 5, 31 p.

Hills, E. Sherbon, 1963, Elements of structural geology: John Wiley & Sons, Inc., 483 p.

Keys, J. N., and W. J. Nelson, 1980, The Rend Lake Fault System in southern Illinois: Illinois State Geological Survey, Circular 513, 23 p.

Krausse, H.-F., and H. H. Damberger, Clay-dike faults and associated structures in coal-bearing strata—deformation during diagenesis: Compte Rendu, Ninth International Congress of Carboniferous Geology and Stratigraphy, in press.

Krausse, H.-F., H. H. Damberger, W. J. Nelson, S. R. Hunt, C. T. Ledvina, C. G. Treworgy, and W. A. White, 1979, Roof strata of the Herrin (No. 6) Coal and associated rock in Illinois—a summary report: Illinois State Geological Survey, Illinois Mineral Notes 72.

Lepper, C. M., and F. Ruskey, 1976, High-resolution seismic reflection techniques for mapping coal seams from the surface: U.S. Bureau of Mines, Coal Mine Health and Safety Program, Technical Progress Report 101, 17 p.

Nelson, W. J., and H.-F. Krausse, 1981, The Cottage Grove Fault System in southern Illinois: Illinois State Geological Survey, Circular 522.

Nelson, W. J., and C. T. Ledvina, A gravitational slide in the Energy Shale Member overlying the Herrin (No. 6) Coal in southern Illinois: Compte Rendu, Ninth International Congress of Carboniferous Stratigraphy and Geology, in press.

Nelson, W. J., and Roger B. Nance, 1980, Geologic mapping of roof conditions, Crown II Mine, Macoupin County, Illinois: SME-AIME Preprint, 80-308; Illinois State Geological Survey, Reprint 1981-A, 8 p.

Peng, S. S., 1978, Coal mine ground control: John Wiley & Sons, Inc., 450 p.

Serres, Y., and C. Wiles, 1977, Mini-Sosie: New high resolution seismic reflection system for coal and mineral exploration, civil engineering, hydrology, geothermal, and shallow petroleum exploration: 79th AGM of the Canadian Institute of Mining and Metallurgy, Ottawa, Canada, April 20, 1977.

Smith, W. H., and Stall, J. B., 1975, Coal and water resources for coal conversion in Illinois: Illinois State Geological Survey, Cooperative Resources Report 4, 79 p.

Spencer, E. W., 1969, Introduction to the structure of the earth: McGraw-Hill Book Company, 547 p.

Stas, B., 1976, Coal seismic: Foreign Trade Corporation Technical Cooperation Agency, Panska 6, Czechoslovakia.

Willman, H. B., Elwood Atherton, T. C. Buschbach, Charles Collinson, John C. Frye, M. E. Hopkins, Jerry A. Lineback, and Jack A. Simon, 1975, Handbook of Illinois stratigraphy: Illinois State Geological Survey, Bulletin 95, 261 p.

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| *Anticline* | An elongate upward fold in the earth's crust; a structural arch. Frequently traps petroleum and natural gas. |
| *Bedding* | The layering along which coal, shale, and other rocks split. Generally horizontal except where rocks have been folded or faulted. |
| *Bedding fault* | A fault that follows a bedding plane. |
| *Breccia* | Material composed of coarse, unsorted, angular, jumbled rock fragments, held together by clay or by cementing minerals. Often found along fault zones. |
| *Clay dike* | A clay-filled vertical or inclined fracture in coal and adjacent rocks. Usually very irregular; can be up to several feet wide. |
| *Clay-dike fault* | A nontectonic normal fault associated with clay dikes and believed to have been formed by the same process as clay dikes. |
| *Compactional fault* | A fault believed to have formed as a result of stresses caused by unequal rates of compaction in sediments as they hardened into rock. |
| *Dike* | Any intrusion of foreign material (e.g., clay, sand, igneous rock) along a fracture, which cuts across the bedding and layered rocks. |
| *Dip* | The pitch or inclination (measured in degrees from the horizontal) of any surface, such as a bedding plane or a fault plane. Horizontal surfaces have $0^\circ$ dip, and vertical surfaces dip at $90^\circ$. |
| *Dip slip* | The component of displacement on a fault parallel with the dip of the fault surface. |
| *Dip-slip fault* | A fault on which the principal motion was dip slip (up and down). |
| *Displacement* | A term loosely used to refer to the amount of offset on a fault. May be equal to the net slip, but often indicates only the throw or the dip slip. |
| *Dome* | An upward-bulging fold in the earth's crust, shown as roughly circular on a map. Similar to an anticline except that the anticline is shown as elongate on a map. |
| *Drag* | Folding or bending of rock layers adjacent to a fault, caused by friction along the fault. Strata are bent in the direction of movement. |
| *En echelon* | A common arrangement of faults in which individual faults are parallel to but staggered or offset to each other, so that where one fault ends another begins slightly to the right or left. |
| *False drag* | Folding or bending of rock layers observed along some faults, in which the strata are bent opposite to the direction of motion. Causes are poorly understood. |
| *Fault* | Any fracture in the earth's crust along which movement has occurred. |
| *Fault plane* | A fault surface, when essentially planar (not curved). |
| *Fault surface* | The surface of the fault, along which slippage has occurred. May be either curved or planar. |
| *Fault system* | A group of tectonic faults that formed in a common stress field. |
| *Fault zone* | The belt of fractured, brecciated, or pulverized rock found along a large fault. Most large faults have a fault zone rather than a single fault surface or plane. |
| *Footwall* | The block of rock below an inclined fault. |
| *Goat beard* | Informal term for the set of small, closely spaced, mineralized vertical fractures found near the lower end of many small faults in coal. A goat beard in the top coal often warns of the presence of a fault in the roof. |
| *Gouge* | Rock that has been pulverized to a claylike consistency in a fault zone. |
| *Graben* | A block of rock dropped downward between two normal faults that face each other. |
| *Hanging wall* | The block of rock above an inclined fault. |
| *Heave* | The horizontal component of movement along an inclined dip-slip or oblique-slip fault. |
| *High-angle fault* | A fault whose surface dips at an angle of 60 to $90^\circ$ from the horizontal. |

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| *Horseback* | A miner's term for any of various disturbances in coal seams. In Illinois the term usually refers to clay dikes. |
| *Horst* | A block of rock thrown upward between two normal faults that face away from each other. Opposite of graben. |
| *Joint* | A fracture in the earth's crust along which no appreciable movement (slip) has occurred. |
| *Left-lateral fault* | A strike-slip fault on which, to an observer straddling the fault, the left-hand block has moved toward the observer. Or, if the observer stands on one block and looks across the fault, the opposite block has moved from right to left. |
| *Low-angle fault* | A fault whose surface dips at an angle of 0° to 30° from horizontal. |
| *Monocline* | A steplike fold or flexure in layered rocks. Many monoclines overlie a fault at depth; the rocks near the surface are bent rather than broken. |
| *Mullion* | Large polished grooves or furrows along a fault surface. Mullion results from the friction of movement and indicates the angle of net slip. |
| *Net slip* | A measurement of the total offset of two formerly adjacent points along a fault surface. Net slip is a combination of dip slip and strike slip. |
| *Nontectonic fault* | A fault that is formed by stresses that affect sediments as they are being transformed into rock. Difficult to predict. |
| *Normal fault* | A fault with an inclined surface, and predominantly dip-slip movement, along which the hanging wall has moved downward relative to the footwall. The most common type of fault in Illinois. |
| *Oblique-slip fault* | A fault that shows a combination of dip slip and strike slip. Oblique slip may occur in a single episode of movement, or in separate events of dip slip and strike slip. |
| *Reverse fault* | A fault with an inclined surface, and predominantly dip-slip movement, along which the hanging wall has moved upward relative to the footwall. The movement on a reverse fault is opposite to the movement on a normal fault. |
| *Right-lateral fault* | Opposite of left-lateral fault. |
| *Roll* | An informal term for various disturbances in coal seams. As used in Illinois, and as used in this report, roll refers to a generally elongate protrusion of the roof rocks onto or into a coal seam. Rolls are often accompanied by compactional faults. |
| *Slickensides* | The surface of a fault, polished and striated by the friction of movement. Slickensides record the most recent episode of slip on the fault. |
| *Slice* | A narrow sliver or block of rock within a fault zone or between two closely spaced parallel faults. |
| *Slip* | Movement along a fault; also used as an informal term for small faults or slickensided surfaces in coal or roof. Most slips are compactional faults. |
| *Strike* | The directional heading of a fault or other geologic surface, as plotted on a map. May be expressed as a direction (northeast), as degrees away from north or south (N45°E), or as degrees on a 360° compass, measuring clockwise from due north (045°). |
| *Strike slip* | The component of displacement on a fault parallel with the strike of the fault. |
| *Strike-slip fault* | A fault on which the principal motion was strike slip (horizontal). |
| *Syncline* | An elongate downward fold in the earth's crust; a structural trough. Opposite of anticline. |
| *Tectonic* | Related to or formed by deep-seated regional stresses within the earth. |
| *Tectonic fault* | A fault that is formed by tectonic stresses. |
| *Throw* | The vertical component of slip on a fault. |
| *Thrust fault* | A reverse fault, generally one whose surface dips less than 30°. |
| *Wrench fault* | A strike-slip fault, especially one of major proportions. |

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