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Faulting in Southwest Indiana

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Faulting in Southwestern Indiana

by

Curtis H. Ault and Dan M. Sullivan

ABSTRACT

Faults of the Wabash Valley Fault System, faults in Perry and Spencer Counties, Indiana, and the Mt. Carmel Fault are of the normal type and high angle and occur as single fault planes or as well-defined compound faults as much as 50 miles long with displacements ranging from a few feet to more than 400 feet. The Wabash faults and those in Perry and Spencer Counties were formally mapped, described, and named for the first time. Although supporting deep-drilling data are sparse, the Wabash and Mt. Carmel faults are probably present at depth, where they may form major structural alignments in basement rocks. No past studies have associated earthquake centers with any of the faults. The Wabash and Perry and Spencer County faults are post-Pennsylvanian and pre-Pleistocene in age. Early movement on the Mt. Carmel Fault is post-Valmeyeran, possibly Chesterian in age. The Wabash faulting is probably related to the regional tectonics that produced the New Madrid disturbance, but it is not a direct continuation of New Madrid faulting across the Rough Creek Fault Zone. The Mt. Carmel Fault may be associated with the hinge line of the eastern shelf of the Illinois Basin.

SUMMARY OF RESULTS

There are three major areas of known faulting in southwestern Indiana, the Wabash Valley Fault System in the southwestern tip of Indiana, the Mt. Carmel Fault and associated faults of south-central Indiana, and faulting in Perry and Spencer Counties at and near the Ohio River. Faults in the Wabash Valley Fault System and in Perry and Spencer Counties were formally mapped, described, and named for the first time. The 50-mile-long Mt. Carmel Fault and its associated faults were delimited and more fully mapped in detail than they had been.

All faults in these three areas are of the normal type with displacements ranging from a few feet to more than 400 feet. All of them are high angle and may occur as single fault planes or in zones with five or more fault planes with 20 feet or more of displacement.

Faulting in the Wabash Valley Fault System is post-Pennsylvanian in age and at least as late as post-Middle Mississippian in the other two areas. None of the faults cut overlying sediments of Pleistocene or Holocene Ages.

Since no recent movement was recognized on any of the faults, no recent seismic activity could be assigned to the faults, and no past studies have recognized epicenters or hypocenters of Indiana earthquakes that are associated with any of the faults.

No thickening or thinning of strata due to growth faulting was determined in any area. Therefore, movement on the faults previous to the times stated above was either nonexistent or too small to be detected with our data.

The Mt. Carmel Fault and faulting of the Wabash Valley Fault System in Indiana appear to extend to basement depths, the Mt. Carmel Fault to one major fault zone and the Wabash Valley faults to three or more major fault zones. Faulting in Perry and Spencer Counties is much less prominent than that mentioned above, and there are no data indicating that these faults extend to the basement.

Regionally, our work does not support a northeasterly extension of the New Madrid Fault Zone across the Rough Creek Fault Zone into the Wabash Valley Fault System of southwestern Indiana. Maximum displacements of the Wabash Valley faults are in southern Indiana. In northwestern Kentucky displacements become less and the faults may die out completely near the Rough Creek faults.

The Mt. Carmel Fault is most likely genetically related to the LaSalle Anticline and possibly hinge lines of the eastern flank of the Illinois Basin. The north-northwesterly trend of the Mt. Carmel Fault is opposed to any northeasterly seismic trend from southwestern Indiana.

The mapping and characterization of the faults in southwestern Indiana are of great value in the exploration for and extraction of large reserves of petroleum and coal found in or associated with the faulted rocks. There is also potential economic mineralization associated with the faulting.

Although this study completes the investigation of large-scale faulting in southwestern Indiana, small-scale surface faulting, particularly as reported in some surface coal mines, remains to be investigated.

PROJECT PRODUCTS

Published maps

Tanner, G. F., J. N. Stellavato, and J. C. Mackey

1980 - Map of southwestern Gibson County, Indiana, showing structure on Cypress Formation (Mississippian): Indiana Geol. Survey Misc. Map 29. (scale 2 inches equal 1 mile)

1980 - Map of northern Posey County, Indiana, showing structure on Cypress Formation (Mississippian): Indiana Geol. Survey Misc. Map 30. (scale 2 inches equal 1 mile)

1980 - Map of southern Posey County, Indiana, showing structure on Cypress Formation (Mississippian): Indiana Geol. Survey Misc. Map 31. (scale 2 inches equal 1 mile)

1981 - Map of southwestern Gibson County, Indiana, showing structure on Springfield Coal Member (V) of the Petersburg Formation (Pennsylvanian): Indiana Geol. Survey Misc. Map 32. (scale 2 inches equal 1 mile)

1981 - Map of northern Posey County, Indiana, showing structure on Springfield Coal Member (V) of the Petersburg Formation (Pennsylvanian): Indiana Geol. Survey Misc. Map 33. (scale 2 inches equal 1 mile)

1981 - Map of southern Posey County, Indiana, showing structure on Springfield Coal Member (V) of the Petersburg Formation (Pennsylvanian): Indiana Geol. Survey Misc. Map 34. (scale 2 inches equal 1 mile)

Published reports

Ault, C. H., D. M. Sullivan, and G. F. Tanner

1980 - Faulting in Posey and Gibson Counties, Indiana: Indiana Acad. Sci. Proc. for 1979, v. 89, p. 275-289.

Tanner, G. F.

1980 - Movement, drag features, and complexity of the Mt. Carmel Fault, south-central Indiana (abs.): EOS, v. 61, p. 1195.

Sullivan, D. M., C. H. Ault, and G. F. Tanner

1981 - Faulting in Perry and Spencer Counties, Indiana: Indiana Acad. Sci. Proc. for 1980, v. 90, p. ___-___.

Report in editorial process

Sullivan, D. M., C. H. Ault, and J. N. Stellavato

19__ - The Wabash Valley Fault System in Indiana and its economic implications: Kentucky Geol. Survey, Ser. X., Spec. Pub.__.

Report related to project

Ault, C. H. and D. D. Carr

1980 - New exploration and evaluation of coal resources in complexly faulted area containing old petroleum production (abs.): Amer. Assoc. Petroleum Geologists Book of Abs., AAPG-SEPM-EMD Ann. Convention, p. 22.

rafted maps and cross sections on file at Indiana Geological Survey

Tanner, G. F.

1981 - Map showing the Mt. Carmel Fault in south-central Indiana: map, Indiana Geol. Survey (scale 1 inch equals 1 mile). Avail. from Indiana U

1981 - Five cross sections of the Mt. Carmel Fault and associated structures

7½-minute topographic quadrangles showing surface trace of the Mt. Carmel Fault on file at Indiana Geological Survey

Allens Creek Quadrangle

Hindustan Quadrangle

Norman Quadrangle

Tunnelton Quadrangle

Unionville Quadrangle

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INTRODUCTION

Faulting in southwestern Indiana was noted as early as 1835 near Cannelton, Perry County, where coal miners encountered small faults in underground coal mines. But the extent of these and other nearby faults was not known in this area until considerable subsurface data were obtained from oil-well drilling in the early and mid 1900's. The longest surface fault in Indiana, the Mt. Carmel Fault in Lawrence and Monroe Counties, was not suspected until 1896 (Hopkins and Siebenthal, 1897) and was not formally described or named until 1903 (Ashley and Kindle). The major fault system in Indiana, the Wabash Valley Fault System in Posey and Gibson Counties in the southwestern tip of the state, remained virtually unknown until sufficient subsurface data, available from oil-well drilling in the 1930's and 1940's, began to reveal the numerous faults covered by Pleistocene and Holocene sediments.

Although parts of the Mt. Carmel Fault have been described in detail, few studies have been conducted or published for much of the faulting in southwestern Indiana, particularly for the Wabash Valley Fault System. (See discussion of individual areas for particular references.)

It was particularly appropriate, therefore, that this 4-year study of the faulting in southwestern Indiana, funded in part by the U.S. Nuclear Regulatory Commission, was undertaken as part of a larger investigation of the regional tectonics, structure, and seismicity of an area within 200 miles of New Madrid, Missouri. The study was conducted by the New Madrid Study Group, a group of geologists and geophysicists from various universities and geological surveys from states in or bordering the study area.

During the first 2 years of the investigation in Indiana, mapping and characterization of the Wabash Valley Fault System were accomplished by using data mostly from numerous geophysical logs of closely drilled wells in Posey and Gibson Counties. Both surface and subsurface investigations were then conducted in a second area of known faulting in Perry and Spencer Counties. Finally, test drilling and concentrated field mapping of the Mt. Carmel Fault in south-central Indiana completed our study.

This report includes investigations of the Wabash Valley Fault System and faulting in Perry and Spencer Counties, which were reported previously, and information on the Mt. Carmel Fault, which is presented here for the first time. Our interpretation of the relationships of the faulting in southwestern Indiana to regional structure and tectonics, especially with reference to the New Madrid study area is also reported. Finally, we have included suggestions for further study of small-scale faulting within the study area.

GEOLOGIC AND TECTONIC SETTING OF SOUTHWESTERN INDIANA

The eastern shelf of the Illinois Basin encompasses southwestern Indiana. The Illinois Basin is an oval intercratonic basin surrounded by broad regional arches. The eastern shelf in Indiana is separated from the Appalachian Basin by the Cincinnati Arch, a long low feature which extends southward into Kentucky. In northwestern Indiana a continuation of this feature, the Kankakee Arch, separates the Illinois Basin from the Michigan Basin (Fig. 1).

The extent of the structural Illinois Basin is measured from the crests of the surrounding arches. But as commonly used, the term Illinois Basin is defined by some boundary arbitrarily determined by a structural interpretation or by the limit of various stratigraphic units (Fig. 1). Basin dimensions vary accordingly.

Within the basin there are three major structural features: the LaSalle Anticline, the DuQuoin Monocline, and the Rough Creek and Cottage Grove Fault Zones (Fig. 2). Of these three major uplifts, only the LaSalle Anticline has influenced the structural setting of southwestern Indiana and is discussed later in this report.

Less than a handful of deep tests have reached the basement rocks in the deeper parts of the structural Illinois Basin, but the record is sufficient to show that parts of the basin received sediments throughout the Paleozoic Era.

The fragmentary early sedimentary history of the southern part of the Illinois Basin has been advanced through recent work by Schwalb (1980), who indicated a depocenter receiving late Precambrian or Early Cambrian deposits south of the Rough Creek Fault Zone. The source of these early sediments were from the southeast and southwest. The total sedimentary section is estimated to be more than 17,000 feet in this trough area and constitutes the thickest rock sequence in the Illinois Basin.

As determined by seismic studies, the extreme southwest corner of Indiana has a sedimentary rock sequence of about 13,000 to 14,000 feet. No basement tests have been drilled to confirm this thickness, however, or to confirm the proposition that the earliest sediments are late Cambrian in age. Extrapolation from deep wells drilled elsewhere indicates that the amount of marine basin-fill sediments far exceeds that of nonmarine sediments in a descending rank of abundance

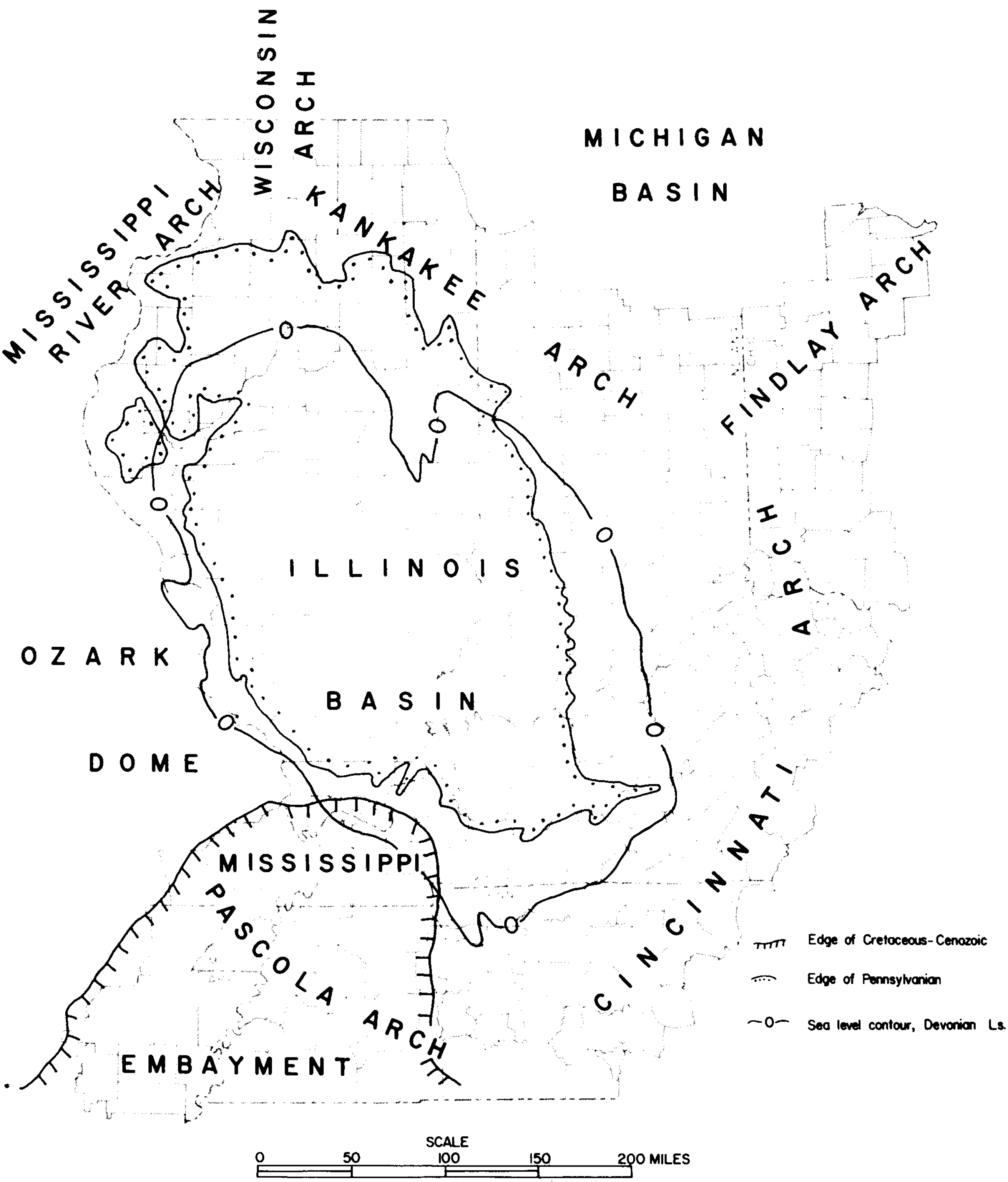


Figure 1. Illinois Basin outline and major bounding structural features. Modified from Swann and Bell (1958).

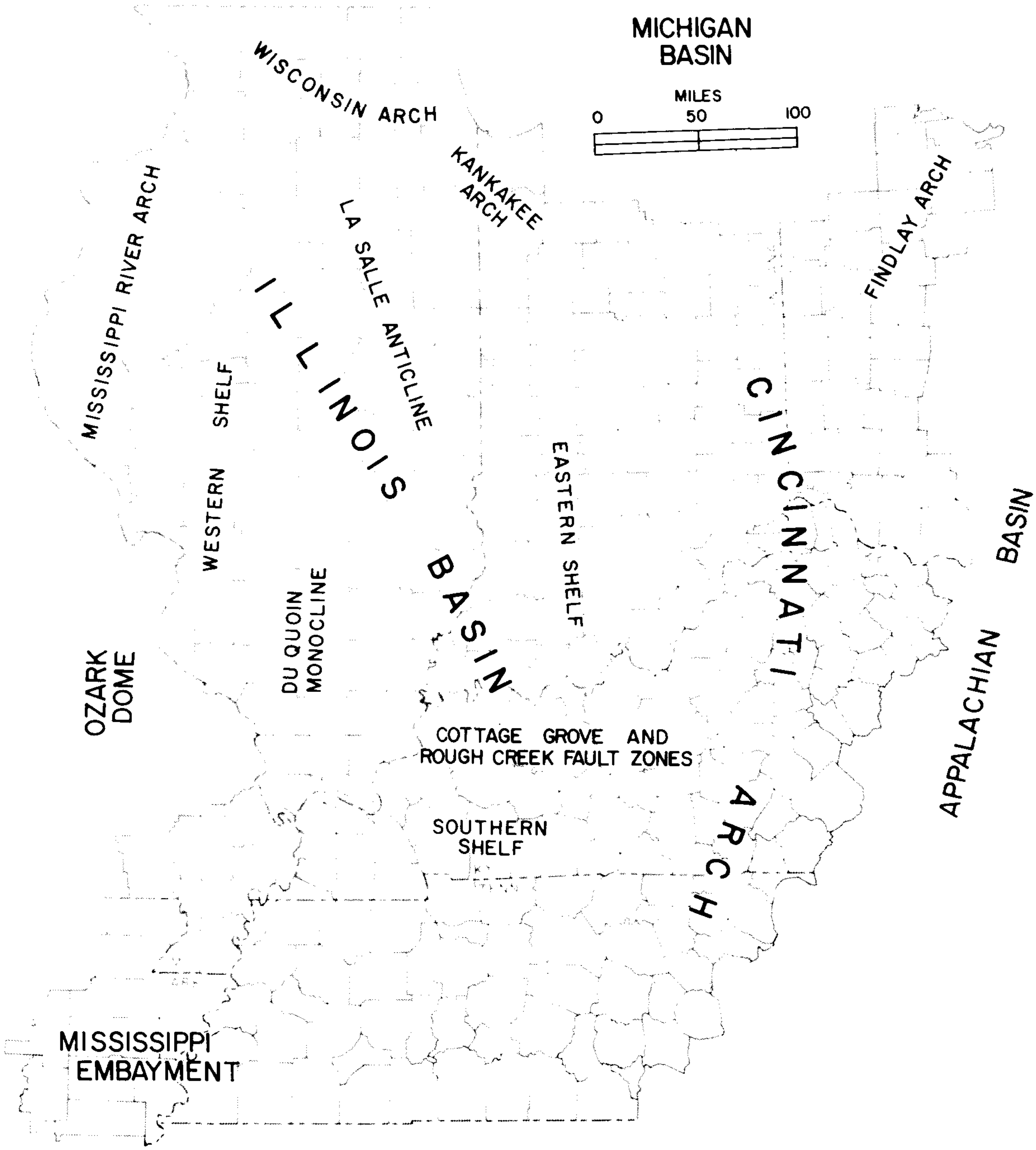


Figure 2. Structural features of part of the midwestern United States. Modified from Bond and others (1971); Illinois and Indiana-Kentucky Geological Societies (1968).

of dolomite, limestone, shale (partly continental), sandstone, chert, anhydrite, and coal.

Major stratigraphic units within the basin thin eastward and westward from the axes of greatest thickness near the boundary between Indiana and Illinois, and nearly all thin northward toward the Wisconsin and Kankakee Arches.

Some of the major regional unconformities evident on the flanks and arches surrounding the basin are not determinable in southwestern Indiana because of insufficient deep-drilling data. However, dramatic unconformities, such as that seen at the top of the Mississippian sequence, are evidence of uplift and erosion and changes in basin setting.

Many geophysicists believe that prominent gravity anomalies in the Midwest result from lithologic changes within the buried basement or from differences in crustal thickness. Thiel (1956) has shown that prominent positive gravity features in the Midwest have originated from dense basalt flows of Keweenawan (late Precambrian) age, and Rudman and Blakely (1965) have shown that aeromagnetic and gravity anomalies in Indiana could originate from similar basalts. Most basement tests in Indiana, however, are concentrated in structurally high areas where pink granites have been found. Rudman and others (1965) have suggested a basement scarp in southwestern Indiana, and Braile and others (1980) have noted that the area is marked by a linear series of positive gravity and magnetic anomalies. However, neither the character nor age of the basement or of the possible fill of such a scarp-lined trough is yet known to support the geophysical data.

FAULTING IN POSEY AND GIBSON COUNTIES, INDIANA[1]

By Curtis H. Ault, Dan M. Sullivan, and George F. Tanner

History of Study

Since the early 1900's more than 6,000 petroleum test wells and other tests have been drilled in Posey County and southern Gibson County, which contain nearly all known faults of the Wabash Valley Fault System in Indiana. Detailed subsurface structural mapping by petroleum companies was conducted from the 1930's and 1940's until the late 1960's, when oil activity declined. But these studies have been proprietary, and the companies have released little or no structural data. Further, oil companies have usually focused attention on the reservoir rocks near the faults rather than on the complexity of the faults themselves.

Part of the Ridgeway Fault of the Wabash Valley Fault System in Illinois was described by Cady (1919). As drilling for petroleum and mining for coal progressed in Illinois, the fault system was further defined in county reports and maps and other fault studies (Stonehouse and Wilson, 1955, for example). The most recent mapping of the faults in Illinois was completed by Bristol and Treworgy (1979).

Faults of the Wabash Valley Fault System that extend into Kentucky have most recently been mapped in detail by geologists of the U.S. Geological Survey (Johnson, 1974; Johnson and Norris, 1976).

Available Indiana studies of the fault system include a study by Patton (1940), which shows a small part of the faulting near Griffin Consolidated Field, and a study by Butler (1967) in Posey County, which was based on about one control point per square mile except in a few areas near the faults where additional data were used. The faults are shown on a regional geologic map published by Gray and others (1970) on a scale of 1/250,000.

Our study is the first using nearly all available geophysical and other data to construct detailed maps and to closely locate and characterize the faulting. Six maps of Posey County and southern Gibson County, on a scale of 2 inches to the mile, were published by the Indiana Geological Survey in 1981 (Tanner and others, 1980a, 1980b, 1980c, 1981a, 1981b, 1981c). These maps show

[1]Reprinted in part with slight modifications from the Proceedings of the Indiana Academy of Science for 1979.

faults, well control, and depths on two horizons, the top of the Springfield Coal Member (V) of the Petersburg Formation (Pennsylvanian) and the top of the Cypress Formation (Mississippian). They are the basis for the description of the faults in this report and should be referred to for detailed fault interpretations.

Tectonic Setting

Faults of the Wabash Valley Fault System, some extending more than 30 miles along the Wabash Valley in both Indiana and Illinois, are confined to Posey and Gibson Counties in southwestern Indiana. The entire Wabash Valley Fault System, which includes extensions of Indiana faults and additional parallel and subparallel faults in northwestern Kentucky and southeastern Illinois, trends north-northeastward from the more extensive and more structurally complex Cottage Grove and Rough Creek Fault Zones in southern Illinois and northwestern Kentucky (Fig. 3).

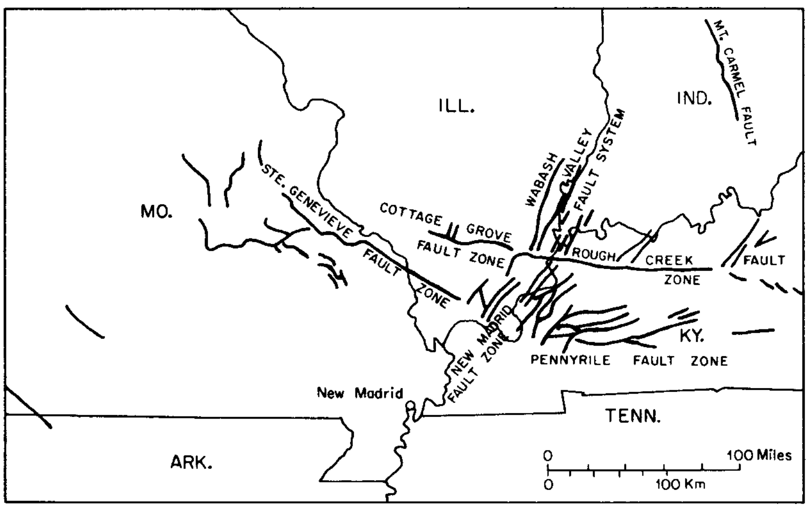


Figure 3. Fault systems near New Madrid, Missouri

The Cottage Grove and Rough Creek Fault Zones are part of the 38th Parallel Lineament, a band of structural features which trend generally east-westward across the eastern United States along the 38th parallel. The most seismically active area in eastern North America is the New Madrid Fault Zone, which is on a trend with the Wabash Valley Fault System south of the Cottage Grove and Rough Creek Fault Zones.

Braile and others (1978) reported a magnetic and gravity anomaly in the southwest corner of Indiana, roughly on strike with the New Madrid Fault Zone, but they did not observe a direct connection between the two structural areas. Recently completed geologic mapping of northwestern Kentucky by the U.S. Geological Survey shows that faults of the Wabash Valley Fault System die out as they approach the Rough Creek Fault Zone, and a study of the system in Illinois by Bristol and Treworgy (1979) found no evidence that the Wabash Valley faults intersect the east-westward-trending faults in southern Illinois.

Some geologists believe much of the present structure within the Illinois Basin was influenced by structures developed by the end of Precambrian time. Seismic data partly supported by subsurface studies indicate that Paleozoic structures, such as the Rough Creek Fault Zone in Kentucky and the LaSalle Anticline in eastern Illinois, are underlain by basement ridges and scarps. Rudman and others (1965), on the basis of seismic studies, projected a Precambrian scarp or ridge from the LaSalle Anticline southward across the southwest corner of Indiana and postulated such a ridge as the primary control in the developing structure during late Paleozoic time. More recently, Braile and others (1978) suggested that continental rifting is significant in the tectonism of southwestern Indiana.

Method of Study

Faults of the Wabash Valley Fault System were mapped by using subsurface information from petroleum, coal, stratigraphic, and other drill tests to a maximum of one control point for every 10 acres in most areas and by using all available information near the faults. The faults were detected by structure mapping and by well-to-well correlation of geophysical logs, mostly electric logs, to ascertain rock sections missing because of faulting. More than 200 wells drilled through normal faults have been recorded in the area of study. No repeated rock sections due to reverse faulting have been found.

Although only maps showing faults on the Springfield Coal Member (V) and the Cypress Formation are included in this report (Figs. 4 and 5), structural data have also been recorded for the West Franklin Limestone Member of the Shelburn Formation (Pennsylvanian), the base of the Menard Formation (Mississippian and the top of the Renault Formation (Mississippian). Data from the latter three structural markers have been used in locating and interpreting the faulting shown in Figures 4 and 5, which are simplifications of the detailed large-scale mapping by Tanner and others.

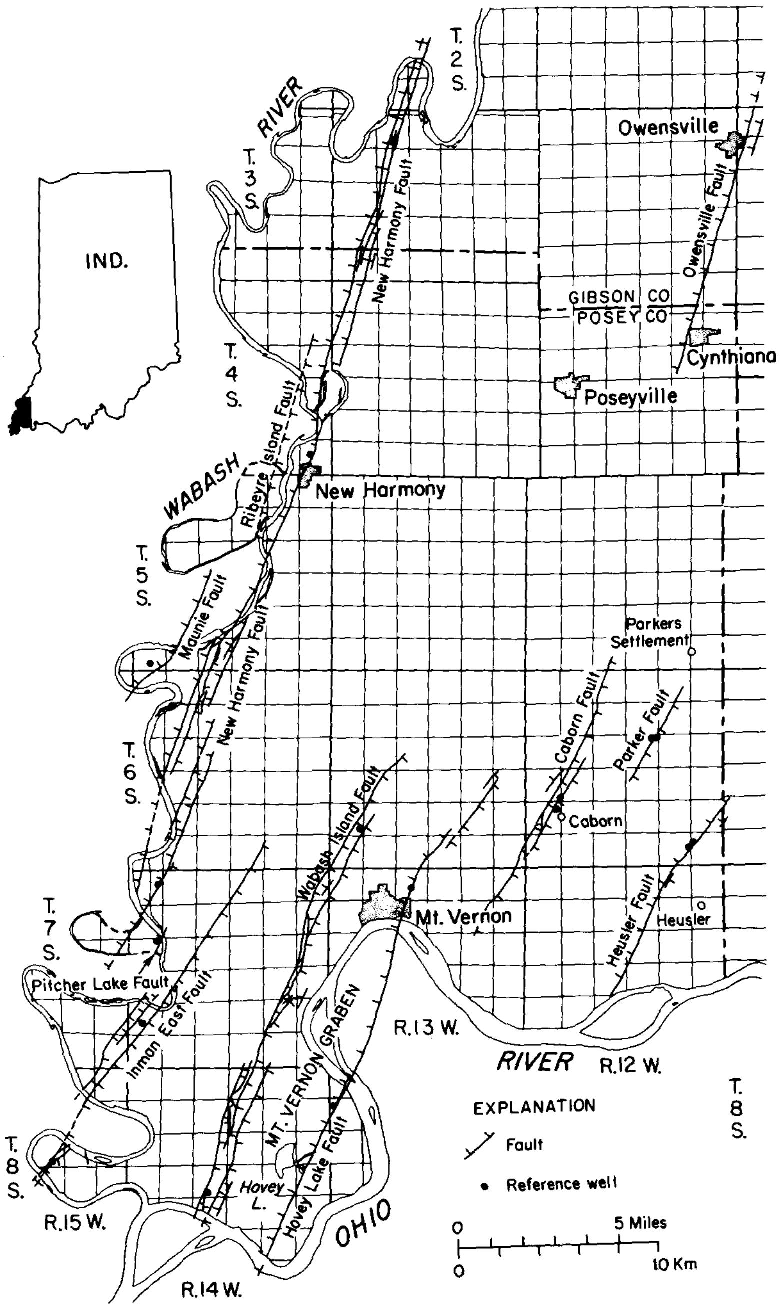


Figure 4. Map of Posey County and southern Gibson County showing faulting on the Springfield Coal Member (V) of the Petersburg Formation. Modified from Tanner and others (1981a, 1981b, 1981c).

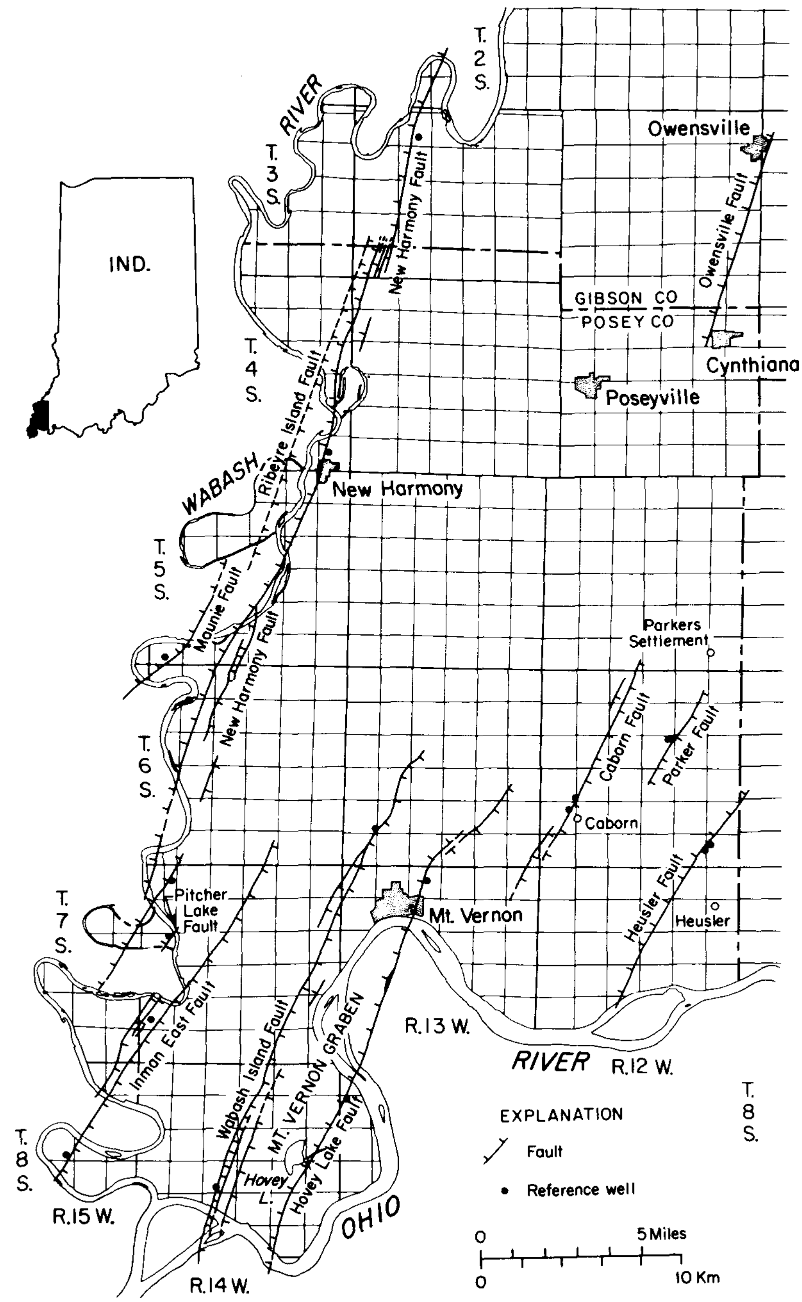


Figure 5. Map of Posey County and southern Gibson County showing faulting on the Cypress Formation. Modified from Tanner and others (1980a, 1980b, 1980c).

Detailed interpretation of the geophysical logs, essential for the close correlation necessary for determining rock sections missing because of faulting, was aided by examination of rock cores of Pennsylvanian age from reference wells drilled by the Indiana Geological Survey, by examination of lithologic strip logs of drilling samples, and by use of coal-test (core-hole) data.

Correlations of electric logs usually uncover only those faults with more than 20 feet of vertical displacement, although there undoubtedly are faults with less displacement in the fault zones. The larger faults are readily mapped in areas of dense drilling, but they were traced as far as possible by abrupt changes in elevation on marker beds in areas where only three or four wells had been drilled per section and no wells which cut the faults had been drilled.

Only a small amount of structural data came from wells drilled in rocks below 3,000 feet. As most of the petroleum wells have been drilled to test the Cypress Formation or deeper rocks, subsurface control is nearly as complete for the Cypress as for the Springfield Coal Member some 1,800 feet shallower. Our confidence in the accuracy of the mapping for both horizons is high.

Numerous cross sections were constructed for correlating fault planes from well to well, determining angles of fault dip, and resolving the complexity of compound faulting. Accurate dip angles were calculated where single fault planes could be correlated from well to well from shallow to deeper horizons. But in some complex zones, we were unable to follow single fault planes between wells.

Attempting to locate faulting by seismic refraction in northern Posey County was unsuccessful because of the lack of shallow reflector beds in which displacement by faulting could be recognized.

Limited surface fieldwork in areas of known faulting found no surface expression of faulting. Eventually some faulting may be detected on the surface, but undoubtedly it will be minor.

Fault Descriptions

Faults of the Wabash Valley Fault System in Indiana trend N. 15° E. to N. 50° E. as single fault planes or as well-defined compound faults in zones usually less than half a mile wide but as much as 1½ miles wide. The faults bound blocks tilted as much as 6° and horst and graben blocks as much as 5 miles wide. The faults are normal type, and strata may be downthrown either eastward or westward.

The fault planes dip at angles ranging from 60° to 80°, and compound faults may consist of as many as five individual fault planes, each with more than 20 feet of vertical displacement. Rock slices between individual fault planes of compound faults include narrow horst and graben structures and downslipped slices among individual en echelon faults (Fig. 6). The number of individual fault planes in a zone decreases with depth from rocks of Pennsylvanian age to rocks of Mississippian age, and our cross sections show that most shallow faults are splinters of deeper faults, although some faults may have displacements dissipated in softer strata.

Growth faulting was not detected; thickening or thinning of stratigraphic units due to differential sedimentation on opposite sides of faults was not found, nor was evidence found indicating differential erosion across faults at the Mississippian-Pennsylvanian unconformity. As far as could be determined, all faults in deeper rocks cut all shallower rocks but did not cut unconsolidated surface materials. All known faulting is therefore post-Pennsylvanian and pre-Pleistocene in age.

The following described Heusler, Parker, Caborn, Owensville, Hovey Lake, and Wabash Island Faults are newly named. The first four are wholly within Indiana. The Hovey Lake and Wabash Island Faults have their maximum vertical displacement in southern Indiana but extend southward into Kentucky where their displacement decreases. The Inman East, Pitcher Lake, New Harmony, Ribeyre Island, and Maunie Faults are extensions of faults in Illinois whose names have been adopted for formal use in Indiana.

Heusler Fault

The Heusler Fault trends N. 30° E. from sec. 28, T. 7 S., R. 12 W., about 7½ miles to sec. 30, T. 6 S., R. 11 W., at the Posey-Vanderburgh county line (Figs. 4 and 5). It dips northwestward and borders the west side of the Heusler Consolidated and Crunk East Fields. It was named for Heusler, 1½ miles east of the fault in sec. 12, T. 7 S., R. 12 W. Two petroleum tests that cut the fault have been designated reference wells: The Moco Drilling Co. No. 1 George P. Martin and the Mayhew Oil Co., Inc., No. 3 Irma Short and Paul Sanders (Table 1).

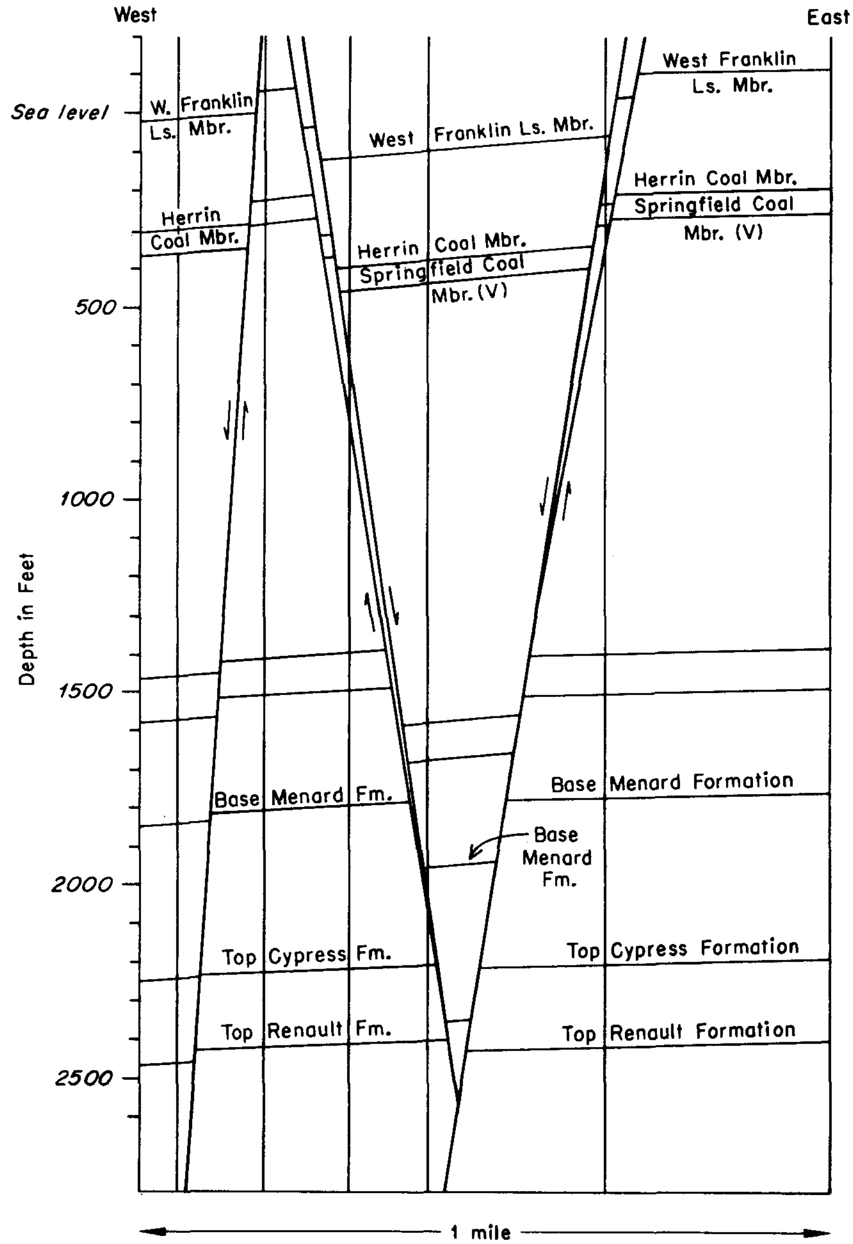


Figure 6. Cross section of compound faulting of the New Harmony Fault (secs. 33 and 34, T. 5 S., R. 14 W.).

Table 1. Reference wells for faults in Posey and Gibson Counties.

Fault	Operator	Farm	Location (Sec-T-R)	Fault displacement depth, and elevation (ft)
Heusler	Moco Drilling Co.	No. 1 George P. Martin	SW¼SW¼NW¼ 36-6S-12W	100 at 880 (-370)
Heusler	Mayhew Oil Co., Inc.	No. 3 Irma Short and Paul Sanders	NE¼NE¼SE¼ 35-6S-12W	140 at 1,230 (-748)
Parker	B. M. Heath	No. 1 Herman A. Boeke	SW¼NE¼NE¼ 15-6S-12W	60 at 465 (-63)
Parker	G. L. Reasor	No. 2 Olus Justus	SE¼NE¼NE¼ 15-6S-12W	30 at 1,720 (-1,309)
Caborn	W. Duncan	No. 1 J. Seifert	NW¼SE¼NE¼ 30-6S-12W	30 at 2,110 (-1,672) 140 at 2,288 (-1,850)
Caborn	Oeth Drilling Co.	No. 1 Tennison	SE¼SE¼SE¼ 19-6S-12W	70 at 670 (-205)
Hovey Lake	Calvert Drilling Co.	No. 1 Harlem & Louisville Railroad Co. Comm.	NW¼NW¼SE¼ 4-7S-13W	80 at 570 (-193)
Hovey Lake	Carter Oil Co.	No. 1 M. E. Dixon	SE¼NW¼NW¼ 7-8S-13W	50 at 1,190 (-830) 110 at 1,540 (-1,188) 90 at 1,800 (-1,748) 60 at 1,910 (-1,558)
Wabash Island	Carl Miles	No. 1 Lynn M. Strack	SE¼NE¼SE¼ 30-6S-13W	60 at 550 (-165) 70 at 1,180 (-786)
Wabash Island	Yingling Oil & Mining Co.	No. 5 Maggie Murphy	SE¼NE¼SW¼ 21-8S-14W	370 at 1,070 (-709)
Inman East	C. E. Brehm Drilling & Producing	No. 1 Eugene M. Fuhrer	NW¼NE¼SW¼ 30-7S-14W	60 at 2,120 (-1,761)
Inman East	Carter Oil Co.	No. 25-W Skiles Unit	1100'FSL x 1340' FEL 15-8S-15W	330 at 1,320 (-976)
Pitcher Lake	Harry B. Mortimer	No. 2-A Greathouse Heirs	330' FNL x 3950' FWL 18-7S-14W	50 at 2,660 (-2,303)
New Harmony	Cherry & Kidd	No. 3 Gyger	2550' FNL x 594' FEL 6-7S-14W	130 at 615 (-260)
New Harmony	Joe Resnik	No. 1 K. D. Owen	1950' FNL x 2150' FWL 36-4S-14W	450 at 1,630 (-1,260)
New Harmony	Ryan Oil Co.	No. 1 Mary Alice Kelley	800' FSL x 330' FWL SW¼SE¼ 8-3S-13W	270 at 1,270 (-889)
Maunie	Gulf Refining Co.	No. 1 Albert Aldrich	665' FSL x 333' FEL 31-5S-14W	50 at 1,914 (-1,554)

Two accessory faults have been mapped in rocks of Pennsylvanian age, both less than half a mile long. One dips southeastward in sec. 2, T. 7 S., R. 12 W., and the other dips northwestward in sec. 25, T. 6 S., R. 12 W., and sec. 30, T. 6 S., R. 11 W. The Heusler Fault dips 60° between two wells cut by the fault in sec. 35, T. 6 S., R. 12 W. Maximum observed vertical displacement (missing stratigraphic section) is 140 feet in the No. 3 Irma Short and Paul Sanders.

Parker Fault

The Parker Fault trends N. 35° E. for about 3 miles from sec. 22, T. 6 S., R. 12 W., to sec. 2, T. 6 S., R. 12 W. (Figs. 4 and 5). It borders the east edge of the Parker Consolidated Field and was named for Parkers Settlement, 1.5 miles north of the fault at the junction of State Road 66 and St. Wendel Road. Two petroleum tests in sec. 15, T. 6 S., R. 12 W., the B. M. Heath No. 1 Herman A. Boeke and the G. L. Reasor No. 2 Olus Justus, cut the fault and have been designated reference wells (Table 1). A dip on the fault plane of 66° to the southeast has been calculated between the two reference wells. Maximum observed vertical displacement is 60 feet. No accessory faulting has been detected.

Caborn Fault

The compound Caborn Fault trends about N. 30° E. for 9 miles from sec. 1, T. 7 S., R. 13 W., to sec. 33, T. 5 S., R. 12 W. Its southwestern limit is uncertain, and it can be mapped as far as sec. 14, T. 7 S., R. 13 W., in rocks of Pennsylvanian age (Figs. 4 and 5). It borders on or is near the southeast edge of the Caborn Consolidated Field for much of its length. It was named for Caborn, which is less than 1 mile southeast of the fault on both sides of the line between secs. 29 and 30, T. 6 S., R. 12 W. Two petroleum tests near Caborn that cut the fault, the W. Duncan No. 1 J. Seifert and the Ooeth Drilling No. 1 Tennison, have been designated reference wells (Table 1).

The Caborn Fault includes individual faults that are discontinuous. Three parallel faults in the Springfield Coal Member in secs. 19 and 20, T. 6 S., R. 12 W., have been mapped, and two parallel faults on the Cypress Formation near the north and south ends of the fault have also been mapped. Dips on the fault planes are difficult to determine because of multiple faulting, but they average near 80°. The fault planes dip southeastward except for the accessory fault in sec. 19, T. 6 S., R. 12 W., which dips northwestward. Maximum vertical displacement determined for the fault is 140 feet in the No. 1 J. Seifert (Table 1).

Owensville Fault

The Owensville Fault trends N. 20° E. from sec. 14, T. 4 S., R. 12 W., in the northeast corner of Posey County, about 10 miles into sec. 31, T. 2 S., R. 11 W., in Gibson County (Figs. 4 and 5). It is bordered on the east by the Owensville Consolidated Field and was named for Owensville, centered in sec. 6, T. 3 S., R. 11 W., immediately west of the fault. A short parallel fault half a mile east of the main fault in secs. 6 and 7, T. 3 S., R. 11 W., has been recognized in the Springfield Coal Member.

The fault is presumed to be normal type and to dip northwestward, but since no petroleum tests have been drilled through the fault, the fault type, whether normal or reverse, has not been substantiated. No reference wells for the fault have been designated.

Hovey Lake Fault

The compound Hovey Lake Fault extends from Union County, Kentucky, into Indiana in sec. 35, T. 8 S., R. 14 W. (Johnson and Norris, 1976). The northwestward-dipping fault trends generally N. 25° E. from sec. 35 about 17 miles into sec. 24, T. 6 S., R. 13 W. (Figs. 4 and 5). Five of the 17 miles are immediatel south of Mt. Vernon, Indiana, in Township Q-20 (Carter coordinates) of Union and Henderson Counties, Kentucky (Johnson, 1974). The fault marks the eastern boundary of the Mount Vernon Graben (described below) and was named for Hovey Lake, which is immediately west of the fault in secs. 13, 14, 23, and 24, T. 8 S., R. 14 W. The Calvert Drilling Co. No. 1 Harlem & Louisville & Nashville Railroad Co. Comm. and the Carter Oil Co. No. 1 M. E. Dixon were drilled through the fault and have been designated reference wells (Table 1).

The No. 1 M. E. Dixon was drilled through four separate fault planes of the compound Hovey Lake Fault (Table 1). Because of the close horizontal distances between the fault planes, the Hovey Lake Fault is depicted as only two traces near the N. 1 M. E. Dixon in Figure 4. In sec. 34, T. 6 S., R. 13 W., where one northwestward-dipping fault of the Hovey Lake Fault dies out, an adjacent parallel-fault plane dips southeastward and continues 2½ miles northeastward. A short accessory fault has been mapped in rocks of Pennsylvanian age in secs. 23 and 24, T. 6 S., R. 13 W., at the northeast end of the Hovey Lake Fault. Fault-plane dips are 70° or greater. Maximum observed vertical displacement in wells that have been drilled through the fault is 310 feet in the No. 1 M. E. Dixon.

Mt. Vernon Graben

The Mt. Vernon Graben, here named for Mt. Vernon, Indiana, is a fault block, 2 to 2½ miles wide, extending from the center of T. 6 S., R. 13 W., southwestward through the center of T. 8 S., R. 14 W., into Union County, Kentucky (Figs. 4 and 5). It is bounded on the east by the Hovey Lake Fault and on the west by the Wabash Island Fault (described below). It is downthrown to about 310 feet at the Hovey Lake Fault and to about 270 feet at the Wabash Island Fault in T. 8 S., R. 14 W. But it shows decreasing displacement toward its northeasterly end and southwestward into Kentucky. The Spencer Consolidated Field produces from a domal structure which has been mapped in the graben in the northeast quarter of T. 8 S., R. 14 W., in rocks of Pennsylvanian and Mississippian age.

Wabash Island Fault

The compound Wabash Island Fault extends from Union County, Kentucky, into Indiana in sec. 28, T. 8 S., R. 14 W., trending about N. 27° E. for 15 miles to sec. 16, T. 6 S., R. 13 W. (Figs. 4 and 5). It parallels the east side of the College Consolidated and Mt. Vernon Consolidated Fields, is the eastern boundary of a westward-tilted fault block, which is 2 to 5 miles wide, and is the western boundary of the Mt. Vernon Graben. The fault was named for Wabash Island, at the confluence of the Ohio and Wabash Rivers in Kentucky. Two petroleum tests that cut the fault, the Yingling Oil & Mining Co. No. 5 Maggie Murphy and the Carl Miles No. 1 Lynn M. Strack, have been designated reference wells (Table 1).

The Wabash Island Fault is a compound fault with at least three fault planes in rocks of Mississippian age in T. 8 S., R. 14 W. The westernmost plane dips southeastward and has as much as 370 feet of vertical displacement. The two fault planes to the east dip northwestward and southeastward and form narrow horst and graben structures with as much as 150 feet of vertical displacement. North of T. 8 S., the Wabash Island Fault is mapped on the Cypress Formation as a single fault plane except for a small accessory fault in secs. 24 and 25, T. 7 S., R. 14 W., and an accessory fault in the northeast corner of T. 7 S., R. 14 W., the northwest corner of T. 7 S., R. 13 W., and the southwest corner of T. 6 S., R. 13 W.

The Wabash Island Fault as mapped on the Springfield Coal Member of the Petersburg Formation is more complex. There are as many as four fault planes in zones as much as 4,000 feet wide in places along its length. The faults are parallel, but our data suggest that some are interconnected with cross faults and some anastomose with each other (Fig. 4). Bristol and Treworgy (1979) reported cross faults between overlapping parallel faults in Illinois.

Because of the multiple fault planes, dips on the faults are difficult to calculate and substantiate. Our data indicate that some of the fault planes have about 65° dips.

Inman East Fault

The compound Inman East Fault extends from Gallatin County, Illinois (Bristol and Treworgy, 1979), into southwestern Posey County in sec. 22, T. 8 S., R. 15 W., and trends about N. 35° E. for 12 miles into sec. 34, T. 6 S., R. 14 W. (Figs. 4 and 5). The Springfield Coal Member is displaced by at least four fault planes in secs. 14, 15, and 22, T. 8 S., R. 15 W., but only one fault has been mapped in this area on the Cypress Formation. Several accessory faults forming narrow horst and graben structures have been mapped on both the Springfield Coal Member and the Cypress Formation in the southwest corner of T. 7 S., R. 14 W., the southeast corner of T. 7 S., R. 15 W., and the northeast corner of T. 8 S., R. 15 W. The Inman East Fault borders the east side of the Inman East, West Hovey, and Black Chapel South Fields. Two petroleum tests drilled through the fault, the C. E. Brehm Drilling & Producing No. 1 Eugene M. Fuhrer and the Carter Oil Co. No. 25-W Skiles Unit, have been designated reference wells (Table 1). Dips where determined on parts of the fault are about 60°. Maximum observed vertical displacement on the fault is 330 feet in the No. 25-W Skiles Unit.

Pitcher Lake Fault

The short Pitcher Lake Fault trends N. 20° E. from White County, Illinois (Bristol and Treworgy, 1979), into Indiana in sec. 18, T. 7 S., R. 14 W., to sec. 8, T. 7 S., R. 14 W. (Figs. 4 and 5). It dips northwestward between 62° and 80° and borders parts of the Welborn Consolidated and Black Chapel South Fields. Observed vertical displacement is 50 feet in the designated reference well, the Harry B. Mortimer No. 2-A Greathouse Heirs (Table 1).

New Harmony Fault

The New Harmony Fault is the longest and has the most displacement of any fault in the Wabash Valley Fault System in Indiana. It is compound and trends about N. 25° E. for nearly 30 miles along the Wabash Valley from White County, Illinois (Bristol and Treworgy, 1979), into Posey County, Indiana, in sec. 13, T. 7 S., R. 15 W., to sec. 28, T. 2 S., R. 13 W., Gibson County, where it enters Wabash County, Illinois (Figs. 4 and 5). The fault, which has about 450 feet of vertical displacement in the reference well, the Joe Resnik No. 1 K. D. Owen (Table 1), has been called the Mt. Carmel-New Harmony Fault in Illinois. The name of this fault in Indiana is confined to the New Harmony Fault, since the name Mt. Carmel has already been used for a major fault in south-central Indiana. Part of the New Harmony Fault was called the Maunie Fault on a regional geologic map by Gray and others (1970) but has been confirmed as the New Harmony Fault by Bristol and Treworgy (1979) and by our study.

The New Harmony Fault borders parts of the Welborn Consolidated, Welborn North Consolidated, Springfield Consolidated, Black River Consolidated, Mumford Hills, and Griffin Consolidated Fields. Dips of about 65° northwestward have been measured on the major fault planes, but some dips may range higher.

The New Harmony Fault and the Ribeyre Island Fault (described below) are a complex zone, 1½ miles wide, with at least five fault planes as mapped in the western half of T. 6 S., R. 14 W., in rocks of Pennsylvanian age. In the same area, only three fault planes of the New Harmony Fault have been mapped on the Cypress Formation. As many as five parallel-fault planes, all dipping northwestward have been mapped in sec. 6, T. 4 S., R. 13 W., at the Posey-Gibson county line. The New Harmony Fault continues as a single fault plane on the Cypress Formation north of this area into Illinois but is more complex on the Springfield Coal Member, where two fault planes or more have been mapped.

Two petroleum test wells, besides the No. 1 K. D. Owen mentioned above, have been designated reference wells: the Cherry & Kidd No. 3 Gyger and the Ryan Oil Co. No. 1 Mary Alice Kelley (Table 1).

Ribeyre Island Fault

The Ribeyre Island Fault, described in Illinois by Bristol and Treworgy (1979), is conjectural in Indiana in the eastern part of T. 4 S., R. 14 W., on the basis of elevation differences of as much as 150 feet per half a mile on rocks of Mississippian and Pennsylvanian age (Figs. 4 and 5). On the basis of sparse data, the fault mapped on the Cypress Formation trends about N. 15° E. from White County, Illinois, into Indiana in sec. 15, T. 5 S., R. 14 W., to sec. 31, T. 3 S., R. 13 W. The elevation differences are less apparent on the Springfield Coal Member for the northern part of the fault, but the fault has been mapped only to sec. 12, T. 4 S., R. 14 W., on that horizon. Since no well has been drilled through this fault in Indiana, no reference well has been designated.

Maunie Fault

The Maunie Fault, in sec. 6, T. 6 S., R. 14 W., and secs. 31 and 32, T. 5 S., R. 14 W., trends about N. 50° E. in Indiana (Figs. 4 and 5) but trends N. 27° E. northward where it enters White County, Illinois (Bristol and Treworgy, 1979). The fault dips northwestward probably between 65° and 80°, although the amount of dip has not been measured directly. The Gulf Refining Co. No. 1 Albert Aldrich, the designated reference well (Table 1), shows 50 feet of vertical displacement on the fault.

Deep Faulting

Few wells have been drilled beneath rocks of Late Mississippian age in Posey and Gibson Counties, the deepest part of the Illinois Basin in Indiana. Precambrian structures are concealed by about 13,000 feet of overlying strata, of which only the upper 2,000 to 3,000 feet have been extensively drilled. Even so, from the scarce data available, the New Harmony and Wabash Island Faults can be recognized in deeper strata, such as the Salem Limestone (Mississippian), the New Albany Shale (Devonian and Mississippian), and the Trenton Limestone (Ordovician) (Fig. 7). Depth to the Trenton surface is about 7,000 feet.

Although not shown on Figure 7 because of sparse drilling data, two lines of evidence lead us to believe that other major faults mapped on shallower horizons are also present at depth. Similar displacements at depth along single fault planes indicate deeper faulting, and the decrease in complexity of the faulting with depth from rocks of Pennsylvanian to Mississippian age appears to be due primarily to splintering of deeper faulting and not to dissipation of fault displacements into surrounding faulted rocks.

Knowledge of the location of faults in basement rocks not only is important in exploring for petroleum and mineral resources at depth but also is necessary in identifying major structural elements in the basement and tectonic which have affected them. If fault dips observed in shallow rocks are similar

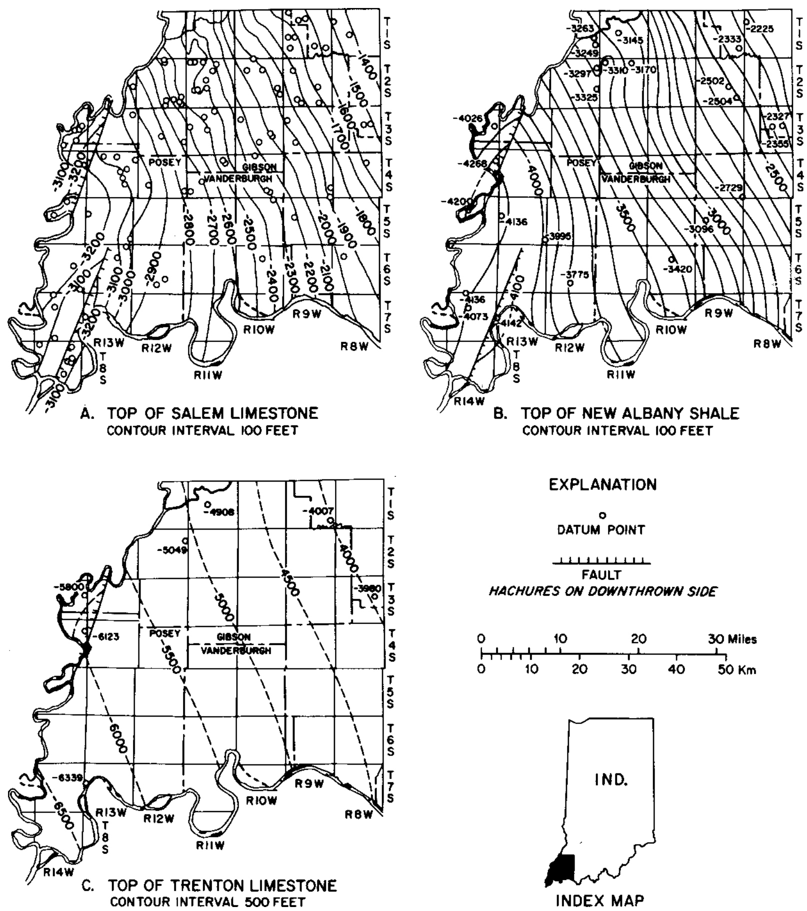


Figure 7. Map of southwestern Indiana showing structure on top of the Salem Limestone, the New Albany Shale, and top of the Trenton Limestone. From Hasenmueller and Bassett (1980).

to dips on the faults at depth, some faults may migrate horizontally more than a mile when they are projected to the basement. Migration of the Wabash Island and Hovey Lake Faults suggests that they may be part of one major fault zone in basement rocks. The Pitcher Lake, New Harmony, Maunie, and Ribeyre Island Faults may also be part of one major fault zone. Migration of the Caborn, Heusler, and Parker Faults appears to be insufficient to be one fault zone, but these faults may still be closely related at basement depths.

ECONOMIC IMPLICATIONS[1]

By Dan M. Sullivan, Curtis H. Ault, and Joseph N. Stellavato

Coal

At least four coals in Posey County and southern Gibson County have commercial potential for underground mining. These are the Herrin Coal Member of the Dugger Formation, the Springfield Coal Member (V) of the Petersburg Formation, the Survant Coal Member (IV) of the Linton Formation, and the Seelyville Coal Member (III) of the Staunton Formation. These range from less than 3 feet to more than 5 feet in thickness. Several other coals, which are usually thinner than the above, might be mined under more favorable economic conditions. The coals underlie all or most of the areas affected by the Wabash Valley Fault System and range in depth from less than a hundred feet to more than 1,000 feet. Because of the complex faulting of the coals in many areas, a knowledge of location and character of the faulting is of vital importance (Ault and Carr, 1980). From our study, the following observations can be made:

1. In Pennsylvanian rocks, faulting occurs mostly in zones of more than one fault; therefore an individual fault in a coalbed is very likely to indicate that other faults are nearby. Electric logs obtained from various oil operations were the primary source of data used in our study, and the well-to-well comparison of these logs allows detection only of faults that have vertical displacements of about 20 feet or more. However, from observations in other parts of Indiana, we believe that small faults with less displacement are common in coalbeds and will be found in abundance in fault zones near our mapped faults.

2. The faulting is post-Pennsylvanian in age, and the youngest beds studied were disrupted by all faults. The fault zones observed in younger coalbeds persist in depth through the entire coal sequence, but some individual faults in the zones die out with depth or, more likely, coalesce with other more major faults. Therefore, the number of individual faults in a fault zone in one coalbed is likely to be fewer in the deeper coalbeds, especially in those that are several hundred feet deeper.

3. All known faults of the Wabash Valley system are normal, tensional faults. Any faults encountered in underground mining would most likely be of

[1]Reprinted and modified slightly from part of a report by Sullivan and others (19__)

this type. Geometric calculations can help locate faulting in coalbeds either above or below a fault known from drill-hole data, although there is some uncertainty because dip angles can vary from our observed average of 60° to 80°.

4. Since the faults are of the normal type, the attitude of a fault encountered in mining will indicate the upthrown side and the direction a faulted coalbed has been displaced.

5. Although we do not have detailed data to document the principle in coal-bearing rocks of the study area, it has been shown elsewhere that a given fault plane dips at somewhat different angles in rocks of different lithologies. We would expect angles of a single fault plane to differ to a small degree among the shales, coals, and limestones of Pennsylvanian age.

Petroleum

No oil or gas was produced from reservoirs associated with the Wabash Valley Fault System before 1938, when a major discovery was made at Griffin, along the Wabash River in Gibson County. This discovery led to extensive exploration throughout southwestern Indiana, and drilling activity, including that associated with later secondary operations, continued at an average rate of about 1,000 wells per year for three decades. The deepest production in Indiana is in Posey and Gibson Counties where Middle Mississippian carbonate rocks are productive at depths in excess of 3,000 feet, but most of Indiana's oil has been derived from shallower and younger rocks. A significant amount of the oil produced in southwestern Indiana has come from fields affected by the Wabash Valley Fault System.

The amount of time, effort, and exploration that have gone into the discovery and development of the oil associated with the faults in Indiana is incalculable, and we do not attempt in this report to detail the significance of the faulting as it affects the entrapment mechanisms in known fields. However, we believe some shallow units trapped within the fault zones may have some commercial potential. Our data suggest that there is room for reserves in some rock slices between individual faults in complex fault zones. Also, the entrapment of hydrocarbons in reservoir beds in a downthrown position against faults is a possibility not completely tested.

As we enter the era of deeper exploration in the Illinois Basin, we can expect more difficult correlation problems in the carbonate sequences, but those exploring for petroleum will continue trying to determine the presence or absence of porosity and the conditions of entrapment. Areas of known structura anomalies, structural instability evidenced by faulting, or areas of tectonic activity are attractive for future exploration.

There are indications of structural influence in both areas in Indiana that have had recent exploratory success in rocks of the Salem Limestone (Owensville North Field and the Hazelton area of Union-Bowman Consolidated Field in Gibson County). The Owensville North area of production is closely associated with the Owensville Fault that can be mapped on the Cypress horizon (Fig. 5) and on the shallower Springfield coal (Fig. 4). Although no faults have been mapped in the Hazelton area, an underlying positive basement feature has been interpreted from aeromagnetic data (Henderson and Zietz, 1958).

In our study we find individual faults for which there is adequate subsurface control to be consistent in dip and vertical displacement with depth. We infer that the faults reach basement rocks and believe that calculations can be made to determine valid locations of the faults near deep prospective reservoir rocks.

Reservoir rocks below the Devonian in the faulted area are unexplored. Only seven wells have been drilled into rocks of Devonian age in Posey County, and these provide the first evidence of faulting at depth (Fig. 7). About 30 wells have reached the Salem, and there is additional evidence of faulting at this horizon (Fig. 7). Porosity zones that have recent proven production in areas to the north are also present in the Posey County area (Keller and Becker, 1980).

The deepest wells that have produced oil from Harrodsburg rocks in southwestern Indiana are closely associated with faults in Posey County. One well exhibits significant fracture porosity.

Our observations of the decrease in complexity and horizontal migration of fault traces in rocks of Mississippian age (Fig. 5) as compared with those in rocks of Pennsylvanian age (Fig. 4) make reasonable the assumption that faults bounding some graben blocks are shallow splinters of deeper single faults and that maps and cross sections showing the extrapolated positions of the faults at depth are worthwhile exploration tools.

Mineralization

Most of the mineralization of the Illinois-Kentucky mining district, which supplies 80 percent of the fluorite produced in the United States, is associated with faulting of the Rough Creek and Shawneetown Fault Zones. Vein deposits of fluorite and lesser amounts of sphalerite and galena are localized by faults and fractures. Most of the veins follow steeply inclined normal faults or fault zones (Grogan and Bradbury, 1968). These faults are similar to those of southwestern Indiana, but no mineralization has been found in the Wabash Valley Fault System in Indiana from available data at the Indiana Geological Survey (Nelson R. Shaffer, oral communication, 1979)

The exploration possibilities for mineralization in faults of the Wabash Valley system in Indiana are far from exhausted, however. The faults remain favorable sites for exploration, although deep mineralization would present economic problems for mining.

FAULTING IN PERRY AND SPENCER COUNTIES, INDIANA[1]

By Dan M. Sullivan, Curtis H. Ault, and George F. Tanner

Introduction

Perry and Spencer Counties border on the Ohio River in southwestern Indiana at the juncture of the Wabash Lowland and Crawford Upland physiographic provinces. Spencer County lies in the Wabash Lowland where the exposed bedrock formations of the county are composed of shales, clays, coals, sandstones, and thin limestones of the Pottsvillian and Alleghenian Series of the Pennsylvanian System. Pennsylvanian rocks that have been faulted in southern Spencer County are covered by alluvial deposits of the Ohio River and other Pleistocene to Holocene Sediments.

Perry County lies immediately east of Spencer County within the Crawford Upland. The erosion of alternating sandstones, shales, and limestones of the Chesterian Series (Mississippian) and sandstones and shales of the lower Pottsvillian Series has resulted in rugged, angular topography, which facilitates surface mapping of the faults in the southern part of the county.

Faulting in Perry County has been known for more than a century. Small faults in a coal-mine tunnel near Cannelton were mapped by E. M. Kindle, who also noted a fault with 35 feet of throw in a bluff near Cannelton (Ashley, 1899). Faulting near Deer Creek was noted by Joseph Lesley, Jr. before 1862 (Owen, 1862); later workers viewed this possible fault with some doubt until it was confirmed after 1900. Many small tunnel coal mines were opened near Cannelton beginning about 1835 (Cox, 1872), and the early miners encountered small faults in some mines.

Hughes (1951) mapped faults in the Deer Creek area, and more recently the Indian Creek Fault was shown on a regional geologic map at a scale of 1/250,000 by Gray and others (1970).

Tectonic Setting

Perry and Spencer Counties lie on the eastern flank of the Illinois Basin, which is bounded on its northeast side in Indiana by the Cincinnati Arch.

[1]Reprinted in part with slight modifications from Sullivan and others (1981).

The faults in Perry and Spencer Counties are 50 to 80 miles east of the more extensive Wabash Valley Fault System, which is well developed in southwestern Indiana in Posey and Gibson Counties (Ault and others, 1980).

The Wabash Valley Fault System, which includes faulting in northwestern Kentucky and southeastern Illinois, trends north-northeastward, as do the faults in Perry and Spencer Counties. Three of the faults in Perry and Spencer Counties are extensions of faults mapped in Kentucky by Goudarzi and Smith (1971), Johnson and Smith (1968), Bergendahl (1965), and Mayfield and Chisholm (1952).

The vertical displacements of the rocks faulted in Perry and Spencer Counties are considerably less than those of the major faults in the Wabash Valley Fault System. All known faults in both areas are of the high-angle normal type. Although faulted rocks at the bedrock surface in Perry and Spencer Counties are older than those in the Wabash Valley area, the time of faulting of the Pennsylvanian beds in Perry County probably relates closely to the post-Pennsylvanian and pre-Pleistocene time of faulting of the Wabash Valley Fault System.

The relationship of the Perry County and Spencer County faulting and the similar-trending faulting southward in Kentucky to the east-westward-trending Rough Creek Fault Zone in Western Kentucky is unclear, and the relationship may not be a close one.

Method of Study

The faults in Perry and Spencer Counties were mapped by using subsurface information from all available petroleum, coal, mineral, and stratigraphic test holes on file at the Indiana Geological Survey. Both Perry and Spencer Counties have been extensively explored for oil and gas since the late 1920's. About 3,000 petroleum tests have been drilled in Spencer County, and about 650 have been drilled in Perry County. Subsurface control, however, is sparse in those areas where the faults are mapped. Most of the holes were drilled with cable tools, and geophysical logs, which are particularly useful in well-to-well stratigraphic correlation, are not common. Driller's logs provide the basic data in southern Spencer County, where there are no visible surface expressions of the faults. In Perry County, however, where the upper Chesterian rocks are exposed in the rugged topography of the Crawford Upland, several good marker beds crop out and provide the basis for detailed surface mapping.

Correlations of electric logs and driller's logs generally uncover only those faults with more than about 20 feet of vertical displacement. Displacements of faults mapped on the surface were calculated by the difference in elevation of closely spaced outcrops of marker beds rather than by direct mapping of the fault planes, which are mostly covered by unconsolidated materials.

Some outcrops mapped near faults in Perry County showed steeply inclined bedding, some dipping in opposite directions than would be expected from normal drag features near the faulting. This suggests that the faulting is complex, that more than one fault plane is in a zone, and that beds dip erratically between the planes. We also found that inclined beds of sedimentary structures could easily be mistaken for fault-affected beds, especially at the Mississippian-Pennsylvanian unconformity. Some previous investigators may have been misled by such structures.

Fault Descriptions

Faults in Perry and Spencer Counties, Indiana, trend from N. 5^{o} E. to essentially an east-west direction with north-northeast being the most prevalent trend (Fig. 8). The faults are all normal type, with high-angle dips on the fault planes. The Little Hurricane Island Fault was the only fault where a dip calculation was possible, and it was greater than 70^{o}. In general, the faults in Spencer County are downthrown eastward, and the faults in Perry County are downthrown westward.

Our depictions of the faults as single planes are oversimplications in that there is undoubtedly more complex faulting near major faults. This is borne out in the area near Cannelton where several small faults were observed in at least one of the early coal mines near the Hawesville Fault. Also, a small accessory fault creates a 1,000-foot-wide graben associated with the major Little Hurricane Island Fault (Fig. 9).

Isopachous maps do not indicate any thickening or thinning of stratigraphic units due to differential sedimentation on opposite sides of faults; therefore, there is no indication of growth faulting. The following described Little Hurricane Island, Africa, and German Ridge Faults are newly

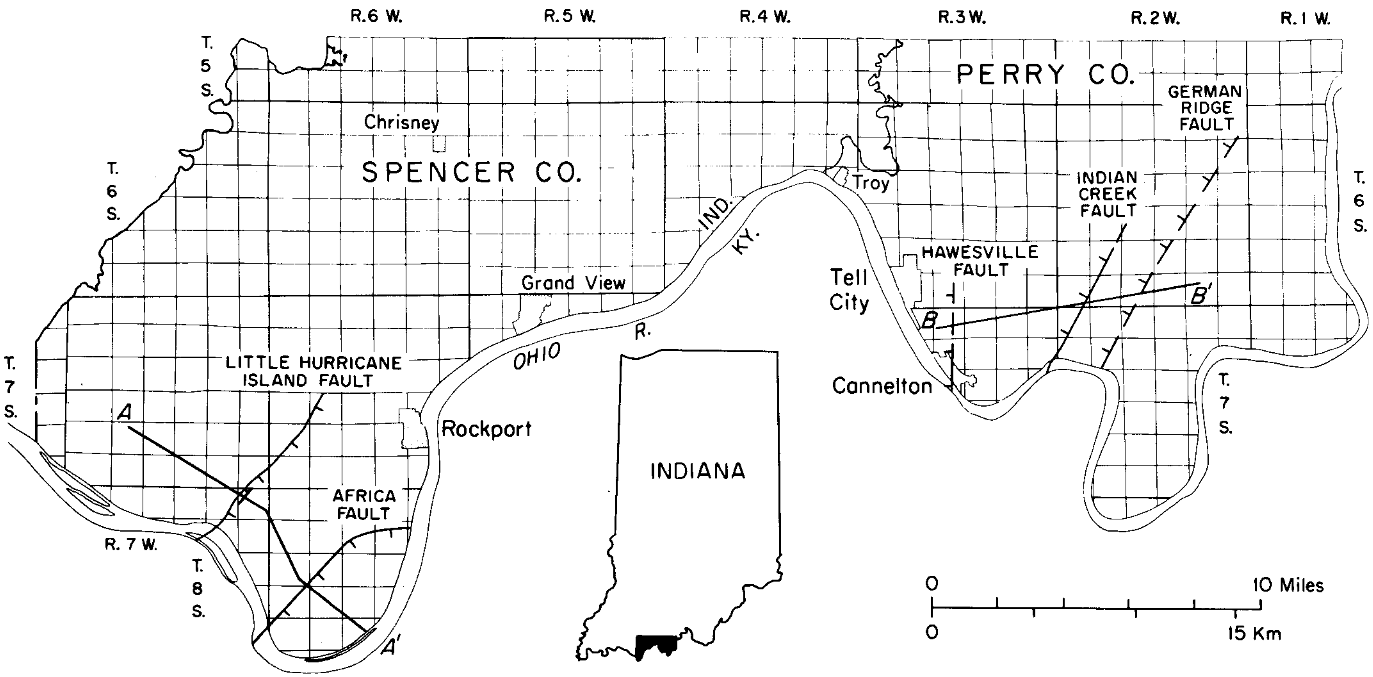


Figure 8. Map showing faults in southern Spencer and Perry Counties, Indiana.

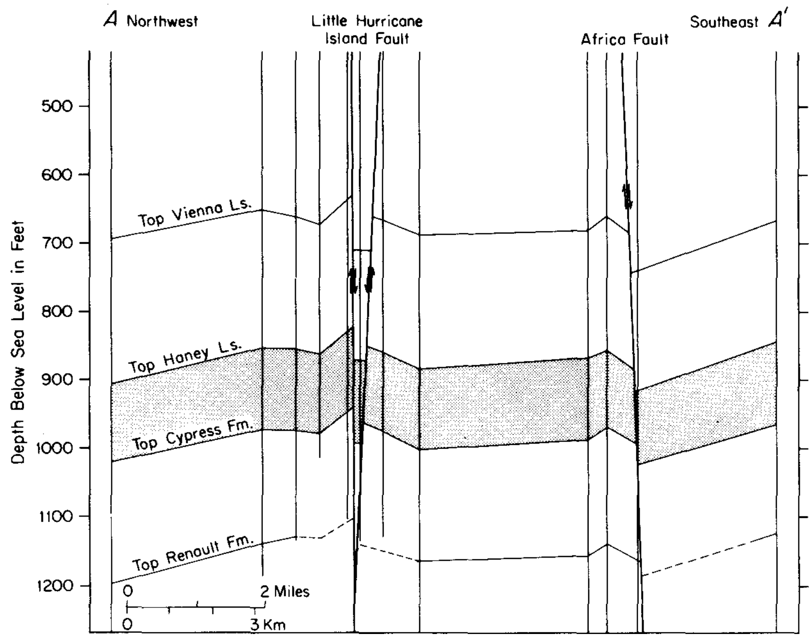


Figure 9. Cross section showing faulting in southern Spencer County, Indiana. (See Fig. 8 for line of section.)

named in Indiana. The Hawesville and Indian Creek Faults are extensions of faults mapped in Kentucky; their names have been adopted for formal use in Indiana.

Hawesville Fault

The Hawesville Fault enters Indiana in Sec. 16, T. 7 S., R. 3 W., from Hancock County, Kentucky, and trends N. 5° E. for 2 1/2 miles. The fault was named for the small river town of Hawesville, Kentucky (Johnson and Smith, 1968). The upthrown side is to the east, and the maximum vertical displacement is 75 feet in sec. 16, T. 7 S., R. 3 W. The throw as expressed on the top of the Cypress Formation (Mississippian) decreases northward to 25 feet in less than 2 miles (Fig. 10). The fault is not mapped north of sec. 33, T. 6 S., R. 3 W., where regional dips of 40 feet per mile are on the top of the Cypress Formation.

Indian Creek Fault

The Indian Creek Fault enters Indiana in sec. 12, T. 7 S., R. 3 W., from Hancock County, Kentucky, and trends N. 27° E. up the Deer Creek

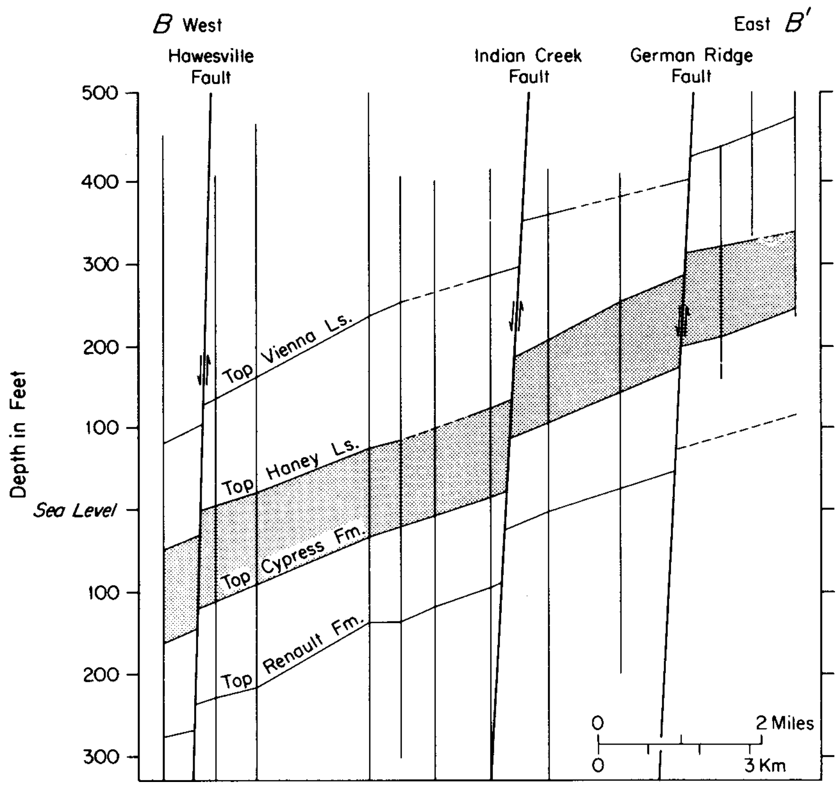


Figure 10. Cross section showing faulting in southern Perry County, Indiana. (See Fig. 8 for line of section.)

valley about 4 1/2 miles. The upthrown side of the fault is to the east. The fault was named for Indiana Creek, an Ohio River tributary in Hancock County, Kentucky (Johnson and Smith, 1968).

Maximum vertical displacement in Indiana is 90 feet in sec. 12, T. 7 S., R. 3 W., on outcrops of the base of the Negli Creek Limestone Member of the Tobinsport Formation (Mississippian) and in the subsurface on the top of the Cypress Formation. Throws decrease to 65 feet on top of the Cypress Formation in sec. 6, T. 7 S., R. 2 W. (Fig. 10), and gradually decrease to less than 20 feet in sec. 21, T. 6 S., R. 2 W. A drag feature exists on the west side of the road in the SE1/4NW1/4NE1/4 sec. 6, T. 7 S., R. 2 W., in the Mt. Pleasant Sandstone Member of the Tobinsport Formation.

German Ridge Fault

The German Ridge Fault trends N. 30^{o} E. about 8 miles, and the upthrown side of the fault is to the east. The fault was named after the highland area known as German Ridge and is not shown on mapping by the U.S. Geological Survey in Kentucky. The south end of the fault extends to the Ohio River in sec. 8, T. 7 S., R. 2 W., and trends north-northeastward 8 miles before dying out in sec. 1, T. 6 S., R. 2 W. (Fig. 8). The maximum vertical displacement is 60 feet in the NW1/4 sec. 23, T. 6 S., R. 2 W., on the top of the Cypress Formation and the Vienna Limestone Member of the Branchville Formation (Mississippian). The throw decreases to the southwest from sec. 23, T. 6 S., R. 2 W., to 30 feet on top of the Cypress Formation in sec. 33, T. 6 S., R. 2 W. (Fig. 10).

Little Hurricane Island Fault

The Little Hurricane Island Fault in Spencer County, Indiana, trends N. 35^{o} E. from sec. 11, T. 8 S., R. 7 W., about 5 miles to sec. 20, T. 7 S., R. 6 W. (Fig. 8). The upthrown side is to the west. The fault was named for Little Hurricane Island in the Ohio River.

The major fault has a short parallel fault about half a mile long in the NW1/4 sec. 1, T. 8 S., R. 7 W., and SW1/4 sec. 36, T. 7 S., R. 7 W. The splinter fault is upthrown to the east and has 30 feet of displacement on top of the Cypress Formation (Fig. 9). The Johnson & Kelly No. 1 Howard well in the NW1/4NW1/4 sec. 1, T. 8 S., R. 7 W., has about 20 feet of missing section in the Sample Formation (Mississippian) due to faulting at a depth of about 1,465 feet. The dip of the fault plane is greater than 70^{o}. The major fault has a maximum vertical displacement of 50 feet on the top of the Cypress Formation in sec. 1, T. 8 S., R. 7 W. (Fig. 9), and throw decreases northeastward and southwestward.

Africa Fault

The fault was named for the hamlet of Africa in sec. 10, T. 8 S., R. 6 W. The Africa Fault trends N. 40^{o} E. from sec. 25, T. 8 S., R. 7 W., on the Ohio River to the NE1/4 sec. 9, T. 8 S., R. 6 W., where the trend changes to east-west, leaving Spencer County, Indiana, in sec. 11, T. 8 S., R. 6 W., and entering Daviess County, Kentucky (Fig. 8). The E. M. D. & G. Drlg. No. 1 Snyder well in NE1/4NE1/4NE1/4 sec. 19, T. 8 S., R. 6 W., has about 40 feet of section faulted out in the Sample Formation at a depth of 1,470 feet. The maximum vertical displacement based on interpretation of structure on top of the Cypress Formation is 75 feet in sec. 19, T. 8 S., R. 6 W.

Figure 9 shows decreasing throw on the fault with depth. The vertical displacement is about 60 feet on top the Vienna Limestone Member and 35 feet on top of the Renault Formation (Mississippian). The throw decreases 25 feet in 460 feet of vertical section, which suggests that the fault is dying out at depth.

Deeper Faulting

In the faulted areas of Perry and Spencer Counties, only one test hole has penetrated below upper Valmeyeran (Mississippian) rocks. The lack of sufficient deep subsurface data, therefore, does not provide a good basis for determining deep faulting in lower Paleozoic strata or basement rocks, and the relatively small displacement of rocks faulted in the Chesterian section compared with that of rocks faulted in the Wabash Valley Fault System does not enhance the possibility of deeper faulting. Rudman and others (1965) have postulated a possible basement scarp underlying the Wabash Valley Fault System, and more recently Braille and others (1978) have suggested a basement rift feature in southwestern Indiana. Involvement of the faults in Perry and Spencer Counties as an expression of the eastern boundary of any such model does not seem justified.

MT. CARMEL FAULT IN SOUTH-CENTRAL INDIANA

By Dan M. Sullivan, Curtis H. Ault, and George F. Tanner

Introduction

The Mt. Carmel Fault was first described by Ashley and Kindle (1903). Hopkins and Siebenthal (1897) and Price (1898) had earlier noted the preservation of strata of Early and Middle Mississippian age below their expectable level west of the surface fault trace but did not propose this as a definite fault phenomenon. Ashley and Kindle used the name Mt. Carmel Fault after the Mt. Carmel Church in the SW1/4 sec. 1, T. 3 N., R. 3 E., in northwestern Washington County. In the same year Newsom (1903) named this fault the Unionville Fault, but the name Mt. Carmel was adopted later by other authors and is continued in this paper.

Logan (1918), Esarey (1925), Freed and Rogers (1932), Harris and Esarey (1940), Fender and Esarey (1949), Fiandt (1950), Melhorn and Smith (1959), Sunderman (1968), Shaver and Austin (1972), and Tanner (1980) have detailed or discussed various aspects of the fault and its associated anticline.

Logan was the first investigator to recognize the significant folding parallel and west of the Mt. Carmel Fault, and Melhorn and Smith proposed the name Leesville Anticline in 1959 for the entire anticlinal fold trending across Monroe and Lawrence Counties into northwestern Washington County and for later extensions.

Tectonic Setting

The Mt. Carmel Fault is mappable for about 50 miles in south-central Indiana (Fig. 11). The trend of the fault is north-northwesterly approximately parallel to the strike of the outcrop of Mississippian strata on the margin of the eastern shelf of the Illinois Basin (Fig. 3). Except in some local areas the normal, high-angle fault is essentially a single trace.

The trend of the fault and the folds associated with the fault on its western downthrown side combine to make the Mt. Carmel Fault unique among the known fault features in Indiana, and the extent of the fault and the associated folds constitute the most prominent structure exposed in

Indiana.

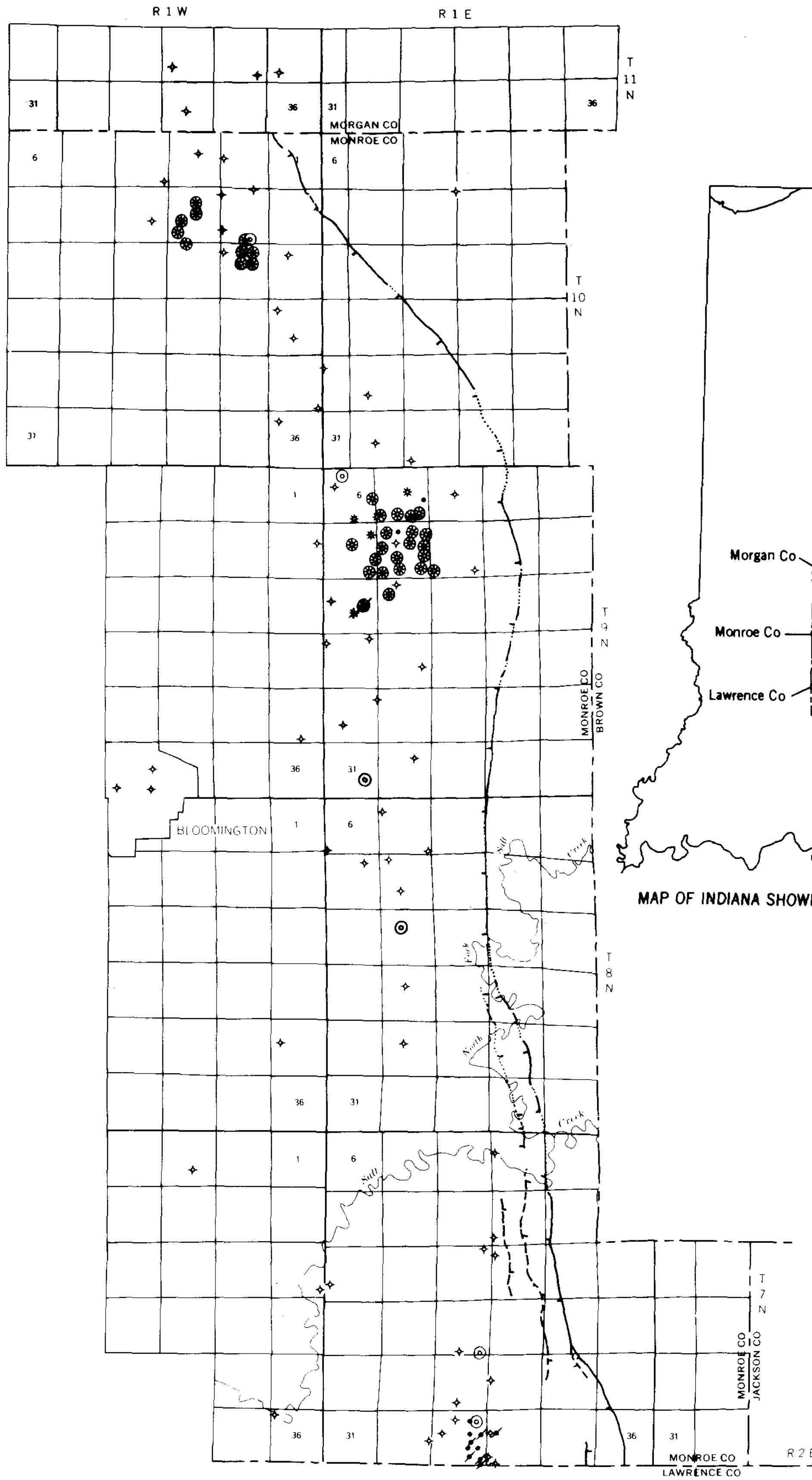
The fault can be mapped to a southern limit in northwestern Washington County, and the northern extent of the fault has been mapped to the northern border of Monroe County, where the fault is obscured by glacial drift. Enhanced interpretation of the northern limit of the fault was possible through this study and is discussed later in this report.

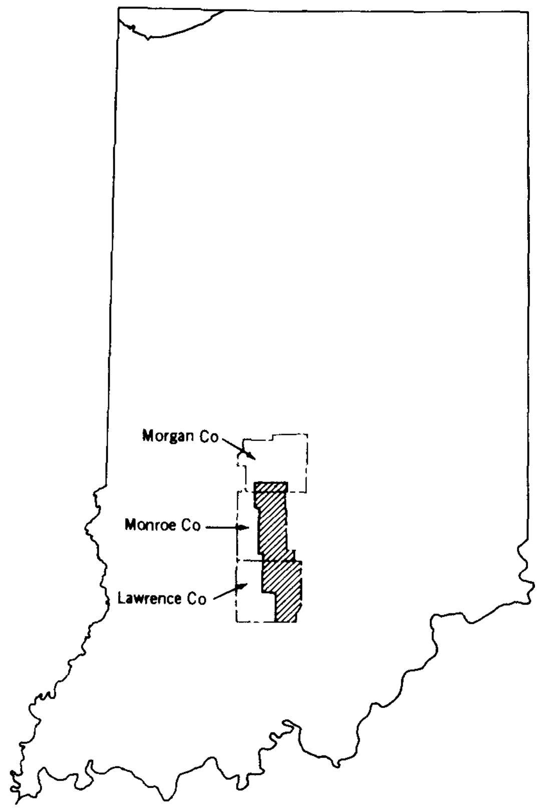
The rocks that exhibit displacement along the surface trace of the Mt. Carmel Fault are Valmeyeran in age, but the exact time of formation of the fault and the related folds has not been determined. Melhorn and Smith (1959) related the Mt. Carmel Fault genetically to the LaSalle Anticline by the general orientation combined with other structural aspects and considered the fault and associated folding to be post-Valmeyeran in age. They suggested that distribution and thickness variations of lower and middle Chesterian rocks indicated that some movement had occurred by that time. Also, they proposed that the deposition of Lower Pennsylvanian sands in Monroe and Lawrence Counties was partly controlled by the folding west of the Mt. Carmel Fault. We could not substantiate this structural influence on regional sedimentation.

Method of Study

The Mt. Carmel Fault was mapped by using all available subsurface information from more than 200 petroleum and stratigraphic tests. Available waterwell data were used in some areas. The detailed characterization of the fault, which is the primary advancement in this investigation over previous work, was accomplished by extensive field mapping along the entire 50-mile length during a year and a half. Direct mapping of the surface fault traces was possible only at a few exposures. Much of the surface mapping was based on displacement and attitude of key marker beds near the fault traces.

Besides the map showing the surface trace of the Mt. Carmel Fault, structural maps showing the fault trace and the associated folding were compiled for the top of the Ramp Creek Formation (Mississippian), the top of the Muscatatuck Group (Devonian), and the top of the Trenton Limestone (Ordovician). Isopachous maps were constructed for the Borden Group (Mississippian) and the interval between the top of the Muscatatuck Group and the top of the Trenton Limestone. Several cross sections showing local details of the fault were





MAP OF INDIANA SHOWING LOCATION OF STUDY AREA

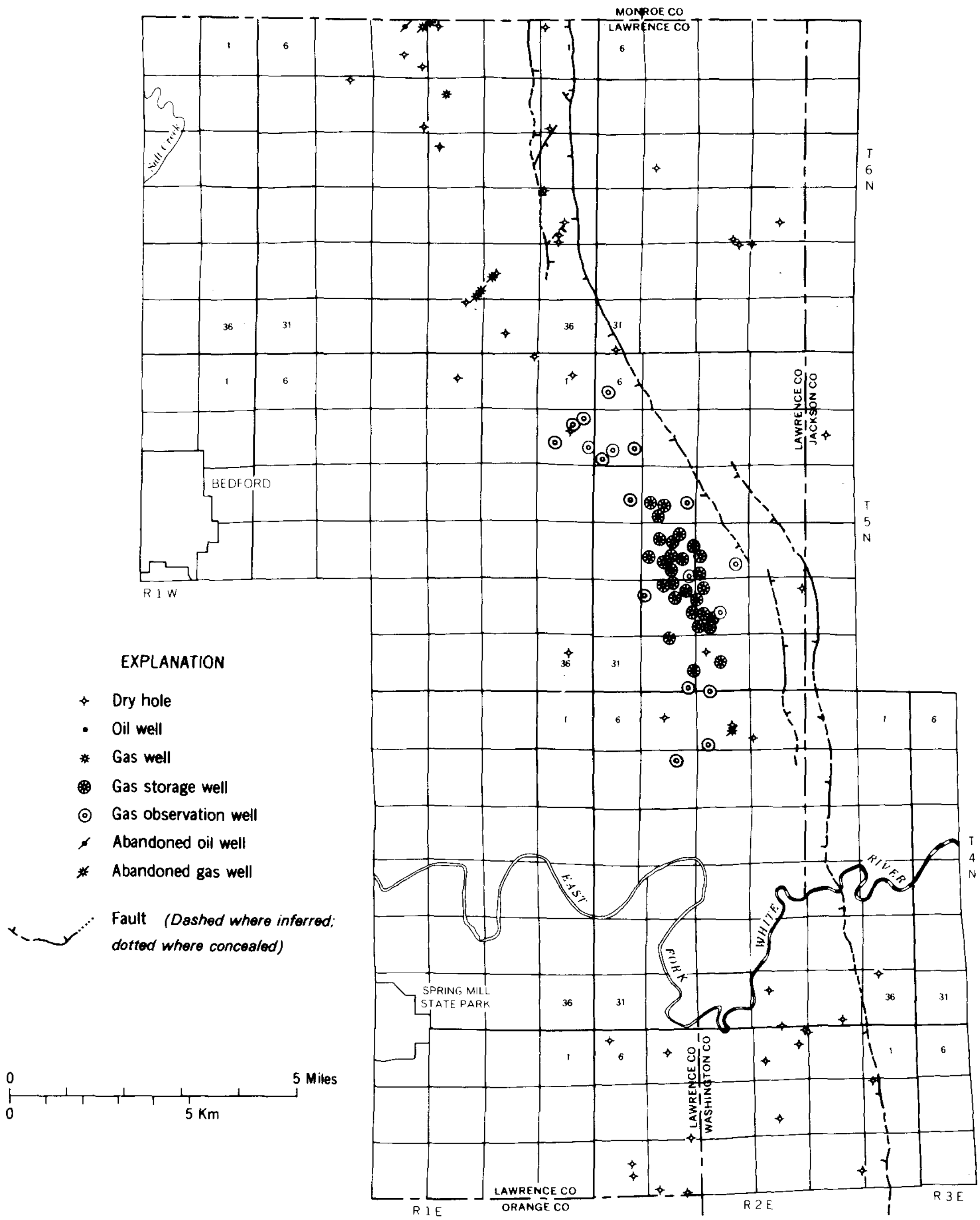


Figure 11. Map of south-central Indiana showing surface trace of Mt. Carmel Fault (above and facing page).

also constructed and are on open file at the Indiana Geological Survey, as are large-scale work maps for the above and 7½-minute topographic quadrangles showing surface traces of the faults.

Fault Description

The Mt. Carmel Fault trends N. 10° W. to N. 15° W. for much of its 50-mile length with deviations at its north end to N. 35° W. Although it is mapped primarily as a single fault trace (Fig. 11), compound faulting in some areas results in several graben blocks where the main Mt. Carmel fault is downthrown westward and is paralled by faults that are downthrown eastward with 10 to 50 feet of displacement. The fault-bound blocks are about half a mile wide and are tilted no more than about 3°, although strata in drag folds near the faults may be tilted as much as 30°.

The normal-type Mt. Carmel Fault is everywhere downthrown to the west, dipping at angles ranging from nearly vertical to about 71° where measured on outcrop and 64° or more where correlated from surface exposures to subsurface faulting in petroleum tests. The maximum observed vertical displacement is about 200 feet. At several locations there are indications of a horizontal component of movement on accessory faults as evidenced by slickensides with striation angles as much as 32° from the vertical. All slickensides observed on the main fault plane were vertical. Fracture zones and conjugate joint sets are present on both sides of the main fault.

Several authors have proposed extensions of the fault, and considerable effort was directed in this study in determining if there are extensions to the north and south. As part of this effort, two test holes were drilled by the Indiana Geological Survey in Morgan County about 1 mile north of the northernmost mapped extent of the Mt. Carmel Fault, which is in the NW¼ sec. 1, T. 10 N., R. 1 W. One hole, Survey drill hole (SDH) 314, in the SW¼SW¼ sec. 25, T. 11 N., R. 1 W., was drilled on the east upthrown side of the projected fault trend, and the other, SDH 315, was drilled about half a mile west in the SE¼SE¼ sec. 26, T. 11 N., R. 1 W., on the downthrown side of the projected fault trend. The Rockford Limestone (Mississippian) marker bed occupies the same approximate structural position in both wells.

These data, correlated with our surface mapping of nearby rocks of Mississippian age, suggest strongly that the northernmost extent of the Mt. Carmel Fault is near its limit as mapped on the surface and that it does not extend farther northward as suggested by some previous authors. Rather, our data indicate only a flattening of structure beyond the north end of the mapped fault. Our information, however, would not detect faulting with less than about 20 feet of displacement, and minor faulting may be present.

The Mt. Carmel Fault was mapped on the surface as far south as sec. 24, T. 3 N., R. 2 E., Washington County, but a lack of key marker beds prevented further mapping. Several test drill holes would be necessary to substantiate or refute faulting farther south. The relationship of the Georgetown Fault in Harrison and Floyd Counties to the Mt. Carmel Fault is not known. Although reconnaisance fieldwork confirmed the presence of the Georgetown Fault, it was not mapped in detail.

Economic Implications

Potential economic exploitation of the Mt. Carmel Fault area has been primarily directed toward petroleum exploration along the Leesville Anticline adjacent to the fault on the west or downthrown side.

Most of the 200 or more subsurface tests drilled near the fault (Fig. 11) have been drilled on the highest structural closures to develop oil and gas reserves.

Hindustan, Unionville, Bartlettsville, Heltonville, Leesville, and Leesville South Fields have been discovered since the early 1900's. Reserves of primary oil and gas have been minor, but currently Unionville and Leesville have significant economic importance as gas-storage fields.

The gas produced along the Leesville Anticline was derived primarily from Middle Devonian carbonate rocks, and the oil was produced from near the top of the Trenton Limestone. Although the entrapment of these hydrocarbons is structurally controlled, there is no indication of enhanced porosity or permeability from fractured reservoirs.

The only basement test hole within the Indiana part of the Illinois Basin was drilled on the Leesville Anticline in Lawrence County. The Knox Dolomite (Ordovician and Cambrian) had a distinctive sandstone section, which Dawson (1960) projected as a possible reservoir in updip areas east of the fault. A slight show of oil was recorded in Devonian carbonate rocks but none in deeper strata. In the early 1960's Pan American Petroleum drilled several Ordovician tests in the graben in T. 6 N., R. 1 E., Lawrence County (Fig. 11), in an unsuccessful attempt to encounter a geologic setting similar to the Trenton oil entrapment found in the Albion-Scipio Field in southern Michigan. A more detailed accounting of this petroleum prospect was provided by Rooney (1966).

In terms of other mineral exploitation in the Mt. Carmel Fault area, the narrow graben area in T. 6 N., R. 1 E., Lawrence County, is the location of a quarry operation in the Salem Limestone (Mississippian) that is preserved far below its normal stratigraphic level.

Erd (1954) reviewed early reports of sphalerite-bearing geodes in Harrodsburg (Mississippian) and Borden (Mississippian) outcrops in Lawrence Count; Recently Shaffer (1981) listed reported occurrences of sphalerite near the Mt. Carmel Fault in outcrops of Mississippian strata and in Devonian dolomite at a depth of about 800 feet. However, no Mississippi Valley-type ore deposits have been discovered to date along the structurally high Cincinnati or Kankakee Arches.

Deeper Faulting and Tectonic Implications Along the Mt. Carmel Fault

There are sufficient test-hole data to map the regional trace of the fault on the top of the Trenton Limestone. Below the Trenton there is only a handful of wells that reach the Knox Dolomite, and the persistence of the fault to the basement is based on seismic data.

Rudman and others (1965) reported a definite change in gradient of the basement in central Indiana at the position of the Mt. Carmel Fault. They suggested that the change in basement gradient marks the position of a structural hinge separating the stable Indiana-Ohio Platform from the subsiding Illinois Basin to the west and reported a similar tectonic setting on the east side of the platform bordering the Appalachian Basin. They speculated that a series of faults and scarps may rim the Illinois and Appalachian Basins about where the change in basement gradient takes place. They cited the Sandwich Fault Zone in northern Illinois as a possible expression of part of a semicontinuous fault system.

Later McGinnis (1966) on the basis of geophysical data suggested that a large basement fault zone was present 20 to 30 miles north of and parallel to the Sandwich Fault Zone and visualized a graben bounded on the south by the Sandwich Fault Zone. Recent work by Kolata and others (1978) on the Sandwich Fault Zone did not confirm McGinnis's proposition on the basis of subsurface data. However, Kolata, Treworgy, and Buschbach suggested that movement on the Sandwich Fault Zone probably coincided with crustal activity that resulted in formation of the LaSalle Anticline. They cited evidence that local movement of he LaSalle Anticline occurred in early Chesterian time, and this time frame s consistent with proposed early movement on the Mt. Carmel Fault suggested y Melhorn and Smith (1959). If the Mt. Carmel and Sandwich faults are tectonically elated, then the coincidence of movement is plausible.

REGIONAL IMPLICATIONS OF FAULTING IN SOUTHWESTERN INDIANA

The major faulting of southwestern Indiana bears uncertain regional relationships to the New Madrid and Rough Creek Fault Zones, the LaSalle Anticline of Illinois and its extension into Indiana, possible basement scarps, shelf hinge lines of the eastern Illinois Basin in Indiana, and a postulated linear basement structural feature in southwestern Indiana on trend with the New Madrid Fault Zone.

The Wabash Valley Fault System of Indiana lies on trend with the New Madrid Fault Zone and north of the 38th Parallel Lineament as expressed by the Rough Creek Fault Zone in northwestern Kentucky. The Wabash Valley faults are believed to extend to basement depths in at least three major fault zones and to form part of a major structural alignment in basement rocks.

The Wabash Valley faults have their greatest displacements, more than 400 feet, in southern Indiana. The displacements decrease drastically southwestward into Kentucky, and the faults may die out completely near the east-westward-trending Rough Creek Fault Zone.

This suggests that the mechanism producing the Wabash Valley faulting was separate from that producing the New Madrid and Rough Creek faulting even though the mechanism may be related regionally to part of the New Madrid disturbances.

No recorded earthquake centers have been associated with the Wabash Valley faults, and our study found no evidence of movement on the faults in recent times. There was no observed displacement of any Pleistocene or Holocene sediments that overlay the faults. Even though the highest seismic activity in the state is in southwestern Indiana, the level of seismicity in this area is much less than in the New Madrid area.

The Wabash Valley faults die out at their northeastern limits in southern Gibson County, and therefore the known faulting in this system is confined to an area of less than 500 square miles in Indiana. Faulting as supporting evidence of a linear basement feature could not be used any farther north than southern Gibson County.

The Mt. Carmel Fault and associated faults are oriented north-

northwesterly on trend with the LaSalle Anticline of Illinois and may be associated with a hinge line of the eastern shelf of the Illinois Basin. The persistence and length (50 miles) of the Mt. Carmel Fault make it an important element of the structural setting of this part of south-central Indiana and suggest that movement or origin of the fault, which is at least as late as post-Middle Mississippian, is strongly related to these structural features.

The trend of the Mt. Carmel Fault is almost the opposite of the northeasterly trend of the Wabash Valley faults and the proposed basement feature from which they originate. If the Mt. Carmel Fault is indicative of a major basement structure, then any projection of the basement linear structure of the Wabash Valley area into this area is at best of secondary importance.

The faulting in Perry and Spencer Counties is much less prominent than that discussed above. There are maximum measured displacements on the faults in those counties of less than 100 feet as compared with the several hundred feet of displacement measured in some Wabash Valley faults. No deep drilling data are present for determining the depth of the faulting in Perry and Spencer Counties, and it would be speculative to project it to basement depths. The faults in this area, although trending similarly to those of the Wabash Valley area, are not of sufficient magnitude to justify characterizing them as the eastern boundary of a basement structural feature that parallels the Wabash Valley Fault System.

The relationship of the faults in Perry and Spencer Counties to the Rough Creek Fault Zone in Kentucky is unclear, and the relationship may not be a close one.

Additional Faulting and Additional Study

Although this study completes our investigation of the known major faulting in southwestern Indiana, the subsurface data used in Posey and Gibson Counties were not capable of revealing faults of less than about 20 feet of displacement. Much of the detailed surface work in Perry and Spencer Counties and near the Mt. Carmel Fault consisted of structural mapping of key marker beds to help in locating the faults, a method that will not reveal faults with small displacements. Small-scale faulting could be detected by direct outcrop observation in only a few places because much of the bedrock in the study area is covered by soil, glacial till, or other unconsolidated sediments.

There are, however, excellent surface exposures in about 140 active strip mines and a few underground mines in southwestern Indiana, and older geologic reports (especially Ashley, 1898 and 1899) contain observations of numerous small-scale faults in the strip mines. Many of the faults may have sedimentologic rather than tectonic origins. We believe an extensive study of the exposures in the coal mines should be undertaken to supplement this study and to complete investigations of faulting and its tectonic implications in southwestern Indiana.

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