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Faulting and Jointing in and Near Surface Mines of Southwestern Indiana

Prepared by C. H. Ault, D. Harper, C. R. Smith, M. A. Wright

Indiana Geological Survey

Prepared for
U.S. Nuclear Regulatory
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Prepared by
C. H. Ault, D. Harper, C. R. Smith, M. A. Wright

Indiana Geological Survey
Bloomington, IN 47405

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FAULTING AND JOINTING IN AND NEAR SURFACE MINES OF SOUTHWESTERN INDIANA

by

Curtis H. Ault, Denver Harper, Christopher R. Smith, and Michele A. Wright

ABSTRACT

Three major areas of faulting have been delimited by past studies in southern Indiana: the Mt. Carmel Fault in south-central Indiana, the Wabash Valley Fault System in Posey and Gibson Counties, and faulting in Perry and Spencer Counties. This project completed the mapping and characterization of the remaining known large faults in southern Indiana, including the Georgetown Fault in Floyd County and the newly named Crandall Fault in Harrison County. The Georgetown and Crandall Faults are normal faults that have a maximum vertical displacement of about 65 feet. They are post-Valmeyeran and pre-Pleistocene in age and are probably the result of hinge-line deformation between the subsiding Illinois Basin and the Cincinnati Arch. In contrast, abundant small-scale faults and joints are related to regional compressive lithospheric stress or to sedimentologic processes that operated penecontemporaneously with deposition of the rocks in which they are found. Structures related to regional stress include small-scale thrust faults with displacements of a few inches to a few feet and joints that are widespread in mines and outcrops in rocks of Mississippian and Pennsylvanian age. The jointing and most of the small-scale thrust faulting indicate that southern Indiana is affected by the Midcontinent Stress Province in the northern part of the study area and by another stress field in the southern part. An east-west boundary can be defined between the two stress fields.

SUMMARY OF RESULTS

Detailed mapping of the Georgetown Fault and the newly named Crandall Fault in Harrison and Floyd Counties completed the mapping of all known major faults in southern Indiana.

The Georgetown Fault is a nearly north-south fault on trend with the Mt. Carmel Fault to the north in Lawrence and Monroe Counties. The Georgetown, a normal fault, has a maximum displacement of about 65 feet and is nearly parallel to the Crandall Fault, which is about 3 miles west and has a maximum displacement of about 50 feet. A normal fault is inferred about 1 mile east of the Georgetown Fault, although the exact location and amount of displacement of the inferred fault are not known because of scarce mapping control. The Georgetown, Crandall, and Mt. Carmel Faults are post-Valmeyeran and pre-Pleistocene in age and are probably related to hinge-line deformation between the subsiding Illinois Basin and the Cincinnati Arch.

Two other possible hinge-line faults have been partly mapped in Martin County. These unnamed normal faults trend north-southward with about 30 to 40 feet of displacement, but structural control is limited, and the extent of the faults is unknown.

In Dubois County, a small distorted structure, possibly involving faulting, was mapped, but its extent is also unknown because of scarce structural data.

Numerous small normal and thrust faults with displacements of a few inches to a few feet were mapped in surface coal mines in southwestern Indiana. These faults have little vertical or horizontal extent and commonly involve only coalbeds and a few feet of associated strata. The small normal faults and some of the thrust faults can be related to sedimentologic processes, including channel filling, slumping, and differential compaction, but many of the small thrust faults are similarily oriented and are apparently the result of regional compressive lithospheric stress.

Joints are ubiquitous where bedrock is exposed. Directional patterns of jointing can reflect regional-stress directions, and measurements of more than 2000 joints at 240 locations in southwestern Indiana show a distinct east-northeast-west-southwest orientation of jointing in the northern part of the study area, the same direction as compressive stress in the Midcontinent

Stress Province. A distinct shift of direction of primary and secondary jointing and orientation of small thrust faults in the southern part of the study area is believed to indicate a different direction of regional stress in that area. An east-west boundary can be defined between the two stress fields.

PROJECT PRODUCTS

Published Reports

Smith, C. R., and Ault, C. H.

1983 - Some lithologic and structural aspects of jointing in southwestern Indiana (abs.): Geol. Soc. America Abs. with Programs, v. 16, p. 196.

Wright, M. A., Ault, C. H. and Harper, Denver

1982 - Implications of faults and other structures in some mines in southwestern Indiana (abs.): Geol. Soc. America Abs. with Programs, v. 14, p. 242-243.

Paper In Preparation

Smith, C. R., and Ault, C. H.

198_ - Major stress-field boundary in southern Indiana.

Maps on Permanent File at Indiana Geological Survey

Wright, M. A.

1983 - Georgetown and Crandall 7 1/2-minute topographic quadrangles showing faulting near Georgetown, Harrison, and Floyd Counties, Indiana.

PREFACE

This is the final report on a 3-year study of faulting and jointing in and near mines in southwestern Indiana. The study was conducted by geologists of the Indiana Geological Survey as part of an overall study of the seismotectonics of the New Madrid area by geoscientists of several universities and geological surveys. The study was funded in part by the U.S. Nuclear Regulatory Commission.

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INTRODUCTION

Background

In previous studies major faults in three areas in Indiana were mapped by geologists of the Indiana Geological Survey (Ault and Sullivan, 1982). Detailed maps were constructed, and descriptions of the Wabash Valley Fault System in Posey and Gibson Counties, smaller faults in Perry and Spencer Counties, and the Mt. Carmel Fault in south-central Indiana (fig. 1) were

Figure 1. Map of southwestern Indiana showing study area, major faults, and an inferred zone of basement rifting proposed by Braile and others (1982).

mapped and characterized in detail.

Faults of the Wabash Valley Fault System are believed to extend to basement depths, although they are more complex at shallow depths, and the amount of displacement probably decreases with depth. From recent seismic profiling in the Wabash Valley, Sexton and others (1984) believe that some of the Wabash Valley faults are expressions of relatively small movements along early graben-bounding faults in the basement. The grabens, which are 1 to 3 kilometers deep, were mostly active during late Precambrian to earliest Paleozoic time. Movements of the Wabash Valley faults were post-Pennsylvanian and pre-Pleistocene in age.

Nelson and Lumm (1984) questioned the origin of the Wabash Valley faults as recurrent deep-seated movements in a rift zone. They hypothesized that the Wabash Valley Fault System resulted from regional extensional stress caused by the same tectonic actions that produced the Cottage Grove Fault Zone of southern Illinois.

Braile and others (1982) suggested that the rifting in southeastern Indiana trends northeastward into south-central Indiana to an area east of the Mt. Carmel Fault and possibly farther (fig. 1). The Mt. Carmel Fault is believed by Ault and Sullivan (1982) to be associated with hinge-line deformation of post-Valmeyeran and pre-Pleistocene age between the relatively stable Cincinnati Arch and the subsiding Illinois Basin.

This study completes the detailed mapping and characterization of major known faults in southern Indiana, including the faulting near Georgetown in Floyd and Harrison Counties. To further determine the extent of faulting and other structures that might indicate tectonic history and the effect of present tectonics on the study area, detailed examinations were made of all structures in exposures in and near the more than 100 active mines of southwestern Indiana. The structures mapped in the mines include small-scale faults, structures of sedimentologic origin, and the nearly ubiquitous jointing of all bedrock exposures throughout the study area.

Study area

The study area includes 28 counties in southwestern Indiana (fig. 1), all within the Illinois Basin and west of the Cincinnati Arch. Rocks of Mississipian and Pennsylvanian age dip gently southwestward into the Illinois Basin. Mississippian rocks in this area have three lithologically distinct parts

(Gray, 1979): an upper part composed of cyclic sequences of sandstone, shale, and limestone; a middle part composed principally of limestone; and a lower part that is a clastic sequence of siltstone and shale. In the study area rocks of the Pennsylvanian System unconformably overlie the rocks of Mississippian age cropping out along the east edge of the Illinois Basin. Pennsylvanian rocks are primarily shales, siltstones, and sandstones with thin but widespread beds of clay, limestone, coal, and black shale. Much of the area is overlain by thin unconsolidated deposits of Wisconsinan and Illinoian tills and outwash, loess, glacial lake silt and clay, and Holocene alluvium.

Methodology

All literature pertaining to faulting in the study area including field notes and maps on file at the Indiana Geological Survey, publications of the Survey, student theses, and abandoned and active mine maps was reviewed. Faulted or anomalous areas reported in the literature were re-inspected in the field. More than 100 active surface and underground mines were visited, and all structures of possible tectonic or sedimentologic origin were described and mapped. Many of the mining operations where structures are prominent were revisited at regular intervals.

Besides mapping faulting in the mines and outcrops, we measured joint and fracture orientations and extent. At least 10 measurements of both prominent and secondary joints were made at each joint site to ensure a representative sampling. Data on lithology of jointed rocks, joint spacing, inclination of jointing, and number of joints were also collected.

FAULTS

Faults studied in this project include small faults measured in exposed highwalls and commonly involving only a coalbed and a few feet of rock above or below the coalbed, major faults in the Georgetown area of Harrison and Floyd Counties, and a few scattered normal faults with more than 10 feet of displacement in other areas.

Faulting in the Georgetown area

Detailed mapping in the Georgetown area in Floyd and Harrison Counties located surface traces of one main fault, a possible subparallel fault about 1 mile east of the Georgetown Fault, and a fault near Crandall, about 3 miles west of the Georgetown Fault (fig. 2).

Ashley and Kindle (1903, p. 91-92) originally described a fault downthrown to the east in sec. 19, T. 2 S., R. 5 E., near Georgetown. Under a paragraph heading "The Greenville Fault," Logan (1929, p. 230) also mentioned a fault near Georgetown, but the fault was not precisely located on the small-scale structure map of Indiana that accompanied the report. Logan stated that the Greenville Fault was downthrown to the west. Stockdale (1931) published a larger scale map showing one fault that he described in some detail and that he named the Georgetown Fault. The Georgetown Fault was downthrown to the east, and Stockdale believed that Logan's Greenville Fault might be a second fault because it was reported downthrown in the opposite direction.

Although Harris (1948) used the term Greenville Fault for Stockdale's Georgetown Fault in an unpublished M.A. thesis, Melhorn and Smith (1959, p. 15) later used the formal name Georgetown Fault in a paper on the Mt. Carmel Fault and related structures. Sunderman (1968), however, decided to use the term Greenville Fault for this fault because he believed Logan had made an inadvertent error in direction and was actually referring to Stockdale's Georgetown Fault.

We retain the name Georgetown Fault, as originally described by Stockdale (1931) and named for Georgetown in secs. 32-34, T. 2 S., R. 5 E., for the fault mapped in detail in our study from sec. 12, T. 2 S., R. 4 E., about 4 miles to sec. 6, T. 3 S., R. 4 E. (fig. 2). The contact between the Edwardsville and Ramp Creek Formations (Mississippian) was used as a structural datum. An accessory or splinter fault was mapped close to and parallel to the Georgetown Fault, mostly in sec. 19, T. 2 S., R. 5 E. The two fault traces in this section are separated by a block that is about 200 feet wide. Both faults strike about N. 15° W. and are nearly vertical or dip very steeply eastward. The total displacement for both faults is about 65 feet.

A zone of shattered siltstone about 10 feet wide is commonly found in creekbeds along the trace of the main fault, and parallel fracture zones are common. But the fault traces are mostly covered by soil and by limestone and siltstone rubble, so that accurate surface mapping, which requires close structural control, is not possible.

A fault in secs. 27 and 34, T. 2 S., R. 4 E., about 3 miles west of the Georgetown Fault, here named the Crandall Fault, was named for the town of

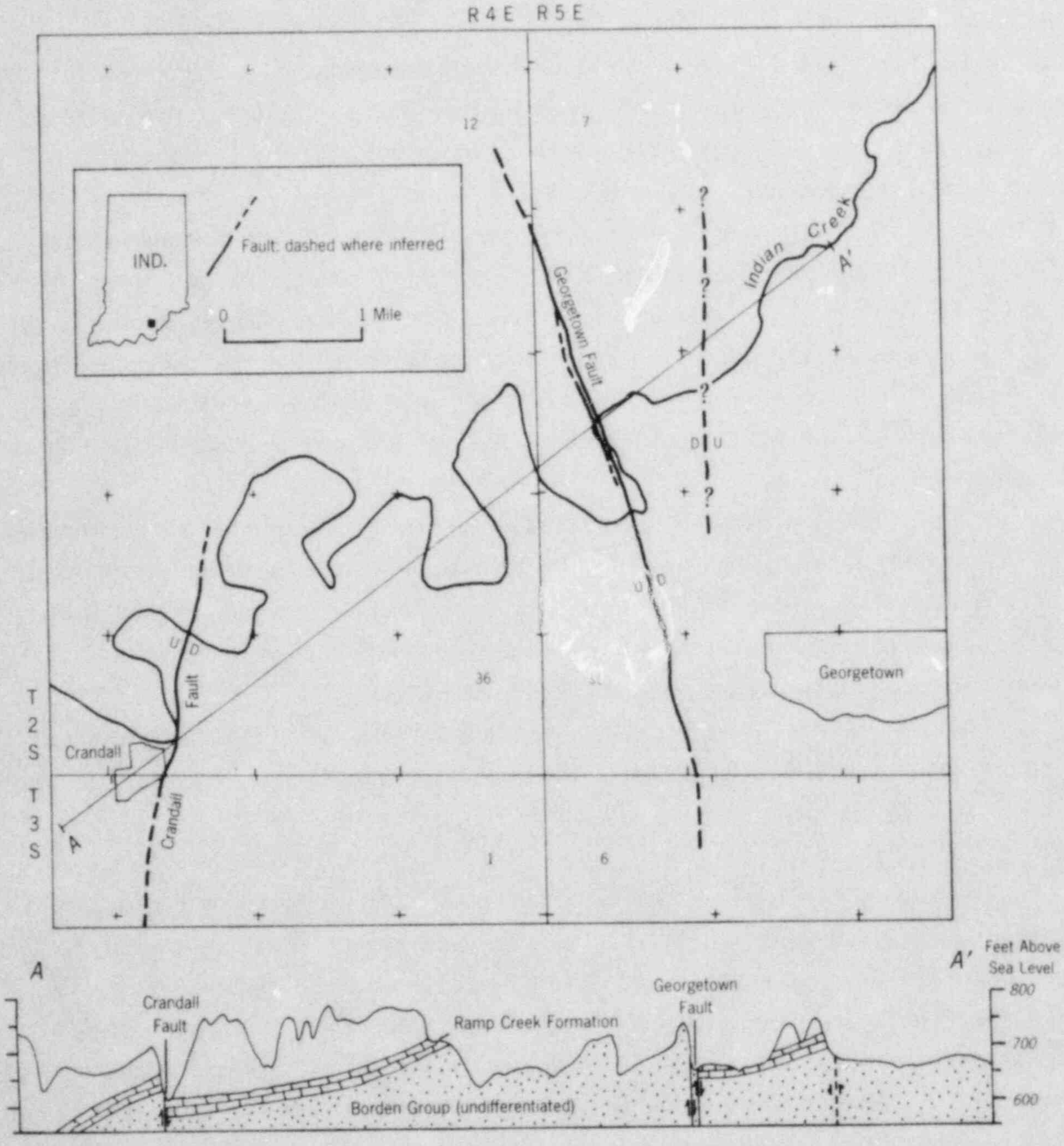

Figure 2. Map showing faulting in the Georgetown area of southern Indiana.

Crandall in sec. 34, T. 2 S., R. 4 E. (fig. 2). The Crandall Fault was mapped for the first time in our study and reported in our 1983 annual report to the Nuclear Regulatory Commission. The maximum displacement of the fault is about 50 feet. The fault is nearly vertical or dips very steeply eastward. The fault may extend 1 mile or farther southward, where fracture zones oriented N. 12^{o} E. are exposed in a creekbed in sec. 9, T. 3 S., R. 4 E., and exposed limestone beds show anomalous dips.

An inferred fault has been mapped about 1 mile east of the Georgetown Fault in secs. 17 and 20, T. 2 S., R. 5 E. Shatter zones that may be associated with the fault are present in rocks exposed in tributaries on the north side of Indian Creek, and structural relationships of the few outcrops in sec. 17 suggest that faulting has occurred as shown in figure 2. Location and displacement of the fault are difficult to confirm, and additional data are needed.

Logan's (1929) Greenville Fault was reportedly downthrown to the west as is our inferred fault in secs. 17 and 20, and Logan may have been referring to this fault rather than to the main Georgetown Fault as mapped in our study. If so, it resolves the discrepancy between Logan's Greenville Fault and the Georgetown Fault, which is downthrown to the east.

Topographic maps on a scale of 1:24,000 showing the fault traces and control points are on open file at the Indiana Geological Survey.

Other large faults

A possible fault of tectonic origin was mapped in northern Martin County (fig. 3). Coals and shales of the Mansfield Formation (Pennsylvanian) are structurally lower than the Glen Dean Limestone (Mississippian) in sec. 31, T. 5 N., R. 3 W. The Mississippian-Pennsylvanian unconformity complicates the relationship of the strata, but elevations on top of the limestone and on sheared and distorted shales in the creekbed south of the exposure indicate a displacement of about 30 feet. The difference in elevation is too great to be explained by differential compaction, especially since the shale and coal overlie the resistant Glen Dean Limestone, which would limit compaction. Another fault with a 40-foot displacement is also 2 miles south of this location (Krothe, Ash, and Smith, 1983). Both of these faults trend north-southward and are suggested to be hinge-line faults similar to the Mt. Carmel and Georgetown Faults.

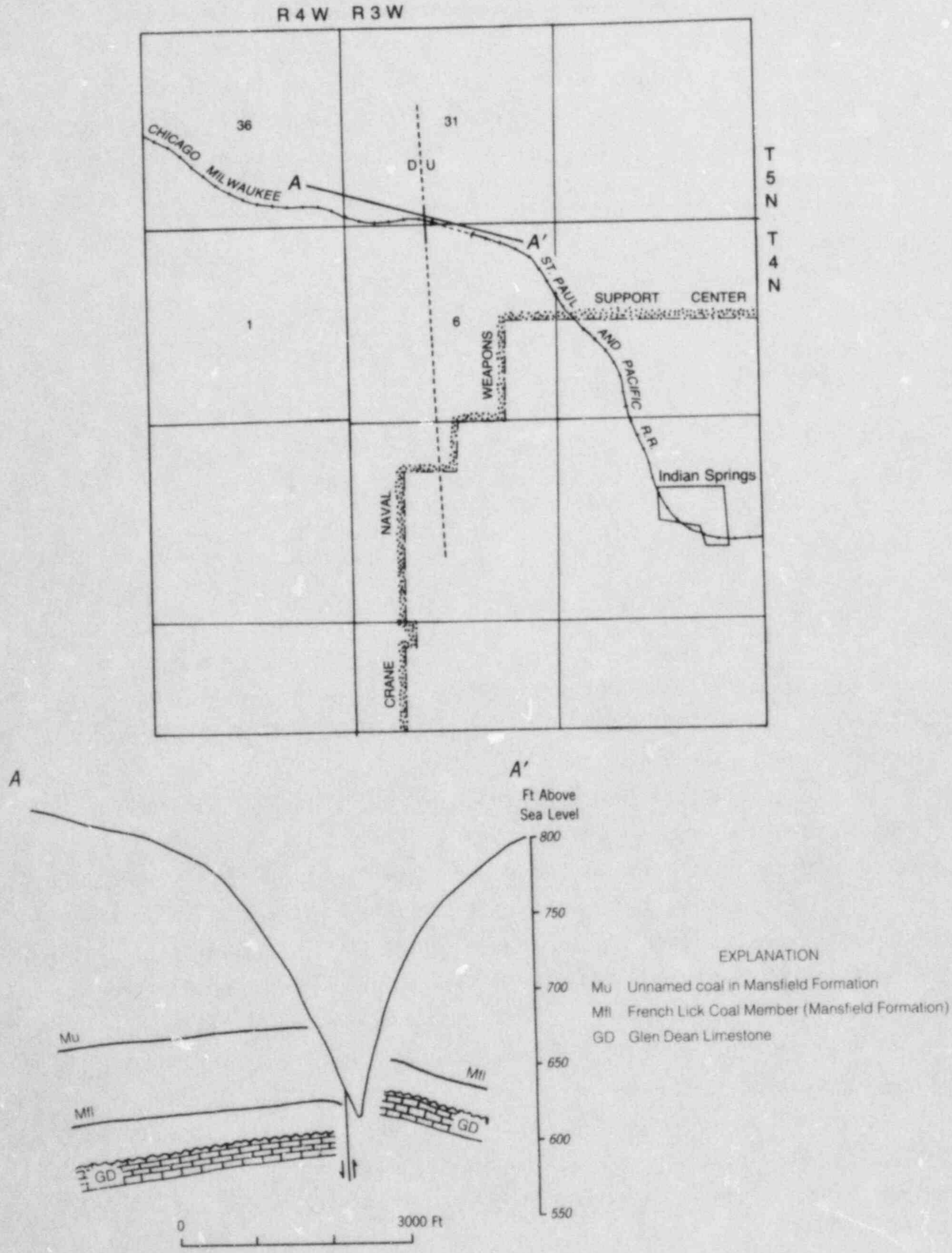

Figure 3. Map showing faulting in Martin County, Indiana.

One other fault has been located near Bretzville in Dubois County. This structure, reported by Whitlatch (1931), is exposed in sec. 32, T. 2 S., R. 4 W. in a cut on the Southern Railway. In this cut a 24-inch coalbed dips steeply 4 to 5 feet westward for 50 yards and is truncated by distorted shale and shaly sandstone (fig. 4). The extent of this structure is unknown because of scarce outcrops and subsurface data.

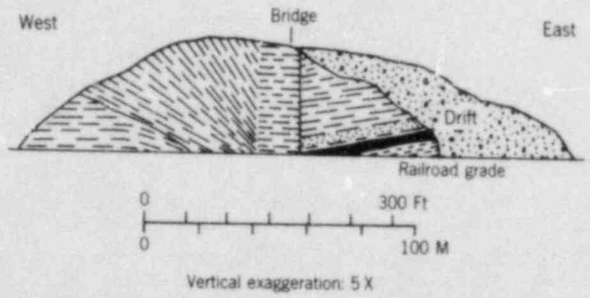

Figure 4. Schematic diagram of a fault in a railroad cut near Bretzville, Indiana (adapted from Whitlatch, 1931).

Small faults

Small faults with displacements of 3 feet or less are common in the coal-bearing strata of Indiana. They commonly involve only a coalbed and a few feet of rock above or below the bed; very few affect all of the exposed section in strip-mine highwalls.

Some of the faults found near modern and ancient alluvial channels (fig. 5) appear to be the result of compression of sediments by accumulating channel sands. Overbank muds laid down on peat produced rolls on top of the coal by deformation of sediments before they had lithified. Muds were in some places apparently squeezed under the top layers of the saturated peat bed, splitting off thin stringers of coal above the rolls. Accumulating channel sands may also have caused faulting. Peat layers may behave as a brittle material before coalification so that some faulting may be penecontemporaneous with channel development.

Other faults appear to be a result of differential compaction of sediments (fig. 6). These are normal faults with little horizontal or vertical extent. These faults also commonly become indistinct and die out in more plastic shales.

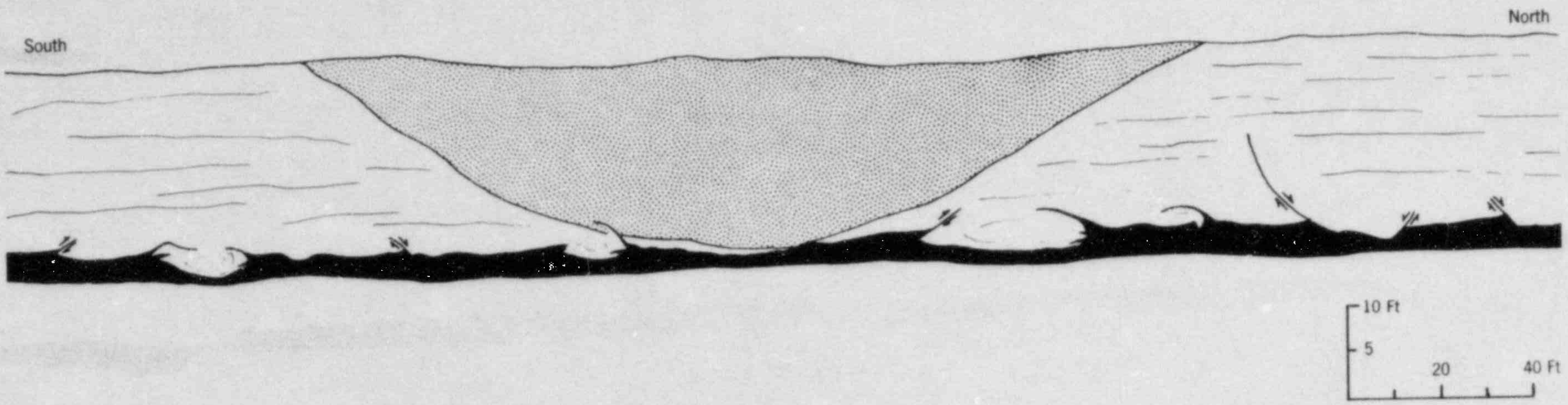

Figure 5. Schematic diagram of faulting and sedimentologic structures associated with channeling and coal deposition in a surface mine near Dugger, Sullivan County.

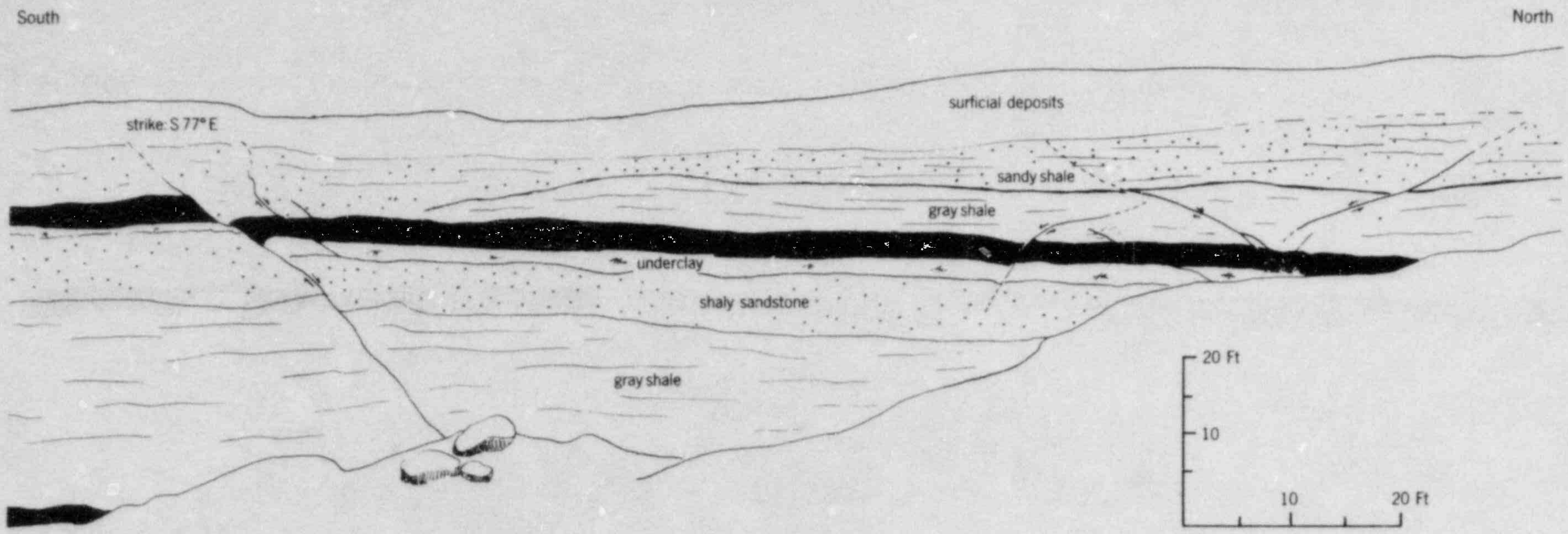

Figure 6. Schematic diagram of normal faulting and other structures in a surface mine in southern Daviess County.

Many small thrust faults in surface mines (fig. 7) have no apparent sedimentologic causes. These thrust faults are low angle and have small displacements that commonly involve only the coalbeds and a few feet of associated strata. In the northern two-thirds of the study area, they generally strike north-northwestward (see fig. 17), a direction that is perpendicular to the regional east-northeast direction of midcontinent regional compressional stress (Zoback and Zoback, 1981, fig. 1). The genesis of thrust faults requires that the greatest principal stress be horizontal (fig. 8), and the consistent alignment of the small thrust faults in the study area suggests that they are related to regional compressional stress.

The thrust faults would not have formed until the least stress was vertical; therefore, considerable erosional unloading was necessary before horizon-

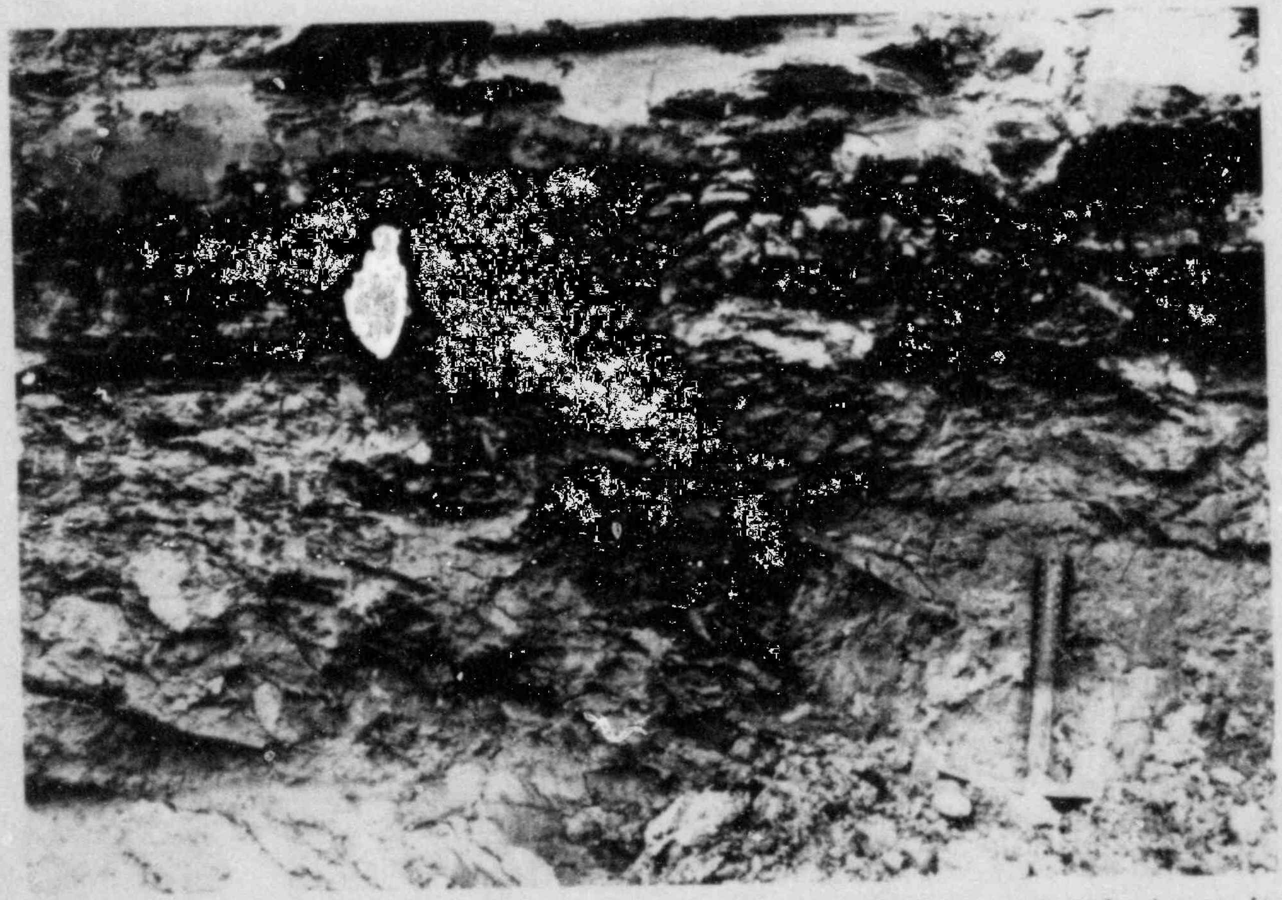

Figure 7. Photograph of a coalbed thrust fault related to regional stress in southwestern Indiana.

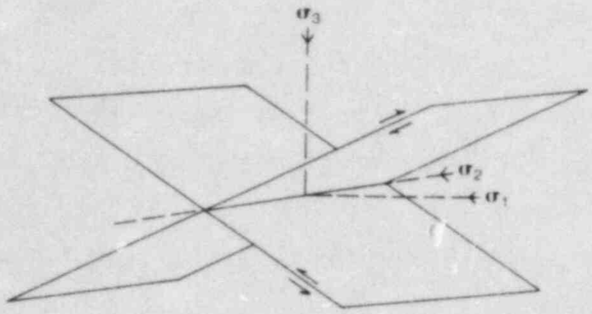

Figure 8. Diagram showing the relationship of thrust faults to the axes of principal stress (adapted from Price, 1966).

tal regional compressional stress became dominant and caused the faulting. This unloading followed formation of the vertical jointing in Indiana (see discussion under joint relationships), which formed while the overburden load was still sufficient to make the vertical stress axis the axis of greatest compression.

The strike of several faults in the southern one-third of the study area deviates from the north-northwest direction of the northern two-thirds. This deviation in strike indicates that the horizontal stress that produced these faults had a different orientation, probably from a different stress field. (See discussion under Regional Stress.)

Nelson and Lumm (1984) described numerous similar small-scale thrust faults in coal mines in Illinois that they believed were caused by regional compressive stress.

JOINTS[1]

Joint relationships

Joint orientations were measured at 240 locations in the study area, and an average of 10 measurements were made at each location (fig. 9). The most prominant joints were designated as primary, and other joints were designated as secondary. Histograms of the data (fig. 10) show an orthogonal relationship between orientations of the joint sets.

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[1]Part of this discussion is modified from Smith and Ault (in preparation)

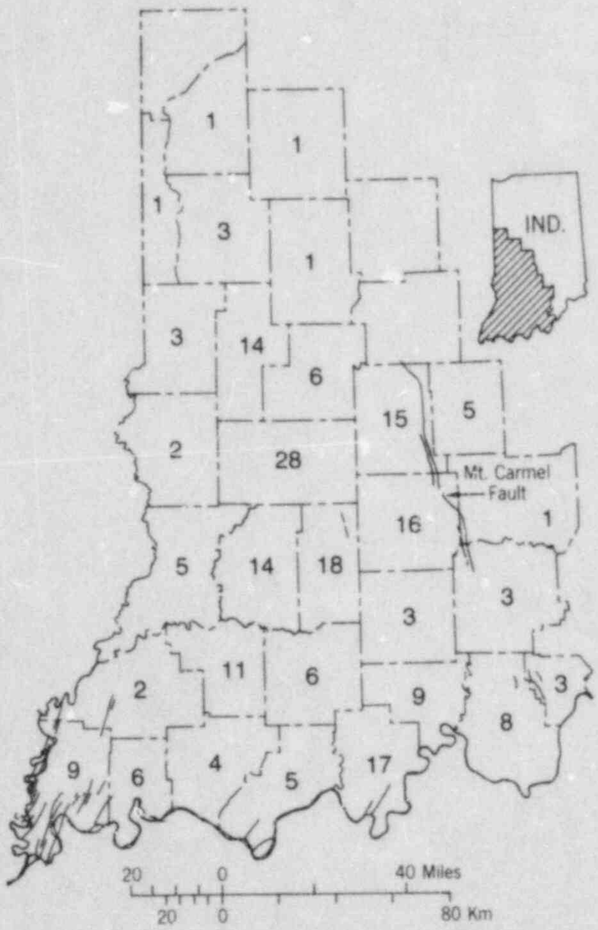

Figure 9. Map of southwestern Indiana showing the number of joint-measurement locations by county.

The primary and secondary joints are apparently the result of tensional forces produced by erosional unloading before the formation of the small-scale thrust faults discussed above. The orthogonal secondary joints formed shortly after the primary joints, possibly following some further erosional unloading, a method of joint formation discussed by Price (1966, p. 135). The secondary joints are not present at some locations and are much less prominent than the primary joints in most parts of the study area (fig. 11). The secondary joints in the northern two-thirds of the study area are oriented perpendicular to the inferred regional compressional stress from the east-northeast. It is likely, though not directly demonstrable, that the regional compressive stress helped suppress the formation of the secondary joints, which might otherwise be nearly as prominent as the primary joints if the stresses had been nearly equal in all horizontal directions.

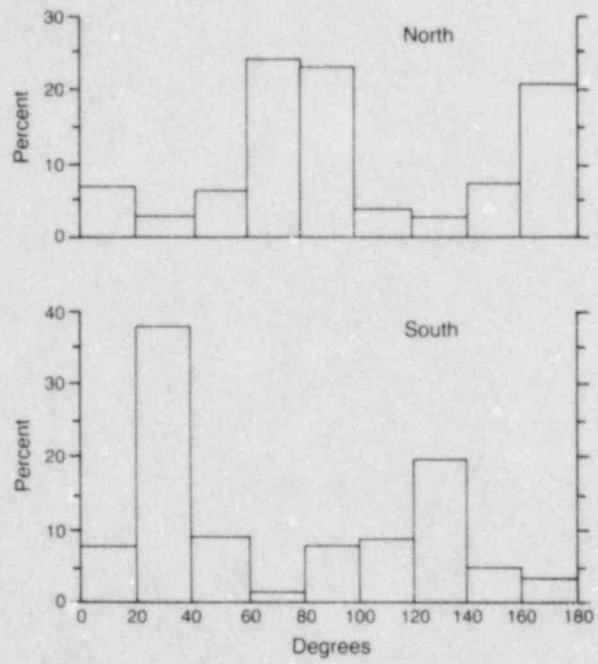

Figure 10. Histograms showing joint orientations north and south of proposed regional stress field boundary in southwestern Indiana. (See boundary location in fig. 18.)

The data for the mapped joints (fig. 11) were compared with the data for other prominent structural features, including the Mt. Carmel Fault and the unconformity between the Mississippian and Pennsylvanian Systems, to check for other possible genetic relationships.

The Mt. Carmel Fault is about 50 miles long in south-central Indiana, and it trends north-northwestward on the east edge of the Illinois Basin. The fault is a high-angle normal fault downthrown to the west with a maximum displacement of about 200 feet.

A series of joint measurements were made on the east and west sides of the Mt. Carmel Fault (fig. 12) to determine any relationship of joints to fault movements or fault stresses. None of the primary joints are parallel or

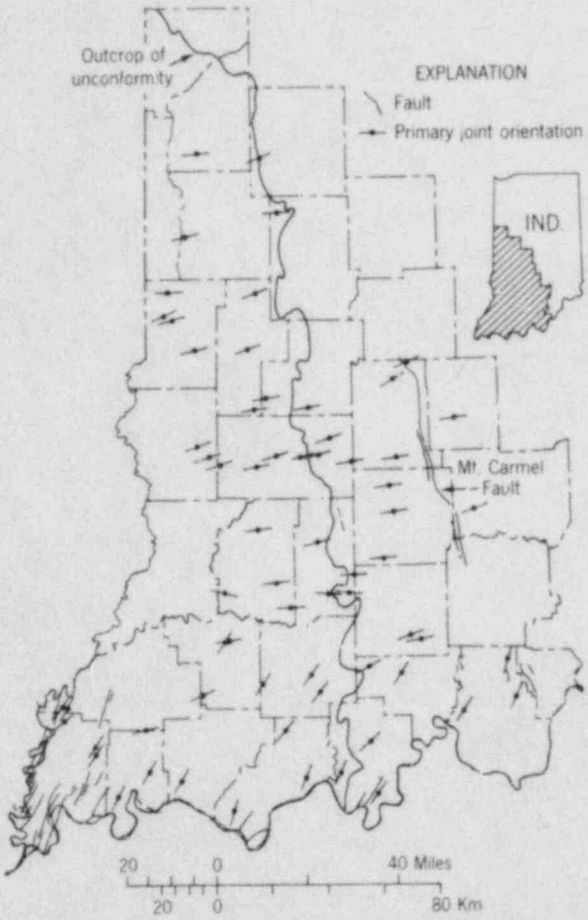

Figure 11. Map of southwestern Indiana showing typical joint orientations, the Mt. Carmel Fault, and the outcrop of the Mississippian-Pennsylvanian unconformity.

subparallel to the fault and none deviate significantly from the regional east-northeast trend in rocks of different ages on either side of the faulting, an indication that the joint orientations were a result of post-faulting stresses.

At the outcrop of the Mississippian-Pennsylvanian unconformity, basal sandstone of the Mansfield Formation (Pennsylvanian) unconformably overlies Chesterian sandstones and limestones. Joint orientations measured in similar localities and in different or similar lithologies but in rocks of different age on both sides of the unconformity do not vary significantly (fig. 13). But measurements of primary joints made at the south end of the traverse vary

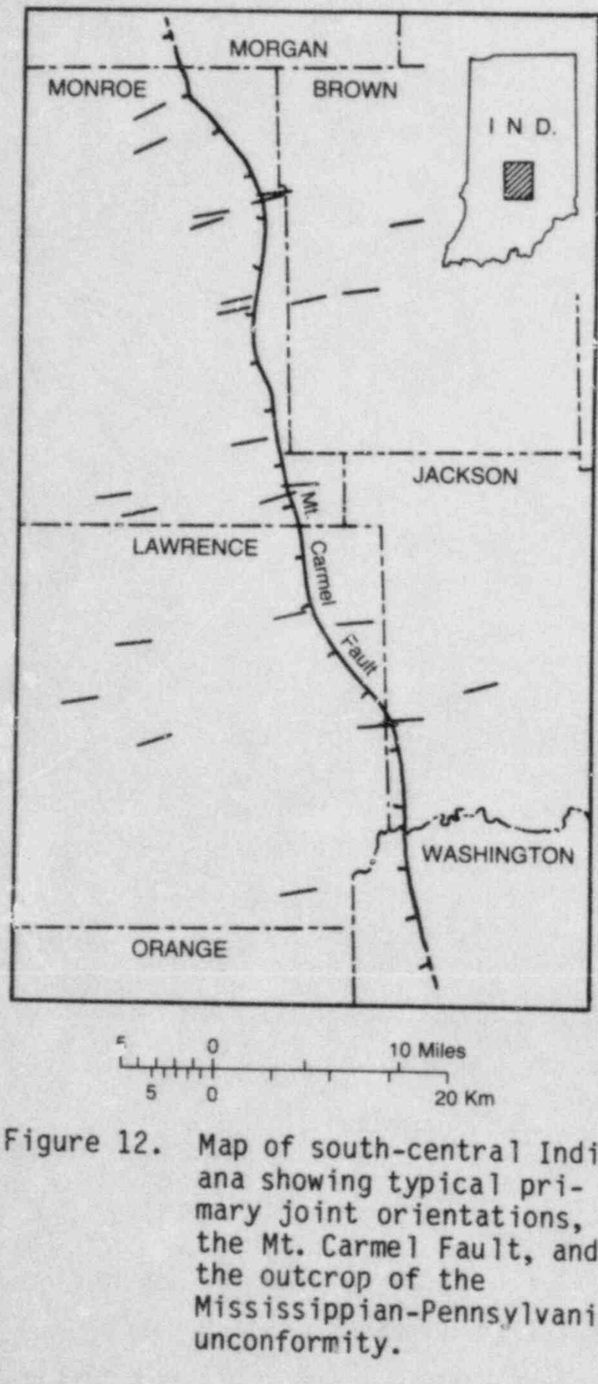

Figure 12. Map of south-central Indiana showing typical primary joint orientations, the Mt. Carmel Fault, and the outcrop of the Mississippian-Pennsylvanian unconformity.

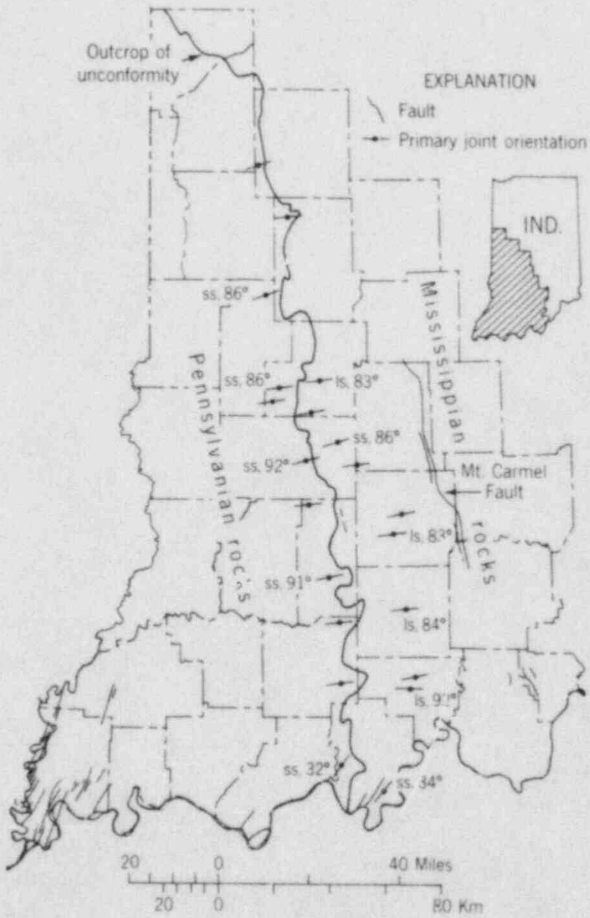

Figure 13. Map of southwestern Indiana showing primary joint orientations near the Mississippian-Pennsylvanian unconformity.

by about 50^{0} from the primary joints measured farther north. This variation is in all lithologies at the south end of the traverse.

Joints along Indiana Highway 37 from northern Monroe County to southern Perry County (fig. 14) were measured in rocks exposed in road cuts, outcrops, stream bottoms, and quarrys. In the northern part of the traverse, the median primary joint orientation is about 80^{0}. This east-northeast direction is relatively constant southward to Crawford County, where a northeast-southwest

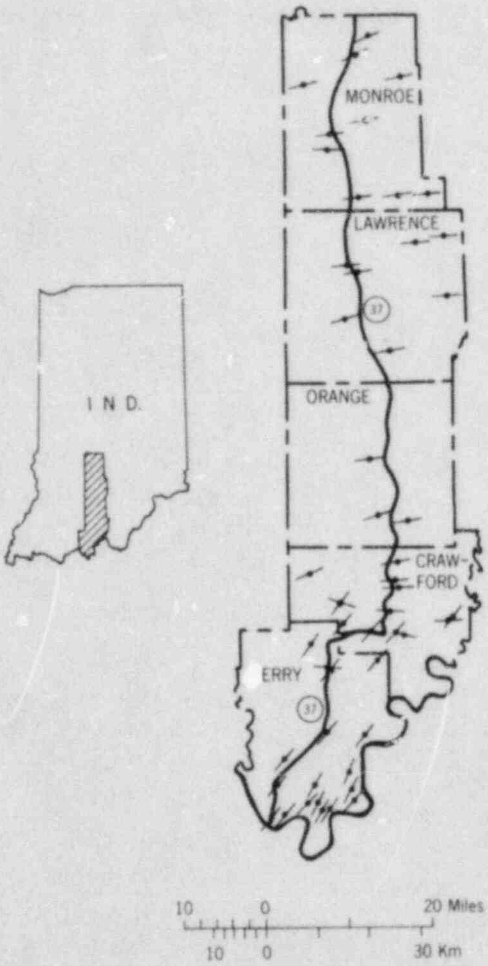

Figure 14. Map of southwestern Indiana showing primary joint orientations along a north-scuth traverse along Indiana Highway 37.

joint set is also present. South of this area, the primary joint orientations are generally 30 to 35°.

A traverse near Interstate Highway 64 from the western border of Indiana eastward from the Wabash River to the east edge of Floyd County shows the two distinct zones of joint orientations (fig. 15). Data available from geologic maps of Kentucky (Kepferle, 1974) and measurements made by Smith in north-central Kentucky show that the joint set with northeast-southwest orientation also exists in Kentucky. Hughes (1983) also found joints of similar orientation in central Tennessee. Part of the boundary between the two joint systems can be drawn across part of southern Indiana in the second tier of counties north of the the Ohio River.

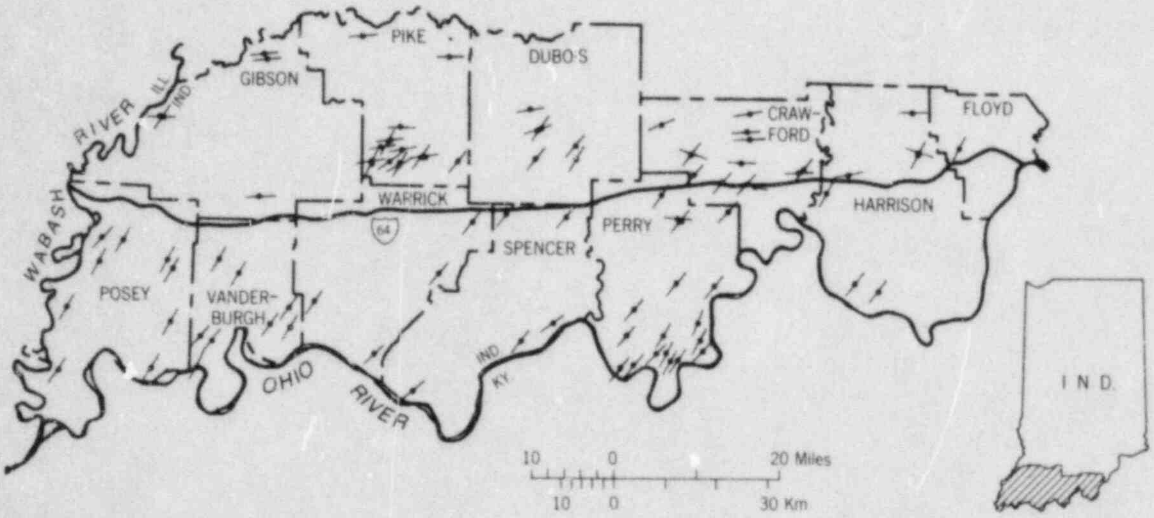

Figure 15. Map of southwestern Indiana showing primary joint orientations along an east-west traverse along Interstate Highway 64.

Butting relationships of joints

Limited data on butting relationships of joints in the northern part of the study area show that most of the primary and secondary joints are cross joints. A few north-northwest joints butt against east-northeast joints, and, conversely, a few east-northeast joints butt against north-northwest joints. At least three separate episodes of joint formation are suggested by the butting relationships, although the predominance of cross joints suggests that only a short overall time span may have been involved in their formation.

In Crawford County, the butting relationships are more complex among several joint sets. As above, cross jointing predominates, but at least four episodes of joint formation are indicated and others may have occurred. Again, the overall time span for the formation of the jointing may have been short. In limestone at one location, weathering zones are about equal in thickness along the sides of two crossing and butting joint sets, an indication of simultaneous or penecontemporaneous formation of the two separate sets.

In the southern part of the study area, limited data show mostly cross jointing, but some secondary joints butt against primary joints. We believe, however, that more data are necessary to draw conclusions on the overall sequence of jointing in this area.

REGIONAL STRESS[1]

Indiana lies within the extensive Midcontinent Stress Province outlined by Zoback and Zoback (1980) and Zoback and Zoback (1981). This province extends to the Appalachians on the east, the Gulf Coast states on the south, and the southern Great Plains on the west. Indiana also lies near the northeast edge of the Mississippian Embayment, which, although a part of the overall Midcontinent Stress Province, has anomalous horizontal-stress directions that deviate significantly from the generalized east-northeast direction of the Midcontinent province.

Zoback and Zoback (1980, fig. 5) assigned an east-west maximum compression to the Mississippian Embayment on the basis of focal-mechanism solutions of earthquake events by Herrmann (1979). Herrmann noted that 70 percent of his solutions having nearly horizontal-pressure axes trend northeast or east and calculated several compression axes having northeastern trends near New Madrid, Missouri, and in southern Illinois. To our knowledge, no direction of measured stress for present stress fields has been published for all of Kentucky or Indiana. Therefore, a large area, including Kentucky, Indiana, Tennessee, and part of Illinois, still awaits detailed mapping of measured stress directions, and stress relationships to the Midcontinent Stress Province in these areas are still speculative.

The efficacy of studies of jointing and contemporary small-scale folding and faulting as indicators of regional stress directions is becoming more apparent. Engelder (1982) made a convincing case for a spatial and genetic relationship between regional jointing and contemporary stress fields in the northeastern United States. He found that where joint sets could be separated from a genetic relationship to local structures, especially those not related to the regional lithospheric stress, such unrelated jointing is an indication of present compressive stress and should be given as much consideration as faults and folds.

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[1]Part of this discussion is modified from Smith and Ault (in preparation).

Our studies of jointing in southern Indiana support Engelder's (1982) concept of jointing relationships to regional lithospheric stress in the northeastern United States (fig. 16). Primary joint orientations in the northern part of the study area align well with the east-northeast direction of compressional stress of the Midcontinent Stress Province, which is supported by direct stress measurements in parts of Ohio and Illinois. Our joint-orientation measurements in southern Indiana are in agreement with the only other detailed jointing study in the area (Powell, 1976) and with a few other measurements in Owen and Montgomery Counties (Pettineo, written communication).

Figure 16. Map of part of the northeastern United States showing measured stress orientations and selected regional joints (adapted from Engelder, 1982).

The distinct shift in direction of both primary and secondary joint orientations in the southern part of the study area is believed to be caused by a different stress province that extends into Kentucky and farther south.

Our measurements of many small low-angle thrust faults in surface coal mines also support the proposition of two stress fields in southern Indiana, although the faulting probably originated after the jointing. The orientation of many of these faults in the northern part of the study area coincides with the orientation of the maximum compressive stress of the present Midcontinent Stress Province. They strike perpendicular to the principal lithospheric compressional stress. We can find no other explanation for the close alignments shown for these faults in figure 17. The deviation of those few faults mapped in the southern part of the study area shows a definite shift in the horizontal stress that produced the faults. The most likely explanation is

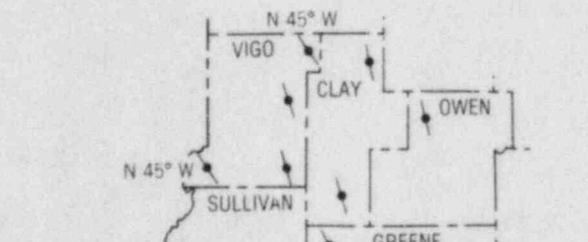

Figure 17. Map of southwestern Indiana showing the orientation of stress-related faults in coal mines.

the influence of a different regional stress field in the southern part of the study area.

On the basis of data from this study, Smith and Ault (in preparation) have proposed a boundary (fig. 18) in southern Indiana between two major stress fields: the Midcontinent Stress Province north of the boundary and a stress field they named the Ohio Valley Stress Province south of the boundary. Direct measurements of regional stress will be necessary to confirm this hypothesis, and the eastern and southern borders of the province are still undefined, although no conflicting information is known as far east as the

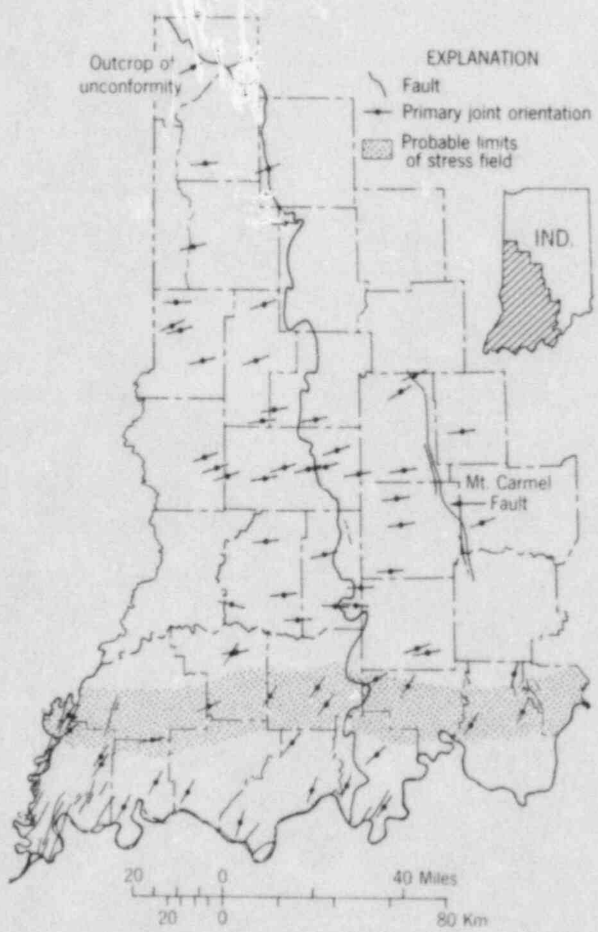

Figure 18. Map of southwestern Indiana showing typical primary joint orientations and proposed boundary between stress fields (Smith and Ault, in preparation).

Ridge and Valley Province or as far south as Zoback and Zoback's (1980) Gulf Coast Stress Province.

From our investigations in Indiana, we believe that the tectonic events that caused the major faulting in southwestern Indiana, the faulting of the Wabash Valley Fault System, the faulting in Spencer and Perry Counties, and the faulting along the Mt. Carmel Fault, were different from the forces operating in this area today. The present regional compressional stress could not have formed the major faulting in Indiana, which is mostly normal faulting caused by extensional stress or deep-seated vertical forces.

These faults and the extensive major faulting in southern Illinois and northwestern Kentucky described by Nelson and Lumm (1984) show no evidence of significant horizontal slip, a necessary stress-release mechanism for these faults if massive compressional stress was operative. No sediments of Pleistocene or Holocene age have been disturbed over the faults, nor have epicenters of any recorded earthquakes in Indiana been associated with the faults.

Rather, we believe that recent tectonics in southern Indiana have been and are dominated by regional compressive lithospheric stress as indicated in Indiana by aligned small-scale thrust faulting and by oriented jointing.

FUTURE WORK

Besides direct measurements to confirm the above stress-province boundary and stress directions, additional joint mapping is needed in other parts of Indiana, particularly southeastern Indiana where the proposed boundary may also be present. Nelson and Lumm (1984) recently reported two small-scale thrust faults in coal mines in extreme northwestern Kentucky that indicate east-west compressional stress. Much additional fieldwork to map both joints and small faults is needed in Kentucky and Tennessee to determine the relationship of such features to stress fields in those states. Obviously, numerous direct measurements of regional stress are also needed.

A knowledge of jointing patterns and their genesis and predictability is of great importance for many practical purposes, specifically for coal mining and construction in southern Indiana. Much more accurate prediction of jointing patterns should be possible with better delineations of regional-stress directions and boundaries.

An investigation by geologists of the Indiana Geological Survey of major and minor faulting in southern Indiana is complete after nearly 7 years. All known major faulting has been mapped in detail using all available subsurface data, and extensive surface mapping has been completed in those areas where unconsolidated sediments are thin. These data are available in published form and in the files of t·e Indiana Geological Survey.

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13 ABSTRACT (200 words or less)

This project was directed towards the characterization of: (1) the known large faults in southern Indiana, i.e., the Georgetown Fault in Floyd County and the newly named Crandall Fault in Harrison County; and (2) the small scale fractures endemic to southwestern Indiana. The Georgetown and Crandall Faults are normal faults that have a maximum vertical displacement of about 65 feet. They are post-Valmeyeran and pre-Pleistocene in age and are probably the result of hinge-line deformation between the subsiding Illinois Basin and the Cincinnati Arch. In contrast, abundant small-scale faults and joints are related to regional compressive lithospheric stress or to sedimentologic processes that operated penecontemporaneously with deposition of the rocks in which they are found. Structures related to regional stress include small-scale thrust faults with displacements of a few inches to a few feet and joints that are widespread in mines and outcrops in rocks of Mississippian and Pennsylvanian age. The jointing and most of the small-scale thrust faulting indicate that southern Indiana is affected by the Midcontinent Stress Province in the northern part of the study area and by another stress field in the southern part. An east-west boundary can be defined between the two stress fields.

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