Stratigraphy and Structure of the Western Kentucky Fluorspar District

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1151-D

Prepared in cooperation with the Kentucky Geological Survey

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By Robert D. Trace *and* Dewey H. Amos

CONTRIBUTIONS TO THE GEOLOGY OF KENTUCKY

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Mississippian and Pennsylvanian limestone and clastic rocks are exposed in northeast-trending horsts and grabens

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By ROBERT D. TRACE[1] and DEWEY H. AMOS[2]

ABSTRACT

The western Kentucky fluorspar district is part of the larger Illinois-Kentucky fluorspar district, the largest producer of fluorspar in the United States. This report is based largely on data gathered from 1960 to 1974 during the U.S. Geological Survey–Kentucky Geological Survey cooperative geologic mapping program of Kentucky. It deals chiefly with the stratigraphy and structure of the district and, to a lesser extent, with the fluorspar-zinc-lead-barite deposits.

Sedimentary rocks exposed in the district range in age from Early Mississippian (Osagean) to Quaternary. Most rocks exposed at the surface are Mississippian in age; two-thirds are marine fossiliferous limestones, and the remainder are shales, siltstones, and sandstones. Osagean deep-water marine silty limestone and chert are present at the surface in the southwestern corner of the district. Meramecian marine limestone is exposed at the surface in about half the area. Chesterian marine and fluvial to fluviodeltaic clastic sedimentary rocks and marine limestone underlie about one-third of the area. The total sequence of Mississippian rocks is about 3,000 ft thick.

Pennsylvanian rocks are dominantly fluvial clastic sedimentary rocks that change upward into younger fluviodeltaic strata. Pennsylvanian strata of Morrowan and Atokan age are locally thicker than 600 ft along the eastern and southeastern margin and in the major grabens of the district where they have been preserved from erosion.

Cretaceous and Tertiary sediments of the Mississippi embayment truncate Paleozoic formations in and near the southwestern corner of the district and are preserved mostly as erosional outliers. The deposits are Gulfian nonmarine gravels, sands, and clays as much as 170 ft thick and upper Pliocene fluvial continental deposits as thick as 45 ft. Pleistocene loess deposits mantle the upland surface of the district, and Quaternary fluvial and fluviolacustrine deposits are common and widespread along the Ohio and Cumberland Rivers and their major tributaries.

Many mafic dikes and a few mafic sills are present. The mafic rocks are mostly altered mica peridotites or lamprophyres that are composed of carbonate minerals, serpentine, chlorite, and biotite and contain some hornblende, pyroxene, and olivine. Most of the dikes are in a north-northwest-trending belt 6 to 8 mi wide and strike N. 20°–30° W. The dikes dip from 80° to 90° and are commonly 5 to 10 ft wide. Radioisotopic study indicates that the dikes are Early Permian in age.

The district is just southeast of the intersection of the east-trending Rough Creek–Shawneetown and northeast-trending New Madrid fault systems. The district's principal structural features are a northwest-trending domal anticline, the Tolu Arch, and a series of steeply dipping to nearly vertical normal faults and fault zones that trend dominantly northeastward and divide the area into elongated northeast-trending grabens and horsts. Formation of these grabens and horsts was one of the major tectonic events in the district. Vertical displacement may be as much as 3,000 ft but commonly ranges from a few feet to a few hundred feet; no substantial horizontal movement is believed to have taken place. Many cross faults having only a few feet of displacement trend northwestward and are occupied at places by mafic dikes. Faulting was mostly post-Early Permian to pre-middle Cretaceous in age.

Many theories have been advanced to explain the structural history of the district. A generally acceptable overall hypothesis that would account for all the structural complexities, however, is still lacking. Useful structural data, such as the structural differences between the grabens and the horsts, have been obtained, however, from the recently completed geologic mapping. Mapping also has more clearly shown the alinement of the Tolu Arch, the belt of dikes, and an unusually deep graben (the Griffith Bluff graben); this alinement suggests that possible igneous activity may have caused tension, stretching, and partial collapse of the crust. Recent magnetic and gravity maps are useful in determining basement structural trends.

About 3¼ million short tons of fluorspar concentrate has been produced in the district since mining began in about 1873. Small quantities of zinc, barite, and lead also have been produced.

Most fluorspar-zinc-lead-barite ore bodies are steeply dipping to vertical vein deposits along northeast-trending faults or they are residual weathering concentrations of fluorite. A few are nearly horizontal bedding-replacement deposits in the Renault or the upper part of the Ste. Genevieve Limestone of Late Mississippian age. Fluorspar veins are commonly 3- to 10-ft-wide fissure fillings along faults and in fault breccia, accompanied by replacement of vein calcite and

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some limestone wallrock. In many veins, sphalerite, galena, and barite are minor minerals; sphalerite or barite is the major constituent in a few veins.

More than two-thirds of the fluorspar production has come from five areas within the district. A few areas have produced only zinc ore or barite. The main potential areas for the discovery of vein deposits are along the hanging-wall faults.

INTRODUCTION

This report summarizes data gathered during the U.S. Geological Survey–Kentucky Geological Survey (USGS–KGS) cooperative program of geologic mapping that began in 1960 and was completed in the fluorspar district in 1974; it includes some data from the 1940's and 1950's. The report and map (pl. 1) are intended primarily for those studying the local stratigraphy and structure.

The western Kentucky fluorspar district (fig. 1) is a part of the larger southern Illinois–western Kentucky fluorspar district. Except for the cryptovolcanic Hicks Dome and associated breccia in Illinois (Baxter and Desborough, 1965; Baxter and others, 1967; Clegg and Bradbury, 1956; Grogan and Bradbury, 1968; Trace, 1974a), the geology and mineral deposits in the two States are similar.

The western Kentucky fluorspar district (hereinafter referred to as the district) consists of about 700 mi², mostly in Livingston, Crittenden, and Caldwell Counties and within the boundaries of thirteen 7½-min quadrangles. Geologic maps of these quadrangles were published at the scale of 1:24,000 (Amos, 1965, 1966, 1967, 1974; Amos and Hays, 1974; Rogers and Trace, 1976; Rogers and Hays, 1967; Seeland, 1968; Trace, 1962a, 1966, 1974b, 1976a). The geology shown on these maps has been slightly modified in compiling plate 1 of this report—a geologic map of the district at the scale of 1:48,000. Plate 1 covers, at a slightly larger scale, most of the area previously mapped by Weller and Sutton (1951).

The district is separated from the Illinois fluorspar district on the north and west by the Ohio River. The Cumberland River flows through the southwestern part of the district. The principal towns include Marion, Smithland, and Salem.

A mature topography characterizes the district; it is expressed mostly by rolling hills of the Shawnee Section of the Interior Low Plateaus (Fenneman, 1938, p. 434–440). Altitudes range from about 300 ft above mean sea level along the Ohio River to almost 850 ft on a few hilltops. Topography is related clearly to lithology and structure and, therefore, is extremely useful in making geologic interpretations. The hills, generally wooded, are commonly capped by resistant sandstone, and the valleys, commonly cleared farm land, are underlain by limestone and shale. Structurally, the hills and ridges reflect northeast-trending grabens where downdropped Lower Pennsylvanian or Upper Mississippian resistant sandstones crop out along faultline scarps adjacent to less resistant middle Mississippian limestones in the valleys. Parts of the district, such as the Fredonia Valley and the Tolu Arch areas, are gently rolling and contain abundant sinkholes; these areas are underlain by middle Mississippian limestones.

This report describes only briefly the fluorspar and associated mineral deposits. Limestone or sandstone quarries and coal or iron mines are not described except that the locations of three active limestone quarries (Dever and McGrain, 1969, p. 88, 110, 182) and one active sandstone quarry are shown in plate 1. Plate 1 also shows a few oil and gas test holes, mostly in the Tolu Arch area, because a substantial amount of Osagean and Meramecian stratigraphic information was obtained from them; other test holes, particularly in the Farmersville Dome area (Crider quadrangle), are not shown.

TABLE 1.—*Authors of U.S. Geological Survey Geologic Quadrangle (GQ) Maps of quadrangles in and near the Kentucky fluorspar district (fig. 1)*

[All maps were published by the U.S. Geological Survey in cooperation with the Kentucky Geological Survey at the scale of 1:24,000]

GQ number	Author	Date	Name of quadrangle(s)
206	Trace	1962	Salem, Ky.
255	Rogers	1963	Eddyville, Ky.
328	Hays	1964	Grand Rivers, Ky.
385	Sample	1965	Princeton West, Ky.
400	Amos	1965	Shetlerville and Rosiclare, Ky.–Ill. (Kentucky parts only)
490	Palmer	1966	Dalton, Ky.
546	Amos	1966	Golconda, Ky.–Ill., and the part of the Brownfield quadrangle in Kentucky
547	Trace	1966	Marion, Ky.
554	Amos and Wolfe	1966	Little Cypress, Ky.–Ill.
607	Rogers and Hays	1967	Fredonia, Ky.
657	Amos	1967	Smithland, Ky.–Ill. (Kentucky part only)
731	Amos and Finch	1968	Calvert City, Ky.
742	Trace and Kehn	1968	Olney, Ky.
754	Seeland	1968	Repton, Ky.–Ill. (Kentucky part only)
873	Amos	1970	Blackford, Ky.
880	Trace and Palmer	1971	Shady Grove, Ky.
1032	Trace	1972	Princeton East, Ky.
1147	Kehn	1974	Dekoven and Saline Mines, Ky.–Ill. (Kentucky parts only)
1149	Amos and Hays	1974	Dycusburg, Ky.
1150	Amos	1974	Burna, Ky.
1201	Trace	1974	Cave in Rock, Ky.
1283	Rogers and Trace	1976	Crider, Ky.
1288	Trace	1976	Lola, Ky.

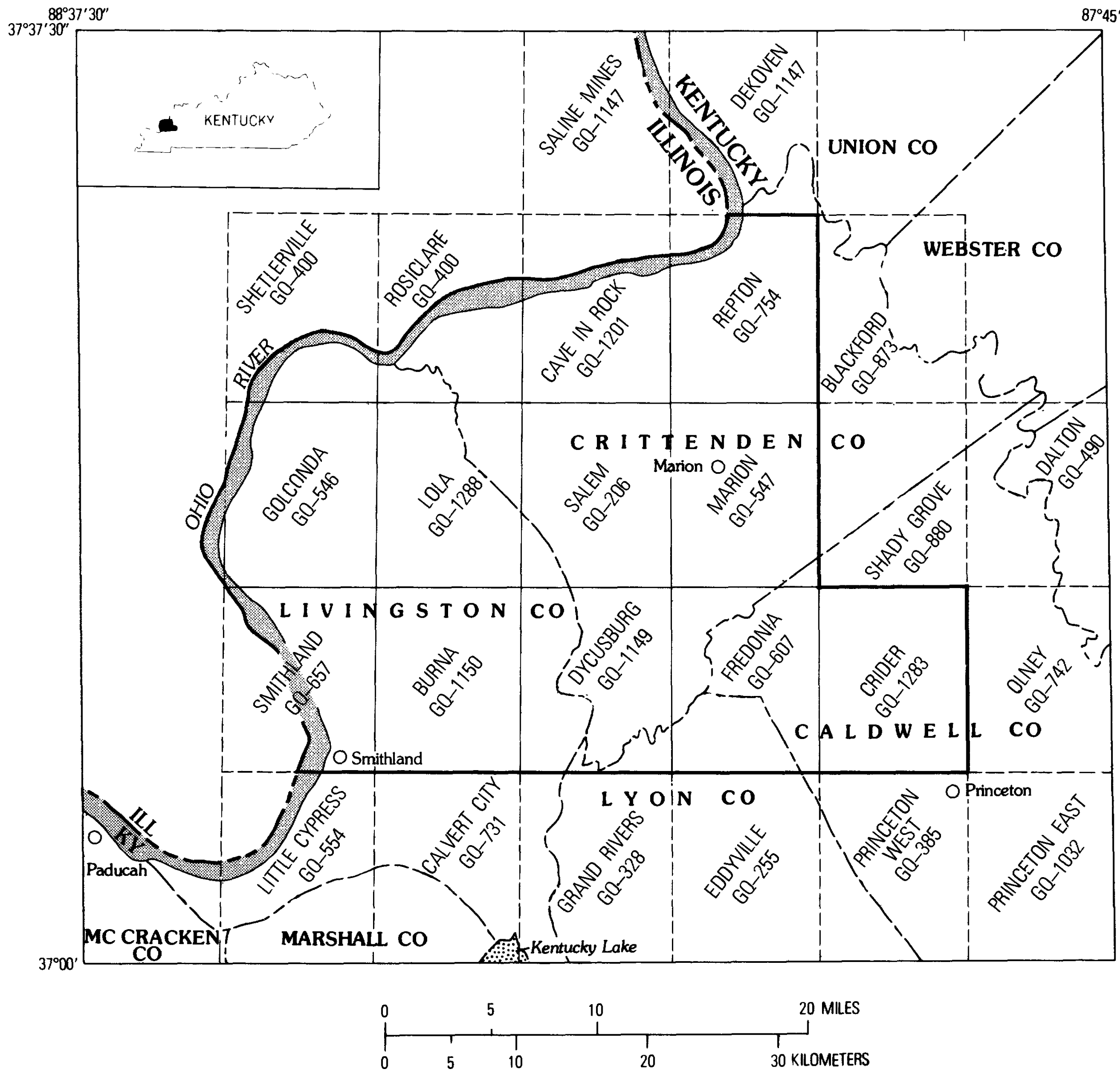


FIGURE 1.—Index map showing numbers of USGS Geologic Quadrangle (GQ) Maps of the Kentucky fluorspar district and adjacent areas in Kentucky. Heavy line outlines area shown in plate 1. Table 1 lists the authors of the GQ's for the quadrangles shown in this figure.

Production

Between 3 million and 4 million short tons of fluorspar concentrate (table 2) and smaller quantities of zinc, lead, and barite have been shipped from the district. Although some mining for lead began much earlier, fluorspar was first produced from the district at the Yandell mine (not shown on pl. 1) in about 1873 (Ulrich, *in* Ulrich and Smith, 1905, p. 20). Although the exact location is unknown, the old Yandell mine is

TABLE 2.—*Fluorspar shipments from Kentucky*

[Data from "Minerals Yearbooks," U.S. Bureau of Mines]

Year	Fluorspar shipments (short tons)
Through 1963	3,016,980
1964	38,214
1965	31,992
1966	28,725
1967	32,952
1968	17,050
1969–75	61,264
Total	3,227,177

on the Tabb fault system near the No. 22 mine, just southwest of the village of Frances. Fluorspar production during the rest of the 1880's was apparently very small, but, about the turn of the century, many new mining operations began.

Recorded production of zinc began in western Kentucky about 1901 (Smith, *in* Ulrich and Smith, 1905, p. 116) from the Old Jim mine and Columbia mine areas. During the period 1901–04, a few hundred to a few thousand tons of smithsonite (zinc carbonate) and sphalerite (zinc sulphide) were produced. Data from several volumes of "Mineral Resources of the United States" by the USGS and data from "Minerals Yearbooks" for 1964–74 by the U.S. Bureau of Mines (USBM) indicate that approximately 74,000 short tons of metallic zinc has been produced in Kentucky. Of this total, about 71,500 short tons was produced from the district; the remainder was produced from central Kentucky.

According to Smith (*in* Ulrich and Smith, 1905, p. 115), "Lead ores were known in this district to the early settlers from about 1812. The first attempt to mine the deposits was made in 1835 by a company headed by President Andrew Jackson." That company operated in the area of the present Columbia mine in the Salem quadrangle. Smith (*in* Ulrich and Smith, 1905, p. 116) reported that at least 1,000 tons of galena was mined from the district by 1880 and that production ceased entirely between 1880 and 1900.

Data in the USGS's "Mineral Resources of the United States" and the USBM's "Mineral Yearbooks" indicate that a little more than 13,000 short tons of metallic lead was produced in Kentucky between 1906 and 1974. A small amount, perhaps as much as 500 short tons, was produced from the central Kentucky mineral district, and thus about 12,500 short tons of metallic lead was produced from the western Kentucky district.

A small quantity of barite was mined as early as 1903 (Smith, *in* Ulrich and Smith, 1905, p. 135; Fohs, 1907, p. 24–25). From then until 1959, however, production probably did not exceed a few thousand tons. From 1959 to 1964 inclusive, about 45,000 short tons of barite was produced, according to the USBM's "Minerals Yearbook"; since 1964, production has been only a few thousand tons. In addition, approximately 40,000 to 50,000 short tons of barite was contained in Fluorbarite[3] that was produced from the early 1930's to the early 1950's. Fluorbarite is a mixture of approximately equal parts of fluorspar and barite that was marketed for ceramic use. Most of the barite and Fluorbarite production has come from the Pygmy, Mico, Ellis, Wright, and Ainsworth mines (pl. 1).

[3]Use of trade names in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

History of Previous Geologic Work

Geologic work in the district, according to Ulrich (*in* Ulrich and Smith, 1905, p. 17), began "in 1854–1857, during the progress of the first geological survey of the State of Kentucky, by David Dale Owen***." Further investigations were done by Norwood (1876a). In 1888, Ulrich began work in the district; he was joined by Smith in about 1900, and together they published the first comprehensive description and geologic map of the district (Ulrich and Smith, 1905).

Fohs (1907), Hoeing (1913), and Jillson (1921) discussed parts of the district, particularly in reference to mining. Stratigraphic data on the district were published by Butts (1917).

Weller (1921, 1923, 1927) mapped and studied the geology, especially the structure and stratigraphy. Concurrently, Currier (1923) examined and studied most of the mines and prospects. During the 1920's, the entire district was mapped for the KGS by Stuart Weller and A. H. Sutton, but, because of lack of funds, their maps were not published until 1951.

In 1940, J. M. Weller and Sutton summarized Mississippian stratigraphy on the basis of work done during the previous 30 years. Nearly all the Mississippian stratigraphic terminology and definitions of units used in this report are similar to those used in their 1940 report.

Beginning in the 1940's, the amount of geologic work in the district increased. From 1942 to 1945, the USGS and the USBM made comprehensive geologic studies of, and collected drill cores from, selected areas within the district (Starnes, 1946, 1947a, 1950; Starnes and Hickman, 1946; Muir, 1947; Swanson and Starnes, 1950; Klepser, 1954; Thurston and Hardin, 1954; Trace, 1954a, 1962b; Hardin, 1955; Hardin and Trace, 1959; Williams and Duncan, 1955).

In 1960, the USGS, in cooperation with the KGS, began a program to map the geology of all the 7½-min quadrangles in the entire Commonwealth of Kentucky. Because Barkley Dam was nearing completion and flooding of crucial areas was imminent, Meramecian-age rocks in the Princeton West, Eddyville, Grand Rivers (fig. 1), and other quadrangles were studied early in the mapping program.

Several oil test holes had been drilled near Tolu in the northern part of the district in 1954–56, and the core from them was made available to the USGS for examination. In addition, a USGS–KGS corehole was drilled in 1962 at the Fredonia Valley quarry (for location, see pl. 1; Rogers and Hays, 1967), and cuttings were also examined from the George Petit No. 1 oil test (Carter coordinates, sec. 5, G–20) completed in 1956 about 2½ mi southwest of Princeton.

Also in the 1960's, the USGS began a study of Mississippi Valley-type ore deposits, including the deposits in the Kentucky district (Heyl and Brock, 1961; Hall and Friedman, 1963; Heyl and others, 1965, 1966; Hall and Heyl, 1968; Heyl, 1969, 1972).

A summary of the Illinois-Kentucky fluorspar district was published in 1968 (Grogan and Bradbury). In a symposium volume edited by Hutcheson (1974), several authors described various aspects of fluorspar deposits in the United States, including those in this district.

STRATIGRAPHY

Deposits exposed in the district range in age from Lower Mississippian (Osagean) to Holocene (fig. 2). Series represented include the Osagean, Meramecian, and Chesterian of Mississippian age, the Morrowan and Atokan of Pennsylvanian age, the Gulfian of Cretaceous age, the Pliocene of Tertiary Age, and the Pleistocene and Holocene of Quaternary age. A few mafic dikes of Early Permian age are also present.

Rocks exposed at the surface are mostly Mississippian; some Pennsylvanian rocks are present, and the southwestern part of the district contains some Cretaceous and Tertiary deposits. Holocene deposits are extensive in the valleys of the Ohio and Cumberland Rivers. Many small previously mapped areas of Tertiary sediments and Quaternary loess are not shown in plate 1.

Mississippian System

The fluorspar district is largely underlain by Mississippian rocks that aggregate almost 3,000 ft in thickness. More than two-thirds of these rocks are marine fossiliferous limestones; the remaining are shale, siltstone, and sandstone. Some limestones are dolomitic, argillaceous, and siliceous; some clastic rocks contain very thin coaly beds and plant fossils, and some clastic rocks are red.

The standard section in the Eastern Interior basin includes the Kinderhookian, Osagean, Meramecian, and Chesterian Provincial Series. Within the district, Kinderhookian rocks, if present, are probably very thin (Baxter and Desborough, 1965, p. 5); none are known to be exposed, and they have not been identified with certainty in the subsurface. The strata that crop out are the Fort Payne Formation (Osagean), the Warsaw, Salem, St. Louis, and Ste. Genevieve Limestones (Meramecian), and 15 units (see fig. 2) from the Renault Formation through the Kinkaid Limestone (Chesterian).

OSAGEAN PROVINCIAL SERIES

The Osagean Provincial Series, about 600 ft thick, is represented by the Fort Payne Formation, which crops out only in small areas, mostly in the southwestern part of the district, east of Smithland, Ky. (Amos, 1967, 1974).

FORT PAYNE FORMATION

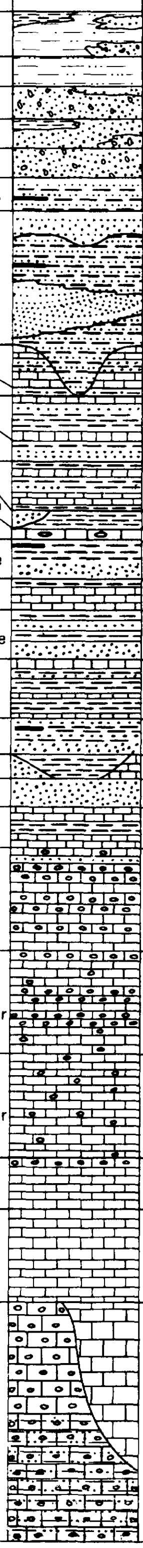
The Fort Payne Formation (Smith, 1890, p. 155–156) is named for Fort Payne, DeKalb County, Ala. Ulrich (*in* Ulrich and Smith, 1905, p. 27–28) described the unit in the fluorspar district as the Tullahoma Formation but recognized it as equivalent to the Fort Payne. The name Tullahoma was abandoned by the USGS (Bassler, 1911, p. 212) in favor of the Fort Payne.

The Fort Payne Formation is exposed in small areas near the southwestern corner of the district (Amos, 1967, 1974). The uppermost 40 ft of the formation was penetrated in the Fredonia Valley quarry by a USGS–KGS cored drill hole (pl. 1), and two of the oil test holes south of Tolu penetrated the entire Fort Payne Formation where it is about 600 ft thick.

The Fort Payne Formation is dark-gray, microgranular limestone, which is argillaceous and extremely siliceous, contains silt-size quartz, and commonly contains 10 to 35 percent small dark-gray chert nodules and lenticular masses and beds from 1 in to 1 ft thick. Fossils are sparse and include a few crinoid columnals, fragments of the bryozoan *Fenestella*, and small brachiopods. The Fort Payne commonly weathers to a light-yellowish-brown clay containing abundant residual chert that is light gray or light brown, is porous, has thin laminations that resemble wood grain, and is highly fractured so that it breaks into small angular fragments. In places, good exposures of residual chert show original bedding, although the beds are commonly distorted by slumping. At places, the chert weathers to a white porous impure tripoli.

The base of the Fort Payne is not exposed in the district, but, just to the south, its contact with the underlying New Providence Shale (Osagean) is sharp (Rogers, 1963). In the George Petit No. 1 oil test well (Carter coordinates, sec. 5, G–20), 2½ mi southwest of Princeton, Ky., 600 ft of typically dark-gray siliceous and cherty Fort Payne is present. In the northern part of the Salem quadrangle in an oil test hole (pl. 1) and in three of the test holes drilled further north in the Cave in Rock quadrangle, the upper one-half to two-thirds of this 600-ft Fort Payne interval is commonly a light-gray, finely to coarsely crystalline calcarenitic limestone, the lower 40 to 50 feet of which contains abundant chert nodules (Trace, 1974b). Abundant fenestellid bryozoans and crinoid fragments are present. The

SYSTEM	SERIES	FORMATION AND MEMBER	THICKNESS, IN FEET	DESCRIPTION
QUATERNARY	Holocene and Pleistocene	Fluvial and lacustrine deposits	0–100+	Silt, clay, sand, and gravel
	Pleistocene	Peoria Loess	3–35	Silt
TERTIARY	Pliocene	"Lafayette" gravel[1]	0–45	Gravel and sand
CRETACEOUS	Gulfian	McNairy Formation	0–80	Sand, clay, and gravel
		Tuscaloosa Formation	0–90	Gravel
PENNSYLVANIAN	Atokan	Tradewater Formation	100+	Sandstone, shale, siltstone; thin coals
	Morrowan	Caseyville Formation	190–495	Sandstone, shale, siltstone; thin coals
MISSISSIPPIAN	Chesterian	Kinkaid Limestone	0–165	Limestone, sandstone, and shale
		Degonia Formation	5–45	Shale and sandstone
		Clore Limestone	80–130	Shale and limestone; thin sandstone
		Palestine Sandstone	45–75	Sandstone and shale
		Menard Limestone	80–145	Limestone and shale; thin sandstone locally
		Waltersburg Formation	20–50	Shale, siltstone, and sandstone
		Vienna Limestone	15–40	Limestone, cherty
		Tar Springs Sandstone	70–120	Sandstone and shale; thin coal locally
		Glen Dean Limestone	40–105	Limestone and shale
		Hardinsburg Sandstone	35–165	Sandstone and shale
		Golconda Formation	90–165	Shale and limestone; thin sandstone common
		Cypress Sandstone	25–125	Sandstone and shale; thin coal locally
		Paint Creek Shale	5–115	Shale, limestone, and sandstone
		Bethel Sandstone	15–120	Sandstone
		Renault Formation	70–125	Limestone and shale
	Meramecian	Ste. Genevieve Limestone	200–300	Limestone, oolitic; thin sandstone
		St. Louis Limestone	500–530	
		Upper Member	200–250	Limestone, cherty, partly oolitic
		Lower Member	250–280	Limestone, cherty; containing *Lithostrotion* colonies
		Salem Limestone	110–160	Limestone, oolitic at top
		Warsaw Limestone	225–260	Limestone, large *Echinocrinus* spines at top
	Osagean	Fort Payne Formation	600±	Limestone, mostly dark gray and very cherty or silty; locally, upper part is light gray



[1]As used by Potter (1955a,b)

Figure 2.—Generalized stratigraphic column of exposed formations in the western Kentucky fluorspar district.

contact with the underlying dark-gray, finely crystalline and cherty rocks characteristic of the Fort Payne to the south is sharp. The name Ullin Limestone was proposed for these light-gray rocks by Lineback (1966). Lineback's Ullin Limestone probably does not crop out in the district, except possibly in the southwestern part (Amos, 1974). Lineback's Ullin is similar to the Warsaw and may, in places, be incorrectly mapped as Warsaw.

The maximum thickness of the Fort Payne Formation in the district is about 600 ft. In the northern part, however, the light-hued limestone correlated with Lineback's Ullin is 340 to 350 feet thick, and the underlying dark part of the Fort Payne ranges from 230 to 280 ft in thickness.

MERAMECIAN PROVINCIAL SERIES

The Meramecian Provincial Series, about 1,050 to 1,150 ft thick, is represented by the Warsaw, Salem, St. Louis, and Ste. Genevieve Limestones. The limestones range from finely to coarsely crystalline and from light to dark gray; they are partly oolitic, are partly dolomitic, and commonly contain abundant chert nodules. A thin calcareous sandstone (Rosiclare Sandstone Member of the Ste. Genevieve) occurs near the top of the Meramecian.

The Meramecian crops out largely in two areas, around the Tolu Arch in the north-central part of the district, and in the southeastern and south-central parts—the Fredonia Valley and west (pl. 1). Smaller areas of exposures are present in several of the fault blocks.

Previous mapping (Weller and Sutton, 1951) indicated that no unit older than the St. Louis Limestone was exposed at the surface of the district, except for a small area of Salem (Spergen) Limestone near Princeton. Butts (1917, p. 28), however, had suggested that Warsaw Limestone was exposed in the area.

WARSAW-SALEM-ST. LOUIS PROBLEM

As a result of the recent mapping and some subsurface studies, the Warsaw, Salem, St. Louis, and Ste. Genevieve Limestones have been retained although their boundaries have been partly revised. In 1960, however, correlation of these units in the district with their type sections in Illinois, Indiana, and Missouri was not clear. This problem resulted from several factors: the structural complexities of the district, the general similarity of many of the massive limestone beds, the poor exposures of these limestones (most exposures are largely weathered to clay soils containing chert residuum), and the sparseness of drill holes. Drilling for fluorspar deposits rarely penetrated below the upper part of the St. Louis Limestone, and, where it did, it included only short stratigraphic intervals near faults of the Ste. Genevieve and the upper part of the St. Louis Limestone.

The uncertainty of correlating units in the district with their type sections was stated by Weller (1927, p. 9): "The formations which are buried beneath the St. Louis Limestone are but little known in the [Cave in Rock 15-min] quadrangle, and in the main the character of the unexposed strata must be inferred from our knowledge of the formations in adjacent regions." Data on units in the Princeton East 7½-min quadrangle, which is near the district (fig. 1), were given by Weller (1923, p. 10–11): "Overlying the dark, impure limestone or silico-calcareous shale which possibly represents the Osage [Fort Payne] division of the Iowa Series, the Cedar Hill well samples are essentially all limestones, from brown to light and dark gray in color, and most of them include numerous fragments of chert, ***If the beds below these limestones are equivalent of the Osage, then these cherty limestones are the equivalents of the Warsaw, Spergen or Salem, St. Louis, and Ste. Genevieve limestone formations."

The Warsaw–Salem–St. Louis boundary problems faced by mappers also are illustrated by the following comments.

Ulrich (*in* Ulrich and Smith, 1905, p. 28) stated that "only the Spergen [Salem] oolitic limestone and the St. Louis Limestone are distinguishable in this [fluorspar] district. The lowest division, the Warsaw formation, is possibly in part equivalent to the lower part of the Spergen [Salem] limestone ***."

Butts (1917, p. 28) described about 250 ft of Warsaw north of the district around Hicks Dome in Hardin County, Ill., as "the limestone lying between the Fort Payne chert below and the lowest beds containing the fossil coral *Lithostrotion proliferum* above ***. Much the greater part of its thickness appears to be a very dark, fine-grained rock [limestone] ***. Interbedded with these dark, fine-grained layers in the upper part at least of the Warsaw, are thick layers of very coarse-grained, light gray limestone." Butts (1917, p. 33) stated, "There is a possibility that it [Spergen or Salem] is represented in Hardin County, Ill., by the upper part of the 250 feet of limestone classed as Warsaw in this report."

Weller and others (1952, p. 59–60) wrote, in reference to the Warsaw and Salem in the same area, "Approximately the lower three-fourths [of 250 ft] is dark to black fine-grained limestone. *** The uppermost fourth of the formation is much lighter colored and may correspond to the Salem limestone of Indiana."

In 1967, however, Baxter and others (p. 8) commented about the same area: "It appears now that the lower part (approximately 125 feet) better fits the description of the Fort Payne (Lineback, 1966, p. 22) and that the upper part can be referred to the Ullin Limestone." If this statement is correct, then the basis for definition of the Warsaw and Salem in pre-1960 literature of areas in and near the district is somewhat doubtful.

The Osagean and Meramecian rocks described above in quotations from Weller (1923, 1927), Butts (1917), Ulrich (*in* Ulrich and Smith, 1905), and Weller and others (1952) were found by the authors of this report to be mostly similar to the rocks in the Fredonia Valley quarry cored drill hole, the George Petit No. 1 oil test southwest of Princeton, and several drill holes near and south of Tolu, Ky. (pl. 1). On the basis of these drill holes, the Salem-Warsaw contact is placed at a pronounced color change, from a light-gray calcarenite of crinoid and bryozoan fragments (Warsaw) to overlying medium- to dark-gray calcarenite (Salem). This contact appears to correspond to the contact in the 250-ft-thick unit described by Butts (1917, p. 33) and Weller and others (1952, p. 59–60). In addition, a zone of abundant spines and plates of *Echinocrinus* is present at, or within a few feet of, this contact (Rogers, 1963; Hays, 1964). Butts in 1922 (p. 123) also described the *Echinocrinus* as being near this contact: "The succession from the Warsaw through argillaceous thick-bedded limestone with fucoids and *Archeocidarsis* [*Echinocrinus*] and commonly *Melonites* [*Melonechinus*] plates, to pure, bluish limestone with *Lithostrotion* is a constant feature of the basal St. Louis in Kentucky ***."

The drill holes described above and surface mapping indicate that the lowermost *Lithostrotion* colonies commonly occur as much as 120 ft above the top of the approximately 250 ft of limestone that Ulrich (*in* Ulrich and Smith, 1905) and Butts (1917) called Warsaw or Warsaw-Salem and that is herein called Warsaw. Only locally have some solitary corals, possibly *Lithostrotion*, been found slightly below that horizon (Hays, 1964). The 120 ft of section referred to above is dominantly medium to coarsely crystalline calcarenite and is the Salem Limestone as used in this report. In contrast, the overlying rocks bearing abundant *Lithostrotion* are dominantly finely crystalline and belong to the St. Louis Limestone of this report. This definition of the Salem-St. Louis contact is believed to agree with the definition given by Lineback (1972, p. 20). A precise contact is difficult to pick at the surface, however, because coarsely and finely crystalline limestones are interbedded within both the Salem and St. Louis Limestones. As a result, the Salem and lower member of the St. Louis have been mapped as a single unit.

The Warsaw, Salem, and St. Louis also are recognized in the Illinois part of the fluorspar district although the stratigraphic names are used differently in Illinois than they are in Kentucky. The Salem Limestone in Illinois is divided into three units (Baxter and others, 1967, p. 9): the lower unit, about 260 ft thick, is the Warsaw of this report; the middle unit of 100 to 120 ft is the Salem of this report; and the upper unit is the lower part of the lower member of the St. Louis Limestone of this report.

Warsaw Limestone

The Warsaw Limestone (Hall, 1857, p. 193) was originally named for limestone and shale that crop out at Warsaw, Ill., about 220 mi northwest of the district. Because the original type section was not well defined, Collinson (1964) designated a new type section in Geode Glen near Warsaw. Definition of the Warsaw has varied considerably since it was first used, as discussed by Weller and Sutton (1940, p. 802–805), Willman and others (1975, p. 138–139), and Lane and Brenckle (1977, p. 3).

The Warsaw Limestone in the district is commonly a light- to dark-gray, finely to coarsely crystalline calcarenite composed dominantly of fenestellid bryozoan and crinoid fragments. It crops out in the southwestern part of the district (Amos, 1974). Abundant *Echinocrinus* spines as much as 1/8 in. in diameter and 2 to 3 in. in length are common in the upper few feet of the formation. Some of the unit, particularly the upper part, weathers to large blocks of coarse bioclastic-textured chert residuum. The Warsaw was penetrated in the Fredonia Valley quarry drill hole (Rogers and Hays, 1967), where it is most commonly light-gray, medium to coarsely crystalline calcarenite.

Several of the oil test holes drilled near Tolu, Ky., cut the entire Warsaw. Approximately the lower two-thirds of the Warsaw is one-half to two-thirds medium- to dark-gray, finely crystalline limestone, in part argillaceous, and contains sparse to common chert nodules. Interbeds of medium- to light-gray, medium to coarsely crystalline calcarenite are common. The upper third of the formation is light-gray, medium to coarsely crystalline calcarenite (Trace, 1974b).

Contact with the underlying Fort Payne is sharp (Rogers, 1963) or transitional (Amos, 1974). The Warsaw ranges from 225 to 260 ft in thickness.

The Warsaw Limestone, as defined in the district, does not occupy the same stratigraphic position as the type Warsaw occupies in western Illinois. According to Lineback (1966, p. 21; 1968, fig. 3), the type Warsaw, or its equivalents, lies below Lineback's Ullin Limestone, whereas the Warsaw as used in this report and map (pl. 1) overlies Lineback's Ullin.

Salem Limestone

The Salem Limestone (Cumings, 1901, p. 233) is named for Salem, Washington County, Ind. At its type locality, the Salem is a light-gray calcarenitic limestone, but the use of the term "Salem" in or near the district has been vague (Weller and Sutton, 1940; Baxter, 1960; Willman and others, 1975). Outcrops of the Salem are present in small areas in the southwestern part of the district (Amos and Hays, 1974; Amos, 1974), and the Salem is near the surface at the Tolu Arch in the north-central part of the district. The entire unit was penetrated in the Fredonia Valley quarry drill hole (Rogers and Hays, 1967) and in several of the oil test holes near and south of Tolu (Trace, 1974b).

The Salem Limestone is medium- to dark-gray, finely to coarsely crystalline limestone that is mostly calcarenitic but is partly argillaceous or dolomitic. The upper part is commonly coarsely crystalline or oolitic and contains abundant tests of the foraminifer *Endothyra*. Sparse chert nodules are present locally. *Melonechinus*-like plates are locally common; a few solitary corals similar to *Lithostrotion* and a few *Hapsiphyllum* are present. The unit weathers to a residuum of reddish-brown clay containing abundant fine-textured chert.

The contact with the underlying Warsaw Limestone is probably conformable and gradational. The Salem ranges in thickness from 110 to 160 ft but probably averages about 120 ft.

On plate 1, the Salem is combined with the overlying lower member of the St. Louis Limestone.

St. Louis Limestone

The St. Louis Limestone was named by Engelmann (1847) for exposures in old quarries and bluffs along the Mississippi River at St. Louis and was later modified to present usage by E. O. Ulrich (as quoted by Buckley and Buehler, 1904, p. 109–110; see also Ulrich, *in* Ulrich and Smith, 1905, p. 36).

Early work on the St. Louis was summarized by Weller and Sutton (1940, p. 813–815). In southern Illinois, Baxter and others (1967) redefined the lower contact upwards. Later work by Lineback (1972) may have modified that contact again, at least for the Illinois-Kentucky fluorspar area.

The St. Louis Limestone crops out principally in two areas of the district: (1) the south-central part near the Cumberland River and the contiguous area to the east and (2) the north-central part at the Tolu Arch. A few small areas of exposure are also present in some fault blocks. The entire formation was penetrated in the Fredonia Valley quarry drill hole, and parts of it were penetrated in the several oil test holes near Tolu.

The St. Louis Limestone is about 500 ft thick in the fluorspar district and has been divided into a lower member and upper member of about equal thickness. The division into two members was introduced by Rogers (1963) and was used in the district by Rogers and Hays (1967). Two geologic maps completed earlier did not use this subdivision of the St. Louis (Trace, 1962a; Amos, 1965).

The Ste. Genevieve–St. Louis contact in the district has been mapped (Weller and Sutton, 1951) and logged in cored drill holes at two different horizons about 140 to 160 ft stratigraphically apart. This 140- to 160-ft interval contains diagnostic criteria of both the Ste. Genevieve (oolitic limestones) and the St. Louis (abundant chert nodules) (Rogers and Hays, 1967). The Ste. Genevieve–St. Louis contact appears to have been commonly mapped by Weller and Sutton at or near the lowest occurrence of oolitic limestone (chiefly oolitic chert residuum) or, in a few places, at the top of abundant in situ chert nodules in limestone. In the 1940's, the USGS used the upper boundary and was unaware of the transition unit problem, which was not recognized until the early 1960's.

Prior to the 1960's, mining geologists in both the Kentucky and Illinois parts of the fluorspar district placed the contact at the top of abundantly cherty limestone, which is easily recognizable in drill core. At that time, the cored drill holes rarely penetrated much below this cherty limestone horizon; even where holes did penetrate this cherty limestone and oolitic limestone was recognized, the oolitic limestone was ignored, as far as the stratigraphic nomenclature used. The Illinois State Geological Survey also mapped the contact at approximately the same horizon as the one used by the mining company geologists (Baxter and Desborough, 1965, p. 8–9; Baxter and others, 1967, p. 10).

The USGS currently uses the upper boundary discussed above because this boundary was used by the area's mining company geologists, by the USGS in the earlier work in the district, and by the Illinois State Geological Survey in southern Illinois.

Lower Member

The lower member of the St. Louis Limestone is light- to dark-gray, dominantly finely crystalline limestone containing scattered interbedded medium to coarsely crystalline calcarenite. It is very slightly oolitic at places and is partly argillaceous and dolomitic. Scattered to abundant spheroids, discoids, and discontinuous layers of light- to medium-gray fine-textured chert and a few vugs and thin seams of gypsum and anhydrite are present. Scattered to abundant colonial corals, commonly identified as *"Lithostrotion" proliferum*

Hall and *Lithostrotion castelnaui* Hayaska, and the foraminifer *Endothyra* are present through much of the member, which weathers to a thick fine-textured chert and clay residuum.

The member is commonly about 250 ft thick and can be divided into two units. The lower unit is 120 to 170 ft thick and consists of dark-gray limestone, mostly finely crystalline, argillaceous, and dolomitic in places, and contains abundant *Endothyra* Foraminifera and colonial lithostrotionoid corals. The upper unit is 65 to 100 ft thick and consists of light- to medium-gray, mostly finely crystalline limestone containing scattered lithostrotionoid corals.

The base of the lower member is placed at the lowest occurrence of abundant colonial lithostrotionoid corals, which approximately coincides with a change from the underlying coarsely crystalline or partly oolitic units (Salem) to overlying finely crystalline limestone (St. Louis). The contact is conformable and apparently gradational. The top of the member is placed at the highest mapped occurrence of colonial lithostrotionoid corals.

Upper Member

The upper member of the St. Louis Limestone is light- to medium-gray or brownish-gray, mostly finely crystalline limestone that contains minor beds of medium to coarsely crystalline calcarenite. Oolitic limestone beds are common in the upper part of the unit, and a few scattered dolomitic limestone beds are present. Sparse to abundant irregularly shaped nodules and layers of light- to medium-gray chert are present. The unit weathers to a thick residuum of dark-reddish-brown clay and finely textured chert fragments. Sinkholes are common, particularly in areas underlain by the upper part of the member.

The upper member, 200 to 250 ft thick, can be divided into two units: a lower unit 60 to 110 ft thick of limestone containing abundant chert nodules in the uppermost 15 to 30 ft and an upper unit 140 to 165 ft thick which is generally similar to the lower unit except that it contains a substantial number of oolitic beds. The uppermost 15 to 30 ft of the upper unit contains abundant chert nodules. A persistent coarsely crystalline, light-gray calcarenite bed containing many very light brown, shiny calcareous grains that show prominent cleavage surfaces on broken surfaces is present at the base of this upper unit. The basal contact of the member is conformable.

Ste. Genevieve Limestone

The Ste. Genevieve Limestone (Shumard, 1859, p. 406) was named from outcrops in the bluffs of the Mississippi River southeast of Ste. Genevieve, Mo. Ulrich (*in* Ulrich and Smith, 1905, p. 39–53) introduced the name in the district. The Ste. Genevieve Limestone crops out principally in the southeastern part of the district—in the Fredonia Valley and in interfault areas near Lola and southeast and northeast of Salem. The lower 160 ft of the Ste. Genevieve was penetrated by the Fredonia Valley quarry drill hole.

The Ste. Genevieve Limestone in the district is divided into three members: the Fredonia Limestone and the Rosiclare Sandstone Members (Ulrich, *in* Ulrich and Smith, 1905, p. 24, 40) and the Levias Limestone Member (Sutton and Weller, 1932, p. 430, 439). Ulrich (*in* Ulrich and Smith, 1905) originally combined the Levias and the overlying Renault Formation of the Chesterian Provincial Series as the Ohara Limestone Member of the Ste. Genevieve Limestone: the lower part of his Ohara was equivalent to the Levias. In the district, Weller (1923, p. 23–24) redefined the top of the Ste. Genevieve as the top of the "Lower Ohara Limestone" (Levias). Swann (1963, p. 29) moved the top of the Ste. Genevieve even further downward to the top of the Fredonia (as defined in this report), although he considered the Levias to be the top of the Valmeyeran Provincial Series; that is, the Osagean and Meramecian Provincial Series. Swann (1963) also divided the Fredonia into four members; in ascending order, the Fredonia Limestone Member (redefined to include only the lower half of the original Fredonia), the Spar Mountain Sandstone Member, the Karnak Limestone Member, and the Joppa Sandstone Member. Swann's members are not recognizable in the district, and, in this paper, we follow the usage of Weller (1923).

The upper boundary of the Meramecian Provincial Series, coinciding with the top of the Levias Limestone Member of the Ste. Genevieve as used herein, is placed at a crinoid break between *Platycrinites penicillus* Meek and Worthen and younger *Talarocrinus* spp. Within the district, the contact is easily recognizable by lithologic differences (see "Renault Formation"), although many workers consider that little time elapsed between deposition of the Ste. Genevieve and deposition of the Renault (Pryor and Sable, 1974, p. 293). The base of the Ste. Genevieve as defined herein is the top of a 15- to 30-ft bed of abundantly cherty limestone. Physical relationships at this contact are conformable and without perceptible break. The Ste. Genevieve Limestone ranges in thickness from 200 to 300 ft. It is thickest in the southern and southeastern parts of the district and thins northward.

Fredonia Limestone Member

The Fredonia Limestone Member, named for the village of Fredonia, Caldwell County, Ky. (Ulrich, *in*

Ulrich and Smith, 1905, p. 39–40), is light- to medium-gray, finely to coarsely crystalline limestone, containing abundant, locally crossbedded oolitic lenses 5 to 25 ft thick. It commonly includes some beds of locally crossbedded fossil-fragmental calcarenite and, in the lower part particularly, some dolomitic beds containing a few chert nodules. A few argillaceous beds may be present locally. Generally chert is sparse except in the northwestern part of the district (Amos, 1965) where chert is abundant in the upper part of the Fredonia. As much as 10 ft of olive-brown or greenish-brown, very fine grained calcareous sandstone or siltstone locally is present 25 to 30 ft below the top of the unit (Trace, 1962a; Amos, 1967, 1974; Amos and Hays, 1974). A few thin interbeds of light-green calcareous shale are present locally. The member contains scattered *Platycrinites penicillus* basal plates and columnals. Locally in the upper part, small pencil-sized colonial corals commonly identified as *Lithostrotion harmodites* are present.

The unit ranges in thickness from 170 to 250 ft and is thickest in the southeastern part of the district. Many sinkholes and caves are present where the surface is underlain by the Fredonia.

Rosiclare Sandstone Member

The Rosiclare Sandstone Member, named (Ulrich, *in* Ulrich and Smith, 1905, p. 40) for outcrops in the bluffs of the Ohio River near the town of Rosiclare, Ill., is mostly light-greenish-gray, very fine grained, commonly crossbedded calcareous sandstone; in places, it contains finely crystalline or oolitic and sandy limestone and sandy or calcareous light-gray to greenish-gray shale. Swann (1963, p. 80) considered the Rosiclare to be nearly synonymous with the Aux Vases Sandstone.

The sandstone beds commonly crop out as porous brown blocks that tend to slump downslope. The unit ranges from 5 to 25 ft in thickness.

Levias Limestone Member

The Levias Limestone Member (Sutton and Weller, 1932, p. 439) was named for Levias, Crittenden County, Ky. According to Sutton (written communication, July 22, 1957), "we [Sutton and J. M. Weller] did not select any specific locality as the type locality." Outcrops of the Levias near the town are poor (Trace, 1962b, p. E7), but an excellent outcrop of the entire unit and part of the underlying Rosiclare and overlying Renault Formation is exposed in an abandoned quarry on the east side of Kentucky Highway 91 about 3 mi northwest of Marion (Trace, 1966).

The Levias Limestone Member is mostly a light-gray, oolitic, fossil-fragmental calcarenite or finely crystalline to sublithographic, partly dolomitic limestone containing streaks of ooliths or fossil fragments. Basal plates and columnals of the crinoid *Platycrinites* are common, and the Levias contains the uppermost occurrence of this crinoid. The Levias ranges in thickness from 10 to 35 ft.

CHESTERIAN PROVINCIAL SERIES

The Chesterian Provincial Series was named by Worthen (1860) for the town of Chester, Randolph County, Ill. The past and current use of the name was summarized by Willman and others (1975, p. 145).

The Chesterian in the district comprises 15 units from the Renault Formation through the Kinkaid Limestone that total approximately 1,200 ft of thickness. Rock units, commonly 25 to 150 ft thick, consist of interbedded shale, limestone, and sandstone, and a few thin coaly beds. Marine fossiliferous limestone-dominated units alternate with terrigenous clastic ones. The Chesterian consists of about 50 percent shale, 25 percent limestone, and 25 percent sandstone. The clastic sediments were transported southwestward by the ancient Michigan River and were deposited as deltaic bodies in the marine embayment of the Illinois Basin. Lateral migrations of the river system and the shoreline caused the alternation of the limestone-dominated and clastic units (Willman and others, 1975, p. 145).

About half the district contains exposures of Chesterian strata. They have been removed by erosion in two areas near Tolu and Fredonia. Except for some formations in the Crider quadrangle (Rogers and Trace, 1976) in the extreme southeastern corner of the district, the lithology of the Chesterian is very similar to that in the adjoining fluorspar area of southern Illinois. In both States, the boundaries of most of the formations in the Chesterian are placed at the same horizons, but the nomenclature for some of the units varies (Swann, 1963; Trace, 1974a, p. 62–63).

RENAULT FORMATION

Strata of the Renault Formation, named for exposures of limestone, shale, and sandstone in Renault Township, Monroe County, Ill. (Weller, 1913, p. 120, 122), are present in the district. The Renault in southern Illinois (Baxter and others, 1963, p. 11, 1967, p. 11) is equivalent to both the Levias Limestone Member of the Ste. Genevieve Limestone and the lower limestone unit of the Renault Formation, as used in this report.

The Renault Formation generally consists of lower, middle, and upper units of dominantly limestone, shale, and limestone, respectively. In the extreme southeastern corner of the district, the middle shale unit is absent, and the entire formation is chiefly limestone.

The lower limestone unit—15 to 45 ft but commonly about 25 ft thick—is chiefly a medium-gray, finely crystalline limestone. Some beds are medium to coarsely crystalline, and a few beds are oolitic, especially in the western part of the district (Amos, 1967). A few thin beds of gray calcareous shale are generally present. The unit is partly fossiliferous and contains basal plates of *Talarocrinus* spp. at places. The lower 2 to 5 ft may be oolitic, pelletal, sandy (Popcorn Sandstone Bed of Shetlerville Member of Swann, 1963, p. 78), or conglomeratic (Rogers and Hays, 1967). The lower limestone unit is equivalent to Swann's Shetlerville Member of the Renault as used in the Illinois part of the fluorspar area (Baxter and others, 1963, p. 11–12; 1967, p. 11).

The basal contact of the Renault is sharp and, in many places, appears to be conformable. The major change in the crinoids between the Levias and Renault, however, strongly suggests a hiatus. Baxter and others (1963, pl. 1, 1967, p. 11) stated that in Illinois the contact is unconformable. This contact is generally easily identified because the Renault is darker than the underlying Levias, has a higher insoluble residue content, and contains basal oolitic or sandy beds. According to Tippie (1943, p. 157), "The contact of the Levias and Renault is characterized by an abrupt change in total residue content, the average content of the Renault being about 40 per cent as compared with the average of 8 per cent in the Levias."

The middle shale unit—15 to 40 ft but commonly about 25 ft thick—is mostly shale and some interbedded argillaceous or at places dolomitic limestone. Calcareous and very fossiliferous shale is generally dark gray or greenish gray and less commonly is reddish brown. Clay minerals are dominantly illite, and some kaolinite is present (Trace, 1962a). Interbeds of argillaceous limestone commonly are medium to dark gray and finely to coarsely crystalline.

Most of the middle unit contains abundant fossils and provides excellent collecting localities for crinoid stems and plates, the blastoid *Penetremites,* and many small individuals of the brachiopods *Composita, Cleiothyridina, Eumetria,* and *Spirifer.* This unit is the Yankeetown Shale described and mapped in southern Illinois by Baxter and others (1963, 1967) and by Baxter and Desborough (1965).

The upper limestone unit—20 to 70 ft but commonly 35 to 40 ft thick—is mostly light- to medium-gray, finely to coarsely crystalline limestone containing abundant ooliths at places. The unit is the Downeys Bluff Limestone as described and mapped in southern Illinois by Baxter and others (1963, 1967) and by Baxter and Desborough (1965). Locally, the limestone is dolomitic or argillaceous and may contain fossil fragments. A few light-brownish-gray chert nodules occur locally in the upper part. Gray or greenish-gray calcareous shale is present in places at the top of the unit.

BETHEL SANDSTONE

The Bethel Sandstone (Butts, 1917, p. 63–64), named for Bethel School (Crittenden Spring School, pl. 1) about 3½ miles west-northwest of Marion, Crittenden County, Ky., commonly forms prominent bluffs 30 to 60 ft high. Butts considered the Bethel Sandstone to be 100 ft thick at the type locality, but he included sandstone of the younger Paint Creek Shale and possibly even Cypress Sandstone.

The Bethel is chiefly composed of a light-gray, fine- to medium-grained sandstone that after slight weathering commonly shows yellowish-brown spots on broken surfaces; it is mostly medium to thick bedded and is characterized by prominent honeycomb weathering and local crossbeds. Thin-bedded sandstone interbeds and medium-gray shale partings are present, especially in the lower and upper parts of the unit, and locally the upper few feet consist of medium-gray siltstone and silty shale interlaminated with very fine grained sandstone. At many places, the basal 3 to 5 ft of sandstone contains interstitial calcareous cement and abundant invertebrate fossil fragments (Trace, 1962a, 1966). A basal coarse-grained sandstone containing quartz granules and small pebbles and less common shale and limestone pebbles is locally present in and near the district (Baxter and others, 1963; Amos, 1965). Pyrite and carbonaceous fragments are locally abundant in the lower one-third of the Bethel. A coal bed less than 1 ft thick is present in the central part of the district about 20 to 30 ft above the base of the Bethel (Trace, 1962a).

The thickness of the Bethel ranges from 120 ft in the western part of the district (Amos, 1966) to about 15 ft in the southeastern part (Rogers and Trace, 1976) and is commonly between 60 and 90 ft. Relief at the base of the Bethel is as much as 10 ft. At places in and near the southeast corner of the district where a Bethel Sandstone channel fill truncates part or all of the underlying Renault Formation and the upper part of the Ste. Genevieve Limestone (Trace and Kehn, 1968; Connor and Trace, 1970; Rogers and Trace, 1976), the Bethel attains a maximum thickness of about 210 ft.

Paint Creek Shale

Strata of the Paint Creek Shale (Weller, 1913, p. 120, 125), named for Paint Creek, Randolph County, Ill., are present in the district. In the Illinois part of the fluorspar area, the name Paint Creek has been abandoned in favor of the name Ridenhower Formation (Swann, 1963, p. 76).

The lithology and thickness of the formation are highly variable. In the western and south-central part of the district (Amos, 1965, 1967, 1974; Amos and Hays, 1974; Trace, 1976a), the sequence is 20 to 60 ft of interbedded sandstone, siltstone, and shale and as much as 15 ft of limestone at or near the top. In the north-central part (Trace, 1962a, 1974b), the sequence is dominantly sandstone and is difficult or impossible to separate from the overlying Cypress and underlying Bethel Sandstones (Swann and Atherton, 1948, p. 279–280; McFarlan and others, 1955, p. 9–10). A similar change in lithology also is observed in the Illinois part of the fluorspar area (Baxter and others, 1963, p. 14, 1967, p. 13; Baxter and Desborough, 1965, p. 11).

In the northeastern part of the district (Trace, 1966; Seeland, 1968), the Paint Creek is 10 to 30 ft of mostly shale; thin limestone beds are near the base. In the southeastern part (Rogers and Hays, 1967; Rogers and Trace, 1976), the sequence ranges from 5 to 115 ft in thickness; it consists mostly of limestone and contains subordinate amounts of shale and sandstone. In the Crider and Olney quadrangles, the Paint Creek consists of a basal unit, a middle unit of interbedded sandstone and shale, and an upper limestone unit (Rogers and Trace, 1967; Trace and Kehn, 1968). These three units are the equivalents of the Beaver Bend Limestone, the Sample Sandstone, and the Reelsville Limestone as recognized by Swann and Atherton (1948, p. 279).

Sandstone of the Paint Creek is a light-gray to light-greenish-gray, fine-grained rock that weathers brown or reddish brown, is locally calcareous and contains brachiopod and other fossil casts, and is also conglomeratic at places (Trace, 1962a). The sandstone is commonly thin bedded, although some beds are as much as 3 ft thick, and ripple marks and crossbeds are common. The shale is medium to dark gray and at places is silty or calcareous. Siltstone is light gray, commonly thin bedded, and partly calcareous. The limestone is light to medium gray, mostly finely to medium crystalline, commonly sandy, and partly calcarenitic. It contains abundant brachiopod, crinoid, and bryozoan fragments. In the southeastern part of the district, the limestone is partly oolitic and dolomitic. The basal contact of the Paint Creek varies from sharp limestone over sandstone, to transitional interfingering sandstone and shale, to sandstone over sandstone.

Cypress Sandstone

The Cypress Sandstone, named by Engelmann (1863, p. 189–190) for exposures in bluffs along Cypress Creek, Union County, Ill., consists of two units. The lower unit—one-half to two-thirds of the Cypress—is chiefly light-gray to light-brown, fine-grained sandstone that is commonly medium to thick bedded. At places, some of the sandstone is massive bedded, especially in the lower part, and may be medium grained. Thin, medium-gray shale partings are rare. Some of the lower beds commonly contain light-gray clay pebbles. At places, calcareous sandstone containing crinoid and other fossil fragments is present at the base (Trace, 1966, 1972). At a few localities, the basal bed is conglomerate as much as 2 ft thick composed of sandstone and clay fragments and subordinate amounts of dolomite and limestone particles in a sandy matrix (Trace, 1962a). Locally the proportions of rock types vary greatly, and, at places, much or all of this lower unit is thin-bedded sandstone and interbedded silty shale. Near the top of the unit, sandstone locally contains disseminated pyrite and carbonaceous material.

The upper unit of the Cypress contains interbedded sandstone, shale, and siltstone in varying proportions. A thin, discontinuous coal as much as 4 ft thick, but mostly less than 2 ft thick (Rogers and Hays, 1967), is present at the base of the unit and commonly is associated with a light-gray underclay that is relatively pure illite (Trace, 1962a). Rarely, a very thin shaly coal or carbonaceous shale is present near the top. Sandstone is light to medium gray, mostly fine to very fine grained, and thin to medium bedded. Locally, the sandstone is light gray and thick bedded, and it commonly contains ripple marks and crossbedding (Amos, 1966). Disseminated pyrite and carbon fragments as well as dolomite cement are locally present where sandstone is at and near the top of the Cypress (Trace, 1962a). Light-gray, thin-bedded micaceous siltstone is commonly interbedded with the sandstone. Medium- to dark-gray shale is more common in the upper part of the unit—some is silty and, locally, part is slightly calcareous, especially at and near the top of the formation. Part of the dark-gray shale is carbonaceous, and, locally, some of the shale has a red or green tint.

The thickness of the Cypress ranges from 125 ft in the southwestern part of the district (Amos, 1974) to 25 ft in the southeastern part (Rogers and Trace, 1976). The Cypress lies unconformably on the underlying Paint Creek Shale, but its base is obscure in parts of the district (Trace, 1962a) where the Cypress, the Paint Creek, and the Bethel form a more or less continuous sequence of sandstones that are partly shaly and contain some siltstone beds. In these areas, the three formations were mapped as a unit by Trace (1962a, 1966) and Rogers and Hays (1967).

Golconda Formation

The Golconda Formation was named by Brokaw (1916, pl. 3; see Brokaw, 1917) and Ulrich (*in* Butts, 1917, p. 91–95) for exposures in bluffs along the Ohio River above Golconda, Pope County, Ill. McFarlan and others (1955, p. 18–22) divided it into three formations: the Beech Creek Limestone (lower), the Fraileys Shale, and the Haney Limestone (upper) in a type section (NE ¼ NE ¼ SE ¼ sec. 9, T. 12 S., R. 10 E.) in the Repton quadrangle in Hardin County, Ill. The Golconda is a group in southern Illinois (Swann, 1963, p. 68). Exposures in the district are rarely complete enough to permit consistent subdivision into mappable units, although, at places, the Beech Creek and the Haney are recognizable.

The Beech Creek Limestone of Malott (1919, p. 11–15) is named for a type section at Ray's Cave, 0.25 mi south of Beech Creek, Greene County, Ind. A medium- to dark-gray and brownish-gray, thick-bedded limestone 1 to 10 ft thick equivalent to the Beech Creek is recognized at the base of the Golconda at many places in the district (Amos, 1966; Trace, 1966, 1974b, 1976a; Amos and Hays, 1974). It is commonly medium crystalline and contains varying amounts of fossil fragments, especially crinoids. The limestone is slightly argillaceous, at places is silty or dolomitic, and commonly weathers a medium to dark brown. Locally some beds are crossbedded.

About two-thirds of the Golconda consists of a very poorly exposed sequence of shale and subordinate amounts of limestone and siltstone-sandstone. The shale is dominantly dark gray, calcareous, and fossiliferous. Reddish- to greenish-gray silty shale associated with siltstone and sandstone is locally common about the middle of the Golconda. Light- to medium-gray and greenish-gray, unfossiliferous or sparingly fossiliferous shale is in the upper part of this sequence. According to X-ray analysis, the shale is illite and subordinate kaolinite (Trace, 1962a). Limestone sporadically intercalated with the shale is variable in character—much is dark gray, fine to medium crystalline, thin to medium bedded, and slightly argillaceous. Medium- to brownish-gray, medium- to thick-bedded limestone is common in the lower part of the sequence. Most beds are fossiliferous, and some consist mainly of coarse fragments of bryozoans and crinoids. A few feet of siltstone and (or) very fine grained sandstone present above the middle of the sequence may be equivalent to the Big Clifty Sandstone Member (Norwood, 1876b, p. 405) of the Golconda present in southern Indiana and west-central Kentucky. The siltstone-sandstone is commonly a medium-gray thin- to medium-bedded argillaceous and calcareous rock. A few beds are red or green. This siltstone-sandstone is thicker and more sandy in the southeastern part of the district. In the Crider quadrangle (Rogers and Trace, 1976), the unit is as much as 25 ft thick and consists mostly of sandstone. It was incorrectly mapped by Weller and Sutton (1951) in places as the Hardinsburg Sandstone. Weller (1923, fig. 12) also called this unit the Cypress Sandstone in Walche's Cut in the Princeton East quadrangle (Trace, 1972).

The uppermost 30 to 60 ft of Golconda strata in the district is equivalent to the Haney Limestone Member of the Golconda (Trace, 1976a) and consists of moderately well exposed limestone and shale. The limestone contains abundant fossil fragments and is commonly medium to dark gray, finely to medium crystalline, and thick to thin bedded; thinner beds are argillaceous. Some beds in the lower part of the Haney consist of medium to coarse fragments of crinoids and bryozoans, and a few beds are oolitic. Medium- to dark-gray and greenish-gray shale, in part calcareous and fossiliferous, forms interbeds and thin sets of beds, especially in the upper part of the Haney. Shale locally present at and near the top of the unit is silty and calcareous.

The thickness of the Golconda Formation ranges from about 165 ft in the southeastern part of the district (Rogers and Trace, 1976) to a minimum of 90 ft in the southwestern part (Amos, 1967). It conformably overlies the Cypress Sandstone. Wing plates of the crinoid *Pterotocrinus capitalis* (Lyon) are locally abundant in the lower part of the middle shale-dominated sequence within the range zone of this crinoid—the lower half of the Fraileys Shale (Willman and others, 1975, p. 157). Axes of the bryozoan *Archimedes* spp. are very abundant in the Golconda and reach a peak in number of species and abundance of specimens in strata equivalent to the Fraileys and Haney (Willman and others, 1975, p. 157).

Hardinsburg Sandstone

The Hardinsburg Sandstone was named by Brokaw (1916, pl. 3; *see* Brokaw, 1917) and Butts (1917, p. 96) for type sections near Hardinsburg, Breckinridge County, Ky., and it is well exposed at many places. It consists of a lower, well-exposed part that is mostly sandstone and an upper, poorly exposed part that is chiefly interbedded shale, sandstone, and siltstone.

A light-gray to white, fine- to medium-grained sandstone that commonly forms small bluffs constitutes most of the lower one-third to one-half of the Hardinsburg. It commonly weathers a medium to light reddish brown. The sandstone is mostly medium to massive bedded and is commonly crossbedded; locally, some bedding-plane surfaces are ripple marked. Dolomite cement is abundant in some of the sandstone (Trace, 1962a), and, at places, thin beds of arenaceous limestone or calcareous sandstone are near the base (Trace, 1962a; Amos, 1965, 1966). Locally, a few clay pebbles are present in some beds. Abundant casts and molds of *Lepidodendron, Stigmaria,* and *Lepidophylloides* occur near the base at a locality in the southeastern part of the district (Rogers and Trace, 1976). This unit is completely exposed in the quarry on Wilson Hill just south of Marion (Trace, 1966).

The upper one-half to two-thirds of the Hardinsburg consists chiefly of interbedded shale, sandstone, and siltstone in varying proportions at different localities. The shale is medium to dark gray, is rarely light gray, and locally has a green or red tint. Much of the shale is silty or contains thin laminae of siltstone or sandstone; the shale may be carbonaceous in the middle of the unit, and locally it contains abundant pyrite (Trace, 1966). Shale at and near the top is commonly calcareous. Sandstone is light to medium gray, fine to very fine grained, commonly medium to thin bedded. It locally weathers a characteristic reddish brown; it is in part micaceous, and, locally, near the top of the unit, it is slightly calcareous or dolomitic and contains sparse invertebrate fossil fragments (Trace, 1962a, 1966). Siltstone is light gray, thin and even bedded, commonly micaceous, in part argillaceous, and rarely carbonaceous. A thin, discontinuous shaly coal a few inches thick associated with a light-gray underclay is present at about the middle of the unit and locally contains abundant leaf impressions (Amos, 1966).

The thickness of the Hardinsburg ranges from about 165 ft at several places in the district (Trace, 1966, 1976a; Seeland, 1968) to 35 ft in the southeastern part of the district (Rogers and Trace, 1976) but is commonly 120 to 130 ft. An unconformity exists at most localities in the district where the base of the Hardinsburg has been observed, although, to the southeast (Trace and Kehn, 1968) and to the north in southern Illinois, the contact with the underlying Golconda Formation is locally transitional from fossiliferous shale upward into silty shale (Baxter and others, 1963; Baxter and Desborough, 1965).

GLEN DEAN LIMESTONE

The Glen Dean Limestone (Butts, 1917, p. 97–102), named for exposures along an abandoned railroad on both sides of the town of Glen Dean, Breckinridge County, Ky., is present in scattered areas throughout the district. The formation is in general poorly exposed but can usually be identified by a thick dark-red soil that may contain sparse angular fragments of chert.

Medium- to thick-bedded fossiliferous limestone and subordinate calcareous shale compose most of the Glen Dean in much of the district. The limestone is dominantly light to medium gray and fossil-fragmental; it contains chiefly crinoids and fenestrate bryozoans. Medium- to dark-gray, finely to medium-crystalline, thin- to medium-bedded limestone is commonly present in the lower part and the upper few feet of the formation. It contains a few scattered fossil fragments, and thinner beds are commonly argillaceous. Locally the limestone contains sparse chert nodules (Baxter and others, 1963; Amos and Wolfe, 1966), and oolitic limestone is locally present in the upper part of the Glen Dean (Baxter and others, 1963; Rogers and Trace, 1976). A few limestone beds at the top contain disseminated pyrite. Medium- to dark-gray and greenish-gray calcareous shale is common in the middle part and as beds and laminae between thicker limestone beds throughout the formation. Abundant fenestrate bryozoans are common on bedding planes of the more calcareous shale. Silty and sandy limestone or a few thin beds of medium-gray, very fine grained calcareous sandstone, or both, are near the middle of the unit at many localities. Some of these beds are dolomitic (Trace, 1962a) or even a silty and sandy dolomite (Baxter and others, 1963) and weather a distinctive buff color. The shale and sandstone increase in thickness eastward (Trace, 1966) and southeastward (Rogers and Hays, 1967; Rogers and Trace, 1976) as both the underlying and the overlying limestone units decrease in thickness.

The thickness of the Glen Dean ranges from about 105 ft in the southeastern part of the district (Rogers and Trace, 1976) to a minimum of 40 ft in the southern part (Rogers and Hays, 1967; Amos and Hays, 1974; Rogers and Trace, 1976). Considerable local variation results from an unconformity at the top.

The bryozoan *Prismopora serrulata* Ulrich is very abundant in the calcareous shale and shaly limestone of the Glen Dean in the district, and, at places, the bryozoan *Archimedes* sp., the crinoid *Pterotocrinus* spp., and the blastoid *Pentremites* sp. are common. The Glen Dean Limestone coincides with the *Pterotocrinus acutus—P. bifurcatus* Assemblage Zone (Willman and others, 1975).

TAR SPRINGS SANDSTONE

The Tar Springs Sandstone (Owen, 1856, p. 174; Butts, 1917, p. 103–105) is named for a cliffside exposure at the village of Tar Springs, Breckinridge County, Ky., and consists of a lower part that is mostly sandstone and an upper shale-dominated unit.

The lower unit—about one-half to two-thirds of the Tar Springs—is chiefly a light- to medium-gray and light-brown, fine- to very fine grained sandstone. Medium to massive beds are commonly crossbedded and may alternate with thinner even-bedded sandstone. A few beds contain flattened clay pellets, and some are ripple marked. Locally, sandstone at the base of the formation is calcareous (Trace, 1966). Thin-bedded, light-gray siltstone that weathers light olive brown and medium- to dark-gray shale that is commonly silty are locally present near the base, where they are commonly calcareous, and near the middle of the formation.

The upper part of the Tar Springs is chiefly dark-gray to black shale, which is dominantly illite and contains minor quantities of kaolinite (Trace, 1962a), interbedded with light-gray siltstone and sandstone. Disseminated pyrite and plant fragments are common. Some shale is silty, and part is carbonaceous. At places, the shale contains nodules and lenses of siderite that are commonly weathered to limonitic material. Some beds of siltstone and sandstone are argillaceous. A very thin impure coal bed is locally present near the top of the formation (Trace, 1976a), and another discontinuous bed as much as 1 ft thick is present about 20 to 30 ft below the top (Trace, 1966).

The thickness of the Tar Springs averages about 100 ft in the district and ranges from 70 ft in the northeastern part (Seeland, 1968) to 120 ft in the south-central part (Rogers and Hays, 1967). Contact with the underlying Glen Dean Limestone is sharp at most places, although, locally, calcareous shale of the Glen Dean is transitional upward into silty shale.

Vienna Limestone

The type section of the Vienna Limestone (Weller, 1920, p. 396–398) is an abandoned quarry west of Vienna, Johnson County, Ill. The calcareous shale locally above the limestone and formerly included with the Vienna is now assigned to the Waltersburg Formation (Trace, 1962a; Swann, 1963, p. 38). Although at a few places, a 1-ft-thick limestone bed is present at the top of this shale (Trace, 1966), the writers concur that the shale unit should be included in the Waltersburg.

The Vienna is typically a dark-gray to dark-brown siliceous limestone in 6-in.- to 2-ft-thick beds that locally contain thin beds and partings of dark-gray calcareous shale, especially in the upper part of the formation. It is commonly very finely to medium crystalline and contains scattered fossil fragments, although a few beds locally contain abundant fragments. Light-gray beds, some of which are oolitic, are present in the lower part of the formation in the southeastern part of the district. Locally, some of the beds are medium- to very coarse grained crinoidal calcarenite held together by clear calcite cement (Rogers and Hays, 1967). Brownish-gray to brown chert, in irregularly shaped nodules and lenticular beds, is abundant and conspicuous in most outcrops, although it is much less evident in the subsurface. The Vienna commonly yields a reddish-brown clay residuum that contains abundant angular chert fragments. Weathered chert commonly has a characteristic surficial waxy luster. In some areas of thick residuum, it is white and porous and contains scattered to abundant molds of brachiopods and crinoids. The Vienna gives a distinctive resistivity curve on electric logs.

The contact between the Vienna and siltstone or silty shale of the underlying Tar Springs Sandstone is sharp. The thickness of the Vienna averages about 25 ft in the district, ranging from a reported minimum of 15 ft (Trace, 1962a; Rogers and Trace, 1976) to a maximum of 40 ft (Amos, 1974).

Waltersburg Formation

The Waltersburg Formation, named by Weller (1920, p. 398) for outcrops near Waltersburg, Pope County, Ill., is present at the surface and subsurface at several places in the district. In much of the district, the Waltersburg consists of poorly exposed shale, siltstone, and sandstone, which are in part interlaminated. A dark-gray clay shale unit 5 to 10 ft thick is rather persistent at the base of the Waltersburg, is commonly calcareous, and contains a few small fossil fragments, chiefly of crinoids. Ironstone concretions are present throughout the shale unit. The middle and upper parts of the formation in most areas are dark-gray silty shale and greenish-gray siltstone and subordinate amounts of interbedded sandstone.

Siltstone laminae and lenses as much as 5 ft thick (Trace, 1962a) are present in thicker shale sequences. Some of the shale is slightly carbonaceous and at places contains small sideritic concretions that cause it to weather medium brown. The siltstone is commonly a well-indurated, light- to dark-greenish-gray rock in even, thin to medium beds containing shale partings; it weathers reddish brown on outer surfaces. According to X-ray analysis, the siltstone contains abundant interstitial chlorite (Trace, 1962a). Subordinate sandstone interbedded in the shale-siltstone sequence is a well-indurated very fine grained greenish-gray rock that weathers greenish brown to brown and is medium to thin bedded. These siltstone and sandstone beds are commonly jointed so as to form rhomboidal slivers as much as 2 ft long and 6 in. wide. These blocks are abundant in and characterize residuum formed from the

Waltersburg. A massive, bluff-forming sandstone facies of the formation similar to that of the type area exists near the eastern (Trace, 1966; Trace and Palmer, 1971) and western (Amos, 1967) borders of the district. It is a light-gray, fine-grained sandstone that commonly weathers medium brown and is locally crossbedded.

The contact with the underlying Vienna Limestone is rarely exposed; locally, the relationship is slightly unconformable (Amos, 1967, 1974). The Waltersburg thickness averages about 35 ft in the district, ranging from a minimum of 20 ft in the southern part (Rogers and Hays, 1967) to 50 ft in the northeastern part (Seeland, 1964).

MENARD LIMESTONE

The Menard Limestone (Weller, 1913, p. 120, 128) is named for a section in a quarry at the Menard State Hospital, Menard, Randolph County, Ill. As originally used, the Menard included the underlying Waltersburg Formation, which is shale in the type area. Swann (1963, p. 38–40) has divided the formation into three limestone members—the Walche (below), Scottsburg, and Allard (above) Limestone Members—that are separated by two unnamed shale members. At localities in the district where thick continuous sections of the Menard are exposed or cut in drill holes, these members are recognizable, but they are not mapped separately in plate 1.

The lower half of the Menard consists of dark- to medium-gray, finely to medium-crystalline limestone that is commonly argillaceous and subordinate medium- to dark-gray calcareous shale. The basal 10 to 15 ft is limestone that contains abundant fragments of crinoids, brachiopods, and fenestellid bryozoans and is equivalent stratigraphically to the Walche Limestone Member named by Swann (1963) for a type section just southeast of the district in Walche's (or Walche) cut on the Illinois Central Railroad, Princeton East quadrangle (Trace, 1972), Caldwell County, Ky. The Walche was previously called the "little Menard" (Swann, 1963, p. 74).

The upper 30 to 45 ft of the lower half of the Menard consists chiefly of medium- to thick-bedded, sparingly fossiliferous limestone. Some beds are dolomite and weather grayish brown. This unit, previously called the "massive Menard," is the Scottsburg Limestone Member named by Swann (1963); the type section of the Scottsburg is along the Illinois Central Railroad east of Walche's cut 2 mi northeast of Scottsburg, Caldwell County, Ky.

Dark-gray calcareous shale that locally contains thin beds and nodules of medium-gray limestone and light-brown dolomitic limestone constitutes the lower 15 to 30 ft of the upper half of the Menard. Some of the shale is silty, and, locally, siltstone is present (Rogers and Trace, 1976). Light-gray, fine-grained sandstone occurs at the base of this interval southeast of the district (Trace and Kehn, 1968; Rogers and Trace, 1976). The upper 30 to 55 ft of the Menard is medium- to dark-gray microgranular to medium-crystalline limestone containing varying amounts of interbedded dark- to medium-gray, calcareous and partly fossiliferous shale that is stratigraphically equivalent to Swann's Allard Limestone Member. Thin limestone beds are argillaceous, and a few are locally dolomitic. Light-gray chert nodules occur locally in limestone in the lower part of this unit. Medium- to coarse-grained calcarenite is present near the top of the Menard in the southern part of the district (Rogers and Hays, 1967; Amos, 1974).

The thickness of the Menard is commonly 110 to 130 ft in the district but ranges from 80 ft (Seeland, 1968) to a maximum of 145 ft (Trace, 1966). Specimens of *Spirifer increbescens* Hall and *Composita subquadrata* (Hall) are locally abundant, and their initial appearance is in the Menard (Weller, 1920). The distinctive pelecypod *Subcatopinna missouriensis* occurs at places. The *Pentremites foshi* Range Zone is in the lower part of the formation (Weller, 1927). Contact of limestone at the base of the Menard with underlying shale of the Waltersburg Formation is sharp.

PALESTINE SANDSTONE

The Palestine Sandstone (Weller, 1913, p. 120), named for outcrops along tributaries (secs. 29, 30, T. 6 S., R. 6 W.) of Tyndall Creek in Palestine Township, Randolph County, Ill., is present at the surface and subsurface in several areas in the district.

The lower part of the Palestine is mostly sandstone exposed in prominent ledges; the upper part is poorly exposed siltstone, shale, and thin discontinuous sandstone beds. Medium- to thick-bedded, light-gray to light-brownish-gray channel-fill sandstone is common. According to Potter (1963), these sandstone bodies regionally have the pattern of a deltaic distributary system. The sandstone is fine grained, commonly is micaceous, and commonly contains prominent crossbedding. Elsewhere the lower part is a thin- to medium-bedded, very fine to fine-grained sheet-type sandstone containing subordinate siltstone and silty shale interbeds and partings. This sandstone weathers brownish gray to medium brown; is micaceous, even bedded, and ripple marked; and, at places, contains light-gray clay pellets, especially in the lower beds. Locally, sandstone near the base of the Palestine is slightly calcareous. Shale dominates the lower part of the upper siltstone-shale unit of the Palestine, and siltstone dominates the upper part, although interbedding and lateral variations in lithology are common. Shale varies from light gray to greenish gray and partly silty to a medium- and dark-gray carbonaceous rock. A few siderite nodules (Trace, 1962a) and some dark-red and medium-green calcareous claystone (Seeland, 1968) are in the shale. The siltstone is light gray, weathers brownish gray, is thin bedded, and commonly has irregular bedding-plane surfaces. Lenses and discontinuous beds of very fine grained locally calcareous sandstone are interbedded with siltstone.

The thickness of the Palestine in the district ranges from 45 ft (Seeland, 1968) to 75 ft (Amos, 1966, 1967). Sections are thickest where they fill channels cut into the underlying Menard Limestone. Sheet-type basal sandstone is present where the formation is thin. The contact of the Palestine with the underlying Menard is sharp everywhere and is markedly unconformable at the base of channels. Fossil fragments of the tree trunks of *Lepidodendron* are common in the formation.

Clore Limestone

The Clore Limestone (Weller, 1913, p. 120) is named for exposures in gullies near Clore School, Randolph County, Ill. In southern Illinois, the formation has been divided (Swann, 1963, p. 40–42) into three members: the Cora Limestone Member (below), the Tygett Sandstone Member, and the Ford Station Limestone Member (above). These members can be recognized at places in the district but only with difficulty inasmuch as the Tygett equivalent is commonly shaly, contains some dolomitic limestone and dolomite, and is poorly exposed.

The lower two-thirds (55 to 85 ft) of the Clore consists of dark- to medium-gray shale and subordinate amounts of interbedded limestone, chiefly in the lower part. Shale is commonly calcareous and locally is fossiliferous. At places, the lowermost few feet are silty to sandy and locally are siltstone or sandstone containing abundant calcareous fossil fragments (Trace, 1962a, 1966). The limestone is commonly medium to thin bedded and has a microcrystalline to finely crystalline texture. Some beds are argillaceous; a few are dolomitic and weather a characteristic buff color. Many beds contain abundant brachiopods and bryozoans and less common bellerophontid gastropods; the *Bastostomella mitidula* Peak zone (Weller, 1927) occurs in this unit. This unit is approximately equivalent to Swann's Cora Limestone Member. Resistivity curves on electric logs of drill holes in the region have a distinctive three-pronged limestone pattern for about the lowermost 30 ft of the Clore.

A 5- to 15-ft-thick, poorly exposed unit about 15 ft below the top of the Clore persists throughout the district. It varies from light-gray, fine-grained sandstone to greenish-gray siltstone to medium-gray silty shale. Secondary porosity is produced by solution of calcareous cement during weathering. Light-brown, very fine grained dolomitic limestone and dolomite having conspicuous banding is present at places in the lower and upper parts of this unit. The unit is equivalent to the Tygett Sandstone Member.

The upper part of the Clore consists of limestone and shale in about the same amounts. Limestone commonly constitutes the upper 10 to 15 ft of the formation. The limestone in this unit includes medium- to dark-gray, microgranular to medium-crystalline rock in thin to medium beds and a few buff-weathering dolomitic beds. Light-brown chert nodules are locally present in the upper part of the unit. Some thinner argillaceous beds are very fossiliferous and contain many bryozoans, brachiopods, and blastoids. Unusually large specimens of *Spirifer increbescens* Hall and *Composita subquadrata* (Hall) are common. The shale is medium to dark gray and commonly weathers brownish gray; it is commonly calcareous and fossiliferous. This unit is probably equivalent to Swann's Ford Station Limestone Member.

The Clore thickness ranges from 80 ft (Amos, 1967; Soeland, 1968) to 130 ft (Amos, 1974) in the district. The basal contact is rarely exposed, but where the contact can be observed, limestone conformably overlies clastic rocks assigned to the Palestine Sandstone.

Degonia Formation

Strata belonging to the Degonia Formation (Weller, 1920, p. 281–290), named for outcrops of massive sandstone on bluffs of the Mississippi River and adjacent small tributaries, Degonia Township, Jackson County, Ill., are poorly exposed in the region.

In the district, the Degonia is a thin siltstone, shale, and sandstone unit containing subordinate bedded chert and dolomitic limestone. Siltstone is the dominant rock type at most localities. It varies from a greenish-gray, thin- to medium- and even-bedded, well-indurated siltstone that breaks into rectangular blocks to a medium- to olive-brown, poorly cemented rock having indistinct bedding planes. Chlorite (Trace, 1962a) and, locally, muscovite are present in the siltstone. Pale-greenish-gray to reddish-brown shale locally variegated red, green, and brown is common throughout the district. Part is silty and some is locally calcareous. Very fine to fine-grained light-brown and medium- to greenish-gray sandstone as much as 15 ft thick is present at places, especially in the lower part of the formation. Light-gray to light-tan bedded chert is present at the base and about the middle of the Degonia in the western part of the district and in adjacent areas of southern Illinois. It has prominent ripple marks on surfaces and grades laterally into fine-grained, well-indurated siltstone. Residuum contains abundant angular chert blocks having chalky white outer surfaces. Locally, as much as 2 ft of dolomitic limestone or siliceous dolomite (Rogers and Trace, 1976; Trace, 1976a) is present near the middle of the formation.

The thickness of the Degonia averages about 25 ft in the district and ranges from 5 ft (Amos, 1966) to 45 ft (Trace, 1976a). A distinct local unconformity is present at the base at many places in the district.

Kinkaid Limestone

The Kinkaid Limestone (Weller, 1920, p. 281–290) is named for outcrops along Kinkaid Creek, Jackson County, Ill. The formation was divided by Swann (1963, p. 42–44) into three distinct members, which are readily identifiable throughout the region: the lower member (Negli Creek Limestone Member), the middle member (Cave Hill Member), and the upper member (Goreville Limestone Member). Strata of Chesterian age above Swann's Goreville in southern Illinois were formerly included in the Kinkaid but are now placed in the overlying Grove Church Formation of Swann (1963, p. 44; Willman and others, 1975, p. 163). The Grove Church has not been recognized in the district and, if originally present, has been removed by pre-Pennsylvanian erosion.

The lower member (Swann's Negli Creek Limestone Member) of the Kinkaid is exposed as prominent small ledges of massive limestone in the district and registers a distinctive resistivity curve on electric logs. It consists mostly of fine- to medium-crystalline, medium-gray limestone that weathers light gray on outer surfaces; some beds are light gray or brownish gray, and a few are microgranular to lithographic in texture. Some beds contain scattered coarse fossil fragments, mostly crinoids and more rarely brachiopods and bryozoans. The limestone is commonly thick to massive bedded, but a few beds, especially in the upper part, are medium to thin bedded, fossiliferous, and slightly argillaceous. Nodules and rare thin layers of medium- to light-gray chert are present in the upper middle part of the lower member in the western part of the district. A few greenish- to light-gray shale partings are present near the top of the member. Algal growths *(Girvanella)* (Swann, 1963, p. 42–43) and large bellerophontid gastropods are common in the lower few feet of the member, which also contains a few small masses of spongiostromatoids (stromatoliths) and *Chaetetella* sp. (Trace, 1966, 1976a). Small biserial Foraminifera occur near the middle of the lower member (Willman and others, 1975, p. 162).

In most of the district, the thickness of the lower member of the Kinkaid averages about 30 ft and ranges from 20 ft (Amos, 1966, 1974; Trace, 1966) to 45 ft (Amos, 1966, 1974). At places in the northeastern part of the district (Seeland, 1968), it has been partly or completely removed by pre-Pennsylvanian erosion. The contact between the lower member and shale of the underlying Degonia Formation is sharp.

The middle member of the Kinkaid (Swann's Cave Hill Member), in much of the district and in nearby areas, consists of two subunits of about equal thickness: a lower shale-siltstone-sandstone subunit and an upper limestone-dolomite-shale subunit.

The lower shale-siltstone-sandstone unit of the middle member of the Kinkaid is chiefly a medium- to dark-gray and greenish-gray silty shale and local silty claystone. Thin- to medium-bedded, light- to medium-gray and greenish-gray siltstone is present at some localities and as thin beds and lenses throughout the district. Siderite concretions are scattered in the shale and in argillaceous siltstone. The proportion of sandstone is variable, and sandstone may locally constitute as much as half the unit. It is commonly very fine to fine grained and light gray, although a few beds are tan or dark greenish gray. Some sandstone beds in the upper part are slightly calcareous. Locally, a few beds of coarsely crystalline limestone are present in the lower part of this unit.

The upper limestone-dolomite-shale unit of the middle member of the Kinkaid consists of about equal amounts of limestone and dolomitic limestone or dolomite and subordinate shale. Medium- to dark-gray, finely to medium-crystalline limestone dominates the upper half of the sequence. It is commonly medium to thin bedded. Thin beds are argillaceous and contain scattered fossil fragments of marine invertebrates. A few thick beds have a microgranular texture. Locally, sparse dark-gray chert nodules are present. Light-gray, brown-weathering, very fine grained to microgranular dolomitic limestone and dolomite constitute much of the lower part of the upper unit. Beds and partings of medium- to dark-gray shale are common; where associated with limestone, the shale is commonly calcareous and contains scattered bryozoans and brachiopods. At places, shale at and near the top of the unit is red and green (Rogers and Trace, 1976).

The middle member of the Kinkaid is consistently 80 to 90 ft thick throughout the district except where it was partly removed by erosion prior to deposition of overlying Pennsylvanian strata. Contact with the underlying lower member is sharp.

The upper member of the Kinkaid Limestone (Swann's Goreville Limestone Member) is recognized in the southern and southeastern part of the district (Rogers and Hays, 1967; Amos, 1974; Rogers and Trace, 1976); elsewhere, it has been removed by pre-Pennsylvanian erosion.

The upper member of the Kinkaid is a brownish-gray to light-gray, very fine to fine-grained limestone that is massive to thick bedded. Coarse grains of crinoidal fragments are common in many beds, and chert nodules are locally present. The unit reaches its maximum thickness of 40 ft in the southeastern part of the district. Although rarely exposed, the basal contact is sharp.

Pennsylvanian System

The Pennsylvanian rocks in and near the district are dominantly fluviatile clastic sedimentary rocks that change upward into younger fluviodeltaic strata. In the district, the sequence is represented by the Caseyville Formation (Morrowan) and the overlying Tradewater Formation (Atokan). Rocks of these formations are preserved as isolated remnants in downdropped fault blocks in the district and also form a continuous belt along the eastern and northeastern margin (Jillson, 1929; Weller and Sutton, 1951).

MORROWAN PROVINCIAL SERIES

The Morrowan Provincial Series is represented by most of the Caseyville Formation. The top of this formation probably does not correlate precisely with the top of the Morrowan (Read and Mamay, 1964; Rice, 1978). However, the upper middle part of the Caseyville is known to be of Morrowan age because it contains a Morrowan marine invertebrate fauna in the Sellers Limestone of Wanless (1939, p. 36, 101) present along the Ohio River in Illinois, and a Morrowan plant-impression flora in the roof shale of the Gentry Coal Member of Kosanke and others (1960). The Morrowan age of most of the Caseyville is confirmed by spores, which are abundant in the coals of the Caseyville.

CASEYVILLE FORMATION

The Caseyville Formation (Owen, 1856, p. 48) is named for Caseyville, Union County, Ky. A type locality across the Ohio River in Illinois between the mouth of the Saline River and Gentry's Landing, a short distance northeast of the district, was described by Lee (1916, p. 15–16).

Fluviatile strata are predominantly sandstone, siltstone, and silty shale; clay shales, underclays, and nonpersistent coals are less abundant. The Caseyville ranges from 190 to 495 ft in thickness in the district (Amos, 1966). This variation is partly a result of deposition on an unconformable surface having more than 200 ft of local relief (Baxter and others, 1963, p. 21; Trace and Kehn, 1968). Thick sections are fillings of sub-Pennsylvanian stream valleys (Bristol and Howard, 1974) or, alternatively, may have resulted from deposition during subsidence of graben structures (Amos, 1966; Trace, 1974a).

Massive orthoquartzitic sandstone and conglomeratic sandstone, about 60 to 70 percent of the Caseyville, are in part mappable as two discrete units: a lower middle unit, the Battery Rock Sandstone Member, and the uppermost member of the Caseyville, the Pounds Sandstone Member (Kosanke and others, 1960). About 30 to 40 percent of the Caseyville consists of thin-bedded siltstone-sandstone-shale strata that have considerable lateral and vertical variation in lithology. Two units in the Caseyville are thick and widespread in the western part of the district and are mapped as members: the basal Lusk Shale Member and an unnamed shale and sandstone member between the Battery Rock and the Pounds. Member divisions are not recognized in the eastern part of the district and elsewhere in the western Kentucky coal field because the Battery Rock and Pounds Sandstone Members grade laterally into units of thin-bedded sandstone, siltstone, and silty shale that cannot be differentiated (Seeland, 1968; Trace and Kehn, 1968; Trace and Palmer, 1971; Kehn, 1974).

Lusk Shale Member

The basal unit of the Pennsylvanian System, the Lusk Shale Member of the Caseyville (Weller, 1940, p. 36), is named for exposures along Lusk Creek, Pope County, Ill. In general, all Pennsylvanian rocks below the Battery Rock Sandstone Member are assigned to the Lusk. It is present in the fault blocks of the western part of the district.

The Lusk consists of siltstone, sandstone, and shale that are partly interbedded, and a few thin discontinuous coal beds associated with underclays. Talus from the overlying unit commonly covers the member. The siltstone is light gray to greenish gray or light brown, thin bedded, and micaceous. Fine- to medium-grained, light-gray sandstone characterized by local coarse-grained beds containing a few white quartz granules and pebbles is common in the middle part of the unit. Thinner beds are commonly ripple marked and sparsely micaceous. Thicker beds are generally crossbedded, contain local limonite concretions, and commonly weather light to medium brown. Light- to medium-gray silty shale is present in the lower and upper parts of the member, and, locally, a thin carbonaceous shale is present near the middle. A chert and (or) white quartz pebble conglomerate having a medium- to coarse-grained quartz sandstone matrix is locally present at the base (Amos, 1965, 1966). The matrix contains abundant nodules and concretions of siderite or limonite and locally is cemented by ferruginous material. In the Rock Creek graben, the basal conglomerate is only about 2 ft thick in outcrop but is as much as 25 ft thick in the subsurface (Amos, 1966). Plant casts are common in siltstones and thin-bedded, finer grained sandstones of the Lusk.

The Lusk locally varies much in thickness and at places may have been partly removed and replaced by post-Lusk sandstone channel fillings. It ranges from 30 to 75 ft in thickness in surface exposures (Amos, 1970, 1974) but is more than 130 ft thick in the subsurface along the axis of the Rock Creek graben (Amos, 1966). The Mississippian-Pennsylvanian unconformity at the base of the Lusk is one of the major breaks in the Paleozoic sequence of mid-North America (Siever, 1951) and has as much as 230 ft of local relief in the region. The base of the Pennsylvanian in the district locally rests on strata as low as the upper part of the Degonia Formation (Seeland, 1968), and, nearby in Illinois, it rests on the upper part of the Menard Limestone (Baxter and others, 1963). No marked evidence exists for compensating variation in thickness of the Lusk and the upper Chesterian units, because thick Lusk sequences overlie the uppermost Mississippian formation (Baxter and others, 1967, p. 23–24).

Battery Rock Sandstone Member

The Battery Rock Sandstone Member of the Caseyville, named for Battery Rock, a bluff on the Ohio River in Hardin County, Ill. (Cox, 1875, p. 204), is present at the surface and in the subsurface in fault blocks in the western half of the district and in southeastern Illinois.

The Battery Rock is a massive, predominantly crossbedded, relatively pure medium- to coarse-grained quartz sandstone. Crossbeds commonly dip westward. Many beds, especially in the lower parts, contain abundant subrounded to rounded white quartz granules and pebbles generally less than ½ in. but as much as 2 in. in diameter. The sandstone is light gray but weathers light yellowish brown to medium brown and commonly has a honeycomb surface. Coarse-grained beds commonly have hematite or limonite concretions, or both, and liesegang layering and boxworks.

In the district, the member ranges in thickness from 35 to 85 ft; the observed local variations in thickness result largely from filling of pre-Battery Rock channels (Amos, 1966, 1967). A marked unconformity is present at the base everywhere the Battery Rock can be definitely recognized.

Sequence Between Battery Rock and Pounds Sandstone Members

A Caseyville unit of poorly exposed sandstone, siltstone, and shale between the top of the Battery Rock Sandstone Member and the base of the Pounds Sandstone Member is unnamed but includes two internal named units, the Sellers Limestone of Wanless (1939) and the Gentry Coal Member of Kosanke and others (1960), formerly called the Battery Rock coal (Owen, 1856). Rocks of this sequence are exposed in grabens in the western part of the district and in southeastern Illinois.

The unit is characterized by much lateral change in, and local variation of, rock type. Fine- to medium-grained, thin- to medium-bedded, light-gray sandstone, generally having ripple-marked bedding surfaces, is the most common rock. Locally, the middle part of the unit is a thick-bedded, predominantly crossbedded, medium- to coarse-grained sandstone as much as 25 ft thick that contains scattered white quartz granules and pebbles. Light- to medium-gray, thin-bedded micaceous siltstone and light- to medium-gray silty shale dominate in the upper and lower parts of this unit. The sandstone, siltstone, and some of the shale weather light to medium brown. The Sellers Limestone of Wanless (1939, p. 36, 101; 1956, p. 9), known only at the type section along the Ohio River at Sellers Landing, Hardin County, Ill., at the northeast margin of the district, is a ferruginous fine-grained arenaceous limestone about 10 ft thick that contains an abundant Morrowan marine fauna (Baxter and others, 1963, p. 25; Willman and others, 1975, p. 177).

A thin discontinuous nonpersistent coal as much as 26 in. thick, the Gentry Coal Member of Kosanke and others (1960, p. 29), is present 10 to 60 ft above the Battery Rock Sandstone Member in the Rock Creek graben (Amos, 1965, 1966). At places, the stratigraphic position of the coal is occupied by carbonaceous shale (Amos, 1974). The coal commonly is underlain by a light-gray silty clay as much as 6 in. thick and overlain by shale that locally contains plant impressions of Morrowan age (Willman and others, 1975, p. 177); the coal is a few feet beneath the locally present thick-bedded sandstone unit. Field relations suggest that the coal is slightly above the Sellers Limestone of Wanless (1956).

Known thickness of this unnamed unit in the district ranges from about 55 to 120 ft. Some of the local variation in thickness probably results from differential compaction of laterally diverse clastic sediments. A marked unconformity is present at the base of the unit.

Pounds Sandstone Member

A prominent bluff-forming sandstone, named the Pounds Sandstone Member (Weller, 1940, p. 38) for outcrops in Pounds Hollow, Gallatin County, Ill., is the uppermost member of the Caseyville Formation. It is present at the surface in the Rock Creek graben and also to the north in southeastern Illinois.

The Pounds is a very light to light-gray, medium- to coarse-grained sandstone containing white quartz granules and pebbles as much as 1½ in. in length commonly in the lower part of beds, especially crossbeds. The crossbeds generally dip south to southwest. Weathered rock is light yellowish brown to reddish brown and, in thick-bedded sequences, commonly shows prominent honeycomb weathering. Most of the member is thick to massive bedded, although medium-bedded sandstone and, near the top, even thin- to shaly-bedded sandstones are present locally. Many quartz grains have quartz overgrowths that impart a characteristic sparkle to the rock. Sparse muscovite is present, particularly in the upper part of unit. At places, coarse-grained beds have hematite and (or) limonite, and, locally, weathered surfaces show prominent liesegang banding and boxworks.

In the Rock Creek graben, the Pounds ranges from 80 ft to more than 120 ft in thickness (Amos, 1965, 1966). Some of the thicker sequences are channel fills entrenched into the underlying member; elsewhere, the contact is poorly exposed but is probably unconformable.

Caseyville Formation, Undivided, Along Eastern Margin of District

Strata of the Caseyville Formation are exposed in a continuous belt along and east of the eastern margin of the district but have been mapped as a single unit. The undivided Caseyville consists of thin- to medium-bedded sandstone, siltstone, and silty shale units that alternate with thick- to massive-bedded sandstone units; it is characterized by much lateral change in, and local variation of, rock type. Sandstone associated with the siltstone and silty shale is light gray, fine to medium grained, and sparsely micaceous and has ripple marks on some bedding surfaces. Plant remains and light-gray clay pellets are locally present in some beds. Thin- and even-bedded, light- to medium-gray micaceous siltstone and light- to medium-gray silty shale in units of variable thickness are interbedded with this sandstone. The sandstone, siltstone, and some of the shale weather light to medium brown.

White to light-gray, relatively pure medium- to coarse-grained quartz sandstone composes the massive sandstone units of the undivided Caseyville. Crossbedding is common, and some beds, especially the lower parts of crossbeds, contain subrounded quartz granules and pebbles. The sandstone weathers light yellowish brown and commonly has a honeycomb weathered surface. Some of the coarser grained beds have ferruginous concretions and (or) liesegang layering and boxworks. A conglomerate consisting chiefly of ellipsoidal white quartz pebbles as much as 2 in. in diameter in a dark-brown to dark-red, sandy-silty, ferruginous matrix is present at the base of the undivided Caseyville just east of the district; it locally contains limestone and sandstone cobbles and boulders (Trace and Palmer, 1971). Several thin coal beds of very local extent are present in the formation. Some have associated dark-gray to black carbonaceous shale and more rarely thin light-gray underclay. The most extensive coal is the Battery Rock coal of Owen (1856) present northeast of the district (Kehn, 1974) and named the Gentry elsewhere in the region (Kosanke and others, 1960, p. 29). A thin, gray sandy limestone in the upper part of the undivided Caseyville is reported from drill-hole data (Trace and Palmer, 1971).

The undivided Caseyville ranges from 225 to 490 ft in thickness along the eastern margin of the district (Palmer, 1966; Trace and Kehn, 1968). Here the basal unconformity has as much as 230 ft of local relief.

SEQUENCE BETWEEN THE POUNDS SANDSTONE MEMBER OF THE CASEYVILLE FORMATION AND THE GRINDSTAFF SANDSTONE MEMBER OF THE TRADEWATER FORMATION IN ROCK CREEK GRABEN

A coal-bearing sequence chiefly of siltstone, shale, and sandstone at the base of the Tradewater Formation below its Grindstaff Sandstone Member in the Rock Creek graben and in southeastern Illinois is unnamed. A discontinuous coal, the Reynoldsburg coal bed (Weller, 1940, p. 9), is exposed there.

Light-gray, thin-bedded, micaceous siltstone containing thin beds and laminae of gray shale dominates the upper half of the interval. The lower part is chiefly medium- to dark-gray, partly carbonaceous shale that commonly weathers rusty brown on bedding-plane surfaces. Light-gray to light-brown, fine- to medium-grained, medium- to thin-bedded sandstone is common in the middle part of the sequence. The Reynoldsburg coal bed, about 5 to 15 ft above the Pounds Sandstone Member of the Caseyville, consists of as much as 3 feet of canneloid to shaly coal in southern Illinois but is at most 18 in. thick in Kentucky. Lenses of dark-gray, very fine grained sideritic freshwater limestone locally are present above the coal (Amos, 1965).

The entire unit ranges from 35 to 45 ft in thickness in the Rock Creek graben (Amos, 1965, 1966).

ATOKAN PROVINCIAL SERIES

Strata of Atokan age in the lower part of the Tradewater Formation include units between the base of the Tradewater, as originally defined by Glenn (1912), and the No. 4 coal bed. In Illinois, units above the Pounds Sandstone member of the Caseyville have been established as Atokan chiefly by spore assemblages (Read and Mamay, 1964; Willman and others, 1975, p. 181).

TRADEWATER FORMATION

The Tradewater Formation is named (Glenn, 1912, p. 27) for exposures along the lower Tradewater River in Union and Crittenden Counties, Ky. Glenn defined the Tradewater to overlie the conglomerate of the Caseyville and to include strata up to the base of his Sebree Sandstone, which is above the No. 6 (Davis) coal bed. Lee (1916) placed the top of the Tradewater at the base of the No. 6 (Davis) coal bed—a practice followed by most recent workers in the area. Kehn (1974) placed the base about 40 to 60 ft higher at the top of the first sandstone below the No. 1b (Bell) coal bed. Remnants of approximately the lower 100 ft of the Tradewater are preserved in the Rock Creek graben (Amos, 1965, 1966).

Fluviatile clastic strata—sandstone, siltstone, and silty shale—that change upward into fluviodeltaic strata compose most of the Tradewater. Clay shales are common, especially in the younger beds. Coals associated with underclays and marine limestone occur throughout the formation but are thicker and more persistent in the upper part. The Tradewater in the region varies considerably in thickness, which ranges from about 450 ft (Amos, 1970) to a maximum of 620 ft (Kehn, 1974). Thickness variations are due chiefly to the presence of local thick sandstone units and to differential compaction of sediments.

Grindstaff Sandstone Member in Rock Creek Graben

Strata of the Grindstaff Sandstone Member of the Tradewater (Butts, 1925, p. 44), named for Grindstaff Hollow, Gallatin County, Ill., are present in the Rock Creek graben. The Grindstaff is chiefly fine- to medium-grained, medium-bedded, light-gray sandstone that weathers light to medium brown. Crossbedding and ripple marks are common. Fine-grained beds are micaceous, and a few thicker coarse-grained ones locally contain sparse white quartz granules and small pebbles. At places, flattened clay pebbles are present in the lowermost few feet of the member.

In the Rock Creek graben, more than 60 ft of Grindstaff is preserved (Amos, 1965). The basal contact is poorly exposed, but it is assumed to be unconformable. Angular discordance with underlying strata of as much as 20° in southern Illinois was described by Potter (1957, p. 2700) and Baxter and Desborough (1965, p. 22), who suggested possible local tectonism in very early Tradewater time.

Tradewater Formation, Undivided, Along Eastern Margin of the District

Siltstone, shale, and sandstone are present in the lower part of the undivided Tradewater Formation in the northeastern part of the district and along the eastern margin and include three designated coal beds, the No. 1a (Owen, 1857, p. 10), No. 1b (also called the Bell coal bed; Owen, 1857, p. 24), and No. 2 (Owen, 1857, p. 23), as well as thin discontinuous limestone units. Kehn (1974) placed the base of the sequence at the top of the first sandstone below the No. 1b coal bed and included the lower part of this interval in the underlying Caseyville Formation.

Thin-bedded, light- to medium-gray micaceous siltstone that weathers light to yellowish brown, interbedded light- to medium-gray silty shale, and lesser amounts of light- to medium-gray clay shale constitute much of the undivided Tradewater here. Locally, the siltstone and silty shale grade laterally into thin- to medium-bedded, light-gray to light-brown, fine- to medium-grained sandstone. At places, the undivided Tradewater contains thick-bedded, medium-grained, brown-weathering sandstone lenses.

The No. 1a coal bed of the undivided Tradewater is absent or is replaced by black carbonaceous shale at many places. The No. 1b (Bell) coal bed is rather persistent in the lower Tradewater River region (Seeland, 1968; Amos, 1970; Kehn, 1974), has a maximum thickness of 55 in., and has been mined extensively at shallow depths. Black carbonaceous shale commonly overlies the coal, which locally is split by as much as 15 ft of carbonaceous shale (Kehn, 1974). The No. 2 coal bed is discontinuous and locally is at least 18 in. thick. Typically, underclay is associated with the No. 1b and No. 2 coal beds. The undivided Tradewater has been reported to contain at least three thin discontinuous limestone beds that are commonly medium to dark gray, fossiliferous, and, in part, sandy (Palmer, 1966; Trace and Palmer, 1971; Kehn, 1974).

Cretaceous System

In the district, Cretaceous-age units consist of residual soil remnants developed on truncated Paleozoic rocks and nonmarine sand, gravel, and clay of the Gulfian Provincial Series (Upper Cretaceous). The Gulfian sediments are erosional outliers and depositional remnants of previously more widespread units; they occur in the southern and southwestern part of the district.

RESIDUAL SOIL

Isolated remnants of an iron-rich residual soil developed on Paleozoic rocks and preserved at the base of the Cretaceous sediments are present near Smithland in the southwestern corner of the district and to the west in southern Illinois (Pryor and Ross, 1962; Ross, 1963). The soil is a red to reddish-brown clay containing a few nodules of dark-brown limonite and angular tripolitic chert pebbles and is as much as 3 ft thick near Smithland. The soil probably formed mostly during the Cretaceous Period but may have originated earlier in the Mesozoic.

GULFIAN PROVINCIAL SERIES

Sediments of Gulfian age in and near the district are gravels and sands of the Tuscaloosa Formation and sands, clays, and gravels of the overlying McNairy Formation.

TUSCALOOSA FORMATION

Separated exposures of the Tuscaloosa Formation are common in the southern part of the district; exposures are more continuous farther south in the vicinity of Lake Barkley. Outcrops of the formation can be traced from the district southward to the type locality along the Tuscaloosa (Black Warrior) River near Tuscaloosa, Ala. (Smith and Johnson, 1887, p. 18, 95–117), where the formation consists of about 1,000 ft of quartzose and micaceous sands and clays containing lenses of pebbles.

The Tuscaloosa is a poorly sorted chert gravel that has very indistinct bedding and a very light, bleached appearance in most outcrops. Crossbedding is rare, and directional elements appear to be erratic. Chert pebbles and cobbles generally have a dull surface luster and are very light to light gray, light yellowish brown, white, or rarely light pink; they range from fresh-appearing clasts to soft, porous tripolitic material. Well-cemented to quartzitic sandstone cobbles are rare in the lower part of the formation. Layers and irregular patches scattered erratically throughout the unit and common in the upper and lower parts are stained yellowish brown, grayish brown, and brown by ferruginous material. The pebbles and cobbles are mostly subrounded spheroids as much as 8 in. in diameter, although some are well rounded and others are subangular discoids as much as 12 in. in length. At and near the base of the Tuscaloosa, angular fragments have been incorporated from residuum developed on underlying Mississippian units.

The gravel contains variable amounts of sand, less common silt and clay interstitial matrix, and, locally, discrete lenses of the same materials. Most is coarse to medium, subangular to rounded chert sand grains that weather to colors similar to those of the weathered pebbles and cobbles. A few medium to fine, angular to subangular grains of unaltered light-gray chert are scattered throughout the matrix, and very rare quartz grains are present in the lower part of the unit. The silt is generally tripolitic chert, and the clay is kaolinite (Pryor and Glass, 1961). Locally, the gravel is weakly cemented by silt and clay matrix or well cemented by silica or iron hydroxides. Silica cement is more common in the upper few feet of the formation, and ferruginous cement is more common at and near the base. At places, especially near faults, the ferruginous cement is present in sufficient quantity to have been exploited as brown iron ore (Nelson and Wood, 1949; Rogers, 1963; Hays, 1964; Amos, 1974; Amos and Hays, 1974; Rogers and Trace, 1976).

Local and erratic thickness variations of the Tuscaloosa Formation are the result of an irregular depositional surface, rapid deposition, and post-Tuscaloosa erosion and faulting (Rhoades and Mistler, 1941; Amos and Wolfe, 1966). Maximum thickness reported in the district is 90 ft (Amos, 1974). Chert pebble, cobble, and sand constituents of the unit are chiefly of local derivation from a thick pre-Tuscaloosa regolith developed on Mississippian limestones of the area. The cherts reflect the oolitic texture of the Ste. Genevieve and the upper member of the St. Louis Limestone; the dense to fine-grained texture of the cherts of the St. Louis Limestone; the porous bioclastic bryozoan-coquina texture of the Warsaw Limestone; and the texture and color of the "wood-grain" dove-colored cherts in the Fort Payne Formation. Quartz sand and sandstone cobbles in the lower part of the Tuscaloosa originated from Chesterian sandstones, and quartzite constituents from these sandstones metamorphosed along pre-Tuscaloosa faults.

Thickness variations and lithologies indicate valley-fill deposition on an irregular pre-Tuscaloosa karst topography formed chiefly on Mississippian limestones and modified by many fault and faultline escarpments. Deposition began in sinkhole depressions and along the base of scarps, and deposits eventually coalesced over lower divides between valleys. Although part or all of the formation has locally been removed by post-Tuscaloosa erosion, the present northeast outcrop limits are probably very close to the original margins of deposition.

The Tuscaloosa Formation in the district rests on a very irregular surface underlain by weathered Mississippian formations ranging from the Fort Payne Formation (Osagean) to the Vienna Limestone (Chesterian) (Amos, 1974). At a few exposures, the unconformity is sharp and distinct, but it is more commonly represented by a zone as much as 5 ft thick of intermixed Tuscaloosa strata and chert residuum from underlying bedrock. Fluorite pebbles are sparse in small prospect pits in this zone along a fault of the Claylick fault system about 1 mi north-northeast of Pinckneyville (Burna quadrangle).

Postdepositional modification by ground-water reworking and mass wastage is common. On hilltops and steep slopes, the interstitial matrix has been removed at places along the surface leaving a cobble-pebble pavement. Surface stains of dull ferruginous and manganiferous material commonly cover particles in this residual material.

McNairy Formation

The McNairy Formation is exposed as erosional outliers in the southwestern part of the district. It is continuous at the surface or in the subsurface with the type section, a railroad cut 1.5 mi west of Cypress Station, McNairy County, Tenn. The McNairy was originally called the McNairy Sand Member of the Ripley Formation (Stephenson, 1914, p. 17–18, 22; Lamar and Sutton, 1930) but was subsequently designated a formation by Pryor (1960, p. 1476).

The McNairy Formation is dominantly micaceous sand containing clay beds and laminations. Surficially exposed sand is commonly light yellowish brown to light brown, but some is also white, light pink, and light reddish brown, and, locally, the uppermost few feet have a brick-red to reddish-brown weathered zone. Unoxidized sand from drill holes is generally medium gray to dark gray. Well-sorted medium- to fine-grained angular quartz grains of low sphericity constitute about 85 percent of the sand, and about 10 percent of the sand is muscovite (Pryor, 1960, p. 1493–1495). The amount of interstitial silt, chiefly quartz and clay, is less than 5 percent. Locally, especially above clay beds and near faults, sand is well cemented by iron hydroxides and crops out as thin ledges. Clay as beds 1 to 4 ft thick, lenses, and thin laminae is common, especially in the lower part of the McNairy (Amos and Wolfe, 1966; Amos and Finch, 1968; Amos, 1974). The thicker clay beds commonly contain quartz silt and sparse muscovite. The clay is light gray to bluish gray, white, or light pink and locally contains lignitic material. It is chiefly kaolinite (Pryor and Glass, 1961). At places, the sand contains many white clay blebs and streaks. Fillings common identified as *Ophiomorpha nodosa* Lundgren are considered to be indicative of a littoral environment (Häntzschel, 1952).

A local basal member of the McNairy (Amos, 1967, 1974) consists chiefly of thick- to medium-bedded intermixed and interbedded gravel and sand generally well cemented by iron hydroxides. Gravel consists of subangular to angular chert pebbles and cobbles, slightly weathered tripolitic, in a matrix of coarse to medium quartz and tripolitic chert sand grains. The gravel is interbedded with medium- to coarse-grained sand commonly cemented by ferruginous materials, especially in the upper half of the member. The sand is composed of angular quartz grains and as much as 15 percent tripolitic chert grains and is interbedded with a few lenses and beds of dark-gray clay.

The formation is as much as 80 ft thick along pre-McNairy fault and faultline scarps in the southwestern part of the district (Amos, 1974). The basal gravel and sand member has a maximum thickness of 15 to 20 ft (Amos and Wolfe, 1966; Amos, 1967). The original extent of the McNairy was probably several miles northeast of its present erosional edge.

The Tuscaloosa–McNairy contact is marked by an unconformity having a few feet of local relief; this unconformity represents a significant hiatus in Gulfian deposition (Pryor, 1960, p. 1476). Depositional overlap of the Tuscaloosa to the north and northeast causes the McNairy to rest on units ranging from the Fort Payne Formation (Osagean) to the Caseyville Formation (Morrowan). Locally derived materials, chiefly weathered chert pebbles and cobbles and tripolitic chert sand, from residuum of the Paleozoic formations are identifiable in the lowermost few feet of the McNairy.

Stearns (1957) and Pryor (1960, p. 1501–1502) concluded that the McNairy is a fluvial and upper delta facies of a widespread Late Cretaceous "McNairy Delta" of the Mississippi embayment. Lithologic and structural characteristics indicate that a nonmarine sand was deposited by rivers dispersing sediment southwestward and westward and that clays and silty clays were deposited in interdistributary areas. Angular quartz, abundant muscovite, and the heavy-mineral suite indicate a provenance composed chiefly of medium- to high-grade metamorphic rocks, such as in the Blue Ridge and Piedmont Provinces to the southeast (Pryor, 1960, p. 1502).

Tertiary System

Coastal Plain sediments of Tertiary age are represented by the Pliocene Series at the surface in the district.

PLIOCENE SERIES

Sediments in the region originally referred to as the "Lafayette" Formation and considered by most to be of late Pliocene age, except for those modified by later reworking, are present as erosional outliers, some of considerable areal extent, in the southern and southwestern part of the district.

"Lafayette" Formation

Isolated deposits of a brown chert gravel and associated sand variously referred to as "Lafayette" Formation, "Lafayette" gravel, "Lafayette-type" gravel, "Tertiary" gravel, and continental deposits and by other names are present in the southwestern part of the district and are more continuous and widespread to the southwest and west. The name "Lafayette," first used by Hilgard (1891, p. 130) for deposits in Lafayette County, Miss., and defined in detail by McGee (1891, p. 497), has been used for lithologically similar gravels of different ages throughout the eastern Gulf and the Atlantic Coastal Plains. Summaries of the history of the geologic names and nomenclature of the deposits were given by Wilmarth (1938, p. 1128–1129) and Potter (1955a, p. 1–3).

The "Lafayette" consists of brown chert gravel and associated reddish-brown sand locally cemented by ferruginous materials. Thicker deposits commonly have crude bedding and conspicuous crossbedding that generally dips west or northwest (Potter, 1955a). Where not reworked, the gravel is composed of medium- to dark-brown to yellowish-brown chert and light- to medium-gray chert pebbles and locally scattered cobbles as much as 5 in. long, subordinate white quartz pebbles (2–20 percent), rare light- to medium-gray quartzite pebbles, and light-yellowish-brown sandstone pebbles and cobbles, all in variable amounts in a sand-silt matrix. Locally, especially near faults, many chert pebbles and cobbles are bleached a light yellowish white. Most chert pebbles and cobbles are subrounded discoids (Lamar and Reynolds, 1952, p. 100; Potter, 1955a); others are subangular to rounded, but well-rounded or angular pebbles are rare. Angular chert fragments are common, however, in the lower part of the "Lafayette" where it directly overlies Mississippian strata that yield chert residuum. Many of these chert fragments have a moderate to high surface polish. Angular to subangular sandstone pebbles and cobbles are also present in the basal part of the "Lafayette" where it directly overlies Chesterian or Pennsylvanian sandstones. Quartz and quartzite pebbles are rounded to well-rounded ellipsoids; they have a moderate surface polish.

The matrix is chiefly medium- to coarse-grained angular to rounded quartz sand and subordinate chert and has fluorite at one locality (Potter, 1955a). The matrix also contains small amounts of quartz and tripolitic chert silt, particularly in the lower part of the unit, and rare kaolinite clay. The amount of matrix is highly variable, but matrix is generally more abundant in the lower part of the "Lafayette" than it is in the upper part. Moderately to poorly sorted sand is present as interbeds, sets of beds, and large lenses throughout but is more common near the top and in the lower parts of the deposits. This sand is similar to the matrix of the gravel except that some is fine grained and contains more admixed silt and has locally abundant angular to subangular tripolitic chert grains near the base of the "Lafayette." The sand is brightly colored; red, reddish brown, yellowish brown, purplish red, reddish orange, and pink are the most common colors. Both gravel and sand are locally well cemented by iron hydroxides and (or) oxides, especially in the lower part of the unit and near faults.

In the district, the "Lafayette" is locally highly variable in thickness and has a maximum thickness in the southwestern part of about 45 ft (Amos, 1967). Thickness variability is due partly to deposition on an irregular surface of considerable local relief and partly to subsequent erosion and reworking of the sediment. Many of the thicker sequences are along fault and faultline scarps. Over a large area between the Cumberland and Tennessee Rivers in the southern part and south of the district, the "Lafayette" is continuous but very thin, commonly less than 3 ft to one pebble layer thick, and has little or no sand-silt matrix. The "Lafayette" truncates Paleozoic, Cretaceous, and Tertiary formations in or near the district. Because the formation does not have the characteristic mineralogy and lithology of Pleistocene glacial outwash and is overlain by weathered and eroded loess and silt of the Pleistocene Illinoian (Willman and Frye, 1970, p. 48, 180), it is probably pre-Illinoian, of Pliocene and Pleistocene age. The basal contact is commonly sharp but at places is gradational where the underlying McNairy (Amos and Finch, 1968) or Tuscaloosa has been reworked.

Potter (1955b) interpreted the "Lafayette" deposits in and near the district as erosional, in part modified remnants of an alluvial fan formed by the Tennessee and Cumberland Rivers where they emerged from Paleozoic uplands onto the Mississippi embayment sediments. Much of the chert detritus in the deposits was derived from Mississippian limestones of the region, and the white quartz granules and pebbles were derived from conglomeratic sandstone in the local Caseyville Formation (Morrowan) and from the basal Pennsylvanian rocks to the east.

Quaternary System

Surficial sediments of the Pleistocene and Holocene Series are widespread in the district. The Quaternary events of the alluvial history of the Ohio River Valley in the region were described by Ray (1963).

PLEISTOCENE SERIES

Pleistocene deposits in the district are residuum developed in situ from weathered bedrock, fluvial deposits of major streams, lacustrine deposits, loess deposits, and aeolian sand deposits. The Peoria Loess is the most widespread unit and mantles the entire upland surface of the region. Many of the post-Peoria deposits of Pleistocene age grade imperceptibly into, and generally cannot be differentiated from, younger Holocene deposits.

Residuum

A residuum, chiefly pre-Peoria Loess in age, partly or entirely covers the bedrock units at most places in the district. Rocks of Osagean and Meramecian age are commonly overlain by thick residuum containing chert fragments, but residuum developed on Chesterian or Pennsylvanian rocks is commonly thin and often is not recognizable as being related to definite units.

Different Paleozoic units yield distinctive residuum, which aids in recognition of underlying bedrock units. The Fort Payne Formation yields a yellowish-brown to light-reddish-brown siliceous clay as much as 10 ft thick that contains abundant fragments of angular finely porous chert of dove-colored shades of light brown and light gray in a pattern that resembles wood grain. At some localities, especially near faults, the Fort Payne has weathered to a saprolite of white, soft, porous, impure tripoli (Amos, 1974). Residuum overlying the Warsaw Limestone commonly is 15 to 20 ft of reddish-brown to brownish-red clay or, rarely, is silty clay containing large irregularly shaped blocks of coarse porous chert that contains fragments of crinoids and bryozoans, preserves bioclastic texture, and is speckled shades of gray. The Salem and St. Louis Limestones are overlain in extensive areas by red-brown to brick-red clay as much as 20 ft thick that commonly contains abundant fragments of angular chert. Much of the chert is porcellaneous or fine textured and is various shades of gray; outer surfaces are bleached white. Residuum developed on the upper member of the St. Louis commonly has some light-gray oolitic chert. An impure tripoli occurs at several localities in the south-central part of the district along and near major faults where at least one wall consists of chert-bearing parts of the St. Louis Limestone (Amos, 1974). The Ste. Genevieve Limestone is overlain by as much as 20 ft of red to reddish-brown clay containing small angular fragments of porcellaneous or oolitic light-brown chert. Chert fragments are absent or are present only in small amounts in extensive areas.

Residuum overlying units of Chesterian and Pennsylvanian age is commonly thin, is rarely more than 10 ft thick, and has highly variable thickness. Limestone units are commonly overlain by reddish-brown clay. Residuum from the Menard, Clore, and Kinkaid Limestones locally contains sparse chert fragments; at places, residuum from the Vienna Limestone and Degonia Formation has abundant chert fragments. A light-brown to light-reddish-brown silty-sandy residuum overlies thin-bedded siltstone and fine-grained sandstone, and a clayey residuum overlies noncalcareous shale. Rectangular blocks of siltstone and fine-grained sandstone are common and locally abundant. Medium- to thick-bedded sandstone units locally have a thin light-brown sandy residuum. White quartz granules and pebbles are present in material derived from the massive sandstone units of the Caseyville Formation.

Peoria Loess

The Peoria Loess of the late Wisconsinan Age mantles the upland surfaces in the region and overlies the older terrace remnants along the Ohio River valley (Ross, 1964, p. 18; Amos, 1965). Leverett (1898, p. 246) introduced the term "Peorian" to designate the interglacial stage during which sediments now exposed in the bluffs of the Illinois River valley near Peoria, Peoria County, Ill., were deposited. The Peoria Loess, a rock-stratigraphic unit (Frye and Leonard, 1951), has its type section south of Peoria in a west bluff of the Illinois Valley and was classified as Woodfordian-Twocreekan-Valderan in age (Willman and Frye, 1970, p. 65–66, 188–189).

The Peoria is chiefly nonstratified, well-sorted, yellowish-brown silt, mottled gray in the B soil horizon, that consists of angular to rounded quartz and subordinate feldspar. Clay minerals generally compose 10 to 15 percent of the deposits. Small amounts of very fine to fine-grained angular to rounded sand are present, especially in the lower parts of thicker sections. The unit is noncalcareous except where it is more than about 20 ft thick on the Ohio River Valley bluffs in the northwest part of the district (Amos, 1965, 1966).

Average maximum thickness for the Peoria ranges from about 15 ft in the northwest part of the district to less than 3 ft in the southeast. On bluffs adjacent to the Ohio River at the northwest edge of the district, thicknesses of as much as 30 to 35 feet are common (Amos, 1965, 1966). The Peoria commonly is separated by a sharp unconformity from the underlying older units of the area. Locally, a transitional zone of intermixed loessial silt and "Lafayette" sand exists, especially where the latter appears to have undergone pre-Peoria weathering. The loess grades upward into the modern soil. A group of radiocarbon dates from Illinois (Willman and others, 1975, p. 228) yields an approximate age of 22,000 to 12,000 years B.P. Thickness, grain-size variations, location, and shape of deposits indicate deposition from westerly winds of material derived from the flood plain of the larger streams of the region.

PLEISTOCENE AND HOLOCENE SERIES

Fluvial and colluvial deposits of Holocene age are common and widespread in the district. Aeolian sand deposits locally overlie fluvial, lacustrine, and fluvio-lacustrine deposits in the Ohio and lower Tennessee River valleys (Amos and Wolfe, 1966; Trace, 1974b).

FLUVIAL DEPOSITS OF MAJOR STREAMS

Fluvial deposits of Pleistocene age exist as valley fill in the valleys of the Ohio and Tennessee and possibly Cumberland Rivers. Valley train deposits from glacial outwash, some possibly as old as Kansan, are present at places in the basal part of the Ohio River valley fill (Ray, 1963, p. B125–B126; Olive, 1966). Silt underlying the older loess-covered terraces along and near walls of the Ohio River valley represents upper Pleistocene valley fill (Ross, 1964; Amos, 1965). The silt is light to medium gray and light brown and contains varying amounts of intermixed sand and clay.

Alluvium of Holocene age at and near the surface along the major streams in the district consists of intermixed clay and silt, silt, and intermixed silt and sand, which are as much as 40 ft thick. These deposits grade downward into medium- to coarse-grained to pebbly sand and locally gravel, which range in thickness from about 65 ft in the northeastern part of the district (Trace, 1974b) to as much as 100 ft under the Ohio River flood plain near the confluence of the Ohio and Tennessee Rivers (Ross, 1964, p. 19).

Silt mixed with clay is yellowish brown at the surface but medium gray in the subsurface and dominates the uppermost few feet of the fluvial deposits. Fragments of modern plants are locally abundant, and mica is sparse throughout the silt-clay mixture. In general, the quantity of silt increases downward, and the unit grades into silty sand and fine- to medium-grained, moderately sorted quartz sand. Some of the sand is in thin lenticular layers, and, along the Cumberland River and the lower parts of its major tributary valleys, it forms prominent natural levees (Amos and Hays, 1974). At places, the sand contains chert grains, mica, and sparse dark minerals.

The lower part of these fluvial deposits consists of well-bedded and laminated lenses of medium- to coarse-grained sand, pebbly sand, and gravel. The sand is yellowish brown, is commonly micaceous, and consists of subangular to well-rounded quartz and subordinate chert grains. Pebbly sand and gravel are more common near the base of the alluvium, and, at places, the gravel directly overlies bedrock (Trace, 1974b). Pebbles are subangular to rounded chert, subrounded to well-rounded quartz, and rare, well-indurated fine-grained sandstone. Some of the lower part of the unit may be glacial outwash of late Pleistocene age that in some places has been slightly reworked.

FLUVIAL DEPOSITS OF MINOR STREAMS

Alluvium along the smaller streams in the district consists of thin, locally derived deposits of intermixed silt, gravel, sand, and rarely clay. Small alluvial fans of similar materials are present at the mouths of many small tributaries. The thickness of the fluvial deposits rarely exceeds 20 ft. Modern plant fragments are locally abundant.

Medium-gray and light- to medium-yellowish-brown silt derived chiefly from the nearby Peoria Loess is predominant in much of the alluvium, and locally it is the dominant material. Poorly sorted gravel is very common and contains sandstone, limestone, and chert fragments. Angular to subrounded chert pebbles and cobbles derived from residuum of rocks of Osagean and Meramecian age and chert gravel from the Tuscaloosa and "Lafayette" Formations are abundant. Angular to subangular sandstone and subordinate limestone fragments are present in areas where the streams cut Pennsylvanian or Chesterian rocks. Poorly to moderately sorted fine to medium micaceous quartz sand is present along streams that drain terrains underlain by Pennsylvanian and Chesterian sandstone and by the McNairy Formation.

LACUSTRINE AND FLUVIOLACUSTRINE DEPOSITS

Lacustrine and fluviolacustrine deposits of Holocene age are present in the district along the lower courses and near the mouths of some of the major tributaries of the Ohio and Cumberland Rivers (Amos, 1966, 1974; Amos and Hays, 1974). Similar deposits have been noted along tributaries of the Tennessee River to the southwest (Amos and Wolfe, 1966). Small, thin areas of deposits of mixed lacustrine and fluvial origin also are found in a few of the larger sinkholes, especially ones that are shallow in relation to diameter.

The deposits consist of well-stratified, light- to medium-gray and light-yellowish-brown clay, silty clay, clayey silt, and silt as much as 45 ft thick (Amos, 1974). They are slightly calcareous at places and contain sparse gastropods and pelecypods. The deposits interfinger and grade up tributary valleys into fluvial deposits. Indistinct bars of reworked gravel of possible lacustrine shoreline origin have been noted along one major tributary valley (Amos, 1974).

Aeolian Sand Deposits

Aeolian sand deposits of late Pleistocene age that underlie or interfinger with the Peoria Loess are widespread south of the district along the east sides of the Tennessee River valley and Kentucky Lake (Hays, 1964; Fox and Olive, 1966; Amos and Finch, 1968); small deposits are present along the east sides of the Cumberland River valley and Lake Barkley (Hays, 1964). Aeolian sand dunes of Holocene age overlie fluvial and fluviolacustrine deposits in the Ohio River valley at the north edge of the district at its junction with a major tributary valley, Caney Fork (Trace, 1974b).

Aeolian deposits consist of light-brown to yellowish-brown, medium- to fine-grained quartz sand that is well sorted and locally bedded. The quartz grains are subangular to subrounded; some are moderately frosted. Minor amounts of dark heavy minerals, chert sand grains, quartz silt grains, and muscovite flakes are present. The sand, which mantles an irregular surface of deposition, was derived from nearby fluvial and possibly lacustrine and fluviolacustrine deposits. Locations and morphology of the deposits indicate local transport of sand by westerly winds.

Colluvium

The lower foreslopes of steep hills are covered by colluvium as much as 30 ft thick. Silt, chiefly reworked, predominates, but angular rock fragments are common and compose the bulk of talus deposits along the base of bluffs. Steep-sloped fans of crudely interbedded and intermixed colluvium and alluvial gravel are present at the mouths of small ravines.

IGNEOUS ROCKS

Many mafic dikes and a few sills are present in the district; most of the known dikes and sills are in a north-northwest-trending belt 6 to 8 mi wide. From the Hobby dike (Crider quadrangle) in the southeastern part of the district (pl. 1), the belt extends northwesterly through the Marion, Salem, and Cave in Rock quadrangles and continues for at least 30 mi into Illinois (Clegg and Bradbury, 1956, pl. 1) from the Rosiclare area, through Hicks Dome, to near Harrisburg. Many identified dikes and sills are in the Salem quadrangle; this relatively high amount, however, may result from a greater amount of subsurface exploration in the Salem quadrangle than in other quadrangles.

West of the above-mentioned belt, mafic rocks appear to be less abundant, possibly because the area has not been thoroughly explored. The best known of the dikes west of the northwest-trending belt are the Hutson (Burna quadrangle), the Sunderland (Lola quadrangle), and the Lasher-Robinson (Golconda quadrangle) (see pl. 1). These three dikes trend more northerly than the dikes in the major belt to the east. Tibbs (1974, p. 88) reported that a dike is also present in mine workings of the Dyer Hill mine (Smithland quadrangle).

Examples of sills include one 15 ft thick in the Tar Springs Sandstone along Claylick Creek in the Salem quadrangle (Weller, 1927, p. 89). Several exploratory drill holes along the Commodore fault system near the north edge of the Salem quadrangle and the south edge of the Cave in Rock quadrangle (Trace, 1974b) cut mafic rocks at about the same horizon in the Tar Springs Sandstone and indicate the presence of a sill. A sill also is present in the Ste. Genevieve Limestone in the Smithland quadrangle (Amos, 1967).

Mafic rocks of unknown structural classification have been discovered in drill holes. Because most known mafic rock bodies in the district are dikes, the tendency is to label all mafic rocks as dikes. Possibly a few of these drill holes may intersect sills.

Mafic rock in the district was first reported by Ulrich in 1890 (see Ulrich and Smith, 1905, p. 19–20, 101) and was described by Diller (1892); subsequent descriptions include those by Ulrich and Smith (1905), Currier (1923), Weller (1927), Koenig (1956), Warren (1956), and Oesterling (1952). Since 1960, several previously unknown mafic bodies have been located, either in surface exposures or, more commonly, during fluorspar exploratory drilling by private industry.

The mafic dikes and sills were classified as mica peridotites and lamprophyres by Koenig (1956). Most of them are so highly altered that the original rock types cannot be precisely classified, but available analyses indicate that they were mafic alkalic rocks. The dikes and sills are mostly dark gray to dark greenish gray and finely crystalline; some are porphyritic. They are composed primarily of calcite, dolomite, serpentine, chlorite, and biotite. Most of the phenocrysts are biotite and serpentine. Accessory minerals are magnetite, ilmenite, leucoxene, marcasite, fluorapatite, garnet, perovskite, iddingsite(?), and goethite. Olivine, hornblende, and pyroxene were the essential primary constituents, but, in most of the dikes, these minerals have been largely altered to serpentine.

Variations from the dark color and fine crystallinity are uncommon; however, the mafic rock rarely may be medium to coarsely crystalline (sample 197 in Zartman and others, 1967); elsewhere, it is light gray and free of chlorite or serpentine. Oesterling (1952, p. 324) described light-green dike rock composed "nearly entirely of fine-grained calcite. The phlogopite [biotite] has been completely replaced by calcite; there is no indication that olivine or pyroxene phenocrysts were ever present ***."

The dikes dip from about 80° to 90° and are commonly 5 to 10 ft thick, rarely as much as 20 ft. Most of the dikes trend N. 20°–30° W., particularly in the eastern part of the district. Three dikes farther west trend more northerly.

The mafic dikes and sills are present in country rocks as old as the Warsaw Limestone in the lower part of the Hutson mine working, and the lower member of the St. Louis Limestone (Adams drill hole, sample 197 in Zartman and others, 1967, p. 853). This drill hole on the Adams property was inadvertently mislocated by Zartman and others (1967, p. 853); the hole is slightly more than a mile north of Sheridan in the north-central part of the Salem quadrangle (pl. 1). Dikes and sills are found in rocks as young as the Caseyville Formation of Pennsylvanian age in the Commodore area, Salem quadrangle (Trace, 1954a). They are present in both horst and graben areas of the district.

Surface exposures are uncommon and difficult to find because the mafic rock decomposes within a few years of being exposed. Where abundant mica plates are present, however, the resulting mica-bearing residuum is usually recognizable. In some places, the decomposed rock is a limonitic mass having a remnant holocrystalline texture. Elsewhere, the mafic rock has completely decomposed to a rather distinctive greenish-gray clay, which in places contains mica flakes.

An example of the speed of decomposition due to weathering at the Howard Stout dike locality (northwestern part of Marion quadrangle) is described below. The dike was exposed in the early 1960's in a small quarry. At that time, the dike with associated fluorite veinlets was about 5 ft wide and trended about N. 20° W., as shown by two shallow shafts and a few holes drilled along the dike. The dike appeared hard, solid, and quite fresh. Because of easy access, several geologists visited this locality during the 1960's and 1970's. Within about 15 years, most of the dike changed from dark gray and holocrystalline through a light brownish-gray stage to a claylike residuum. As visible biotite plates were rare in the unaltered dike, the resulting clay residuum is difficult to recognize as dike material. In 1980, the area of exposure was covered.

Before the early 1960's, the dikes and sills were dated as post-Middle Pennsylvanian on the basis of stratigraphic relations. The crosscutting of the dikes by fault-controlled vein minerals and the absence of any mafic rock along the northeast-trending faults indicate that the mafic rocks are older than the northeast-trending faults. In the western part of the district, the north-trending dikes appear at first glance as though they might be splays from, and part of, the northeast-trending fault systems. If true, these dikes could, therefore, be younger than the dikes in the northwest-trending belt described above. However, all the dikes in the district probably are approximately the same age because (1) the north-trending dikes are not present throughout the district, (2) no mafic rocks are known to exist along the northeast-trending faults near the north-trending dikes, and (3) both the north-trending dikes and the northwest-trending dikes are associated with fractures having very slight displacement and are characterized by horizontal slickensides and abundant zinc mineralization.

Zartman and others (1967, p. 860–861) reported, "two biotites (197B, 238B) from a sill and a dike of mica peridotite were dated by both the K-Ar and Rb-Sr methods. All the ages lie within experimental uncertainty of each other and give an average Early Permian age of 267 million years."

The alteration effect of dike or sill intrusion into the wall rock is minor. The limestone country rock has been recrystallized and slightly silicified a few inches to a few feet from dike or sill contacts. Subsequently, the mafic rocks have been considerably altered by vein mineralization. According to Oesterling (1952, p. 321–322), the dark-green unaltered mafic rocks contain abundant ferromagnesian minerals, and the altered light-green mafic rocks are mostly calcite.

Magnetic surveys have been used to locate mafic dikes (Warren, 1956) where outcrops are lacking. In general, sufficient magnetite and ilmenite are present in most of the mafic rocks to cause easily measurable anomalies.

The spatial relation of mafic dikes to deposits of zinc and fluorspar having substantial byproduct zinc is well known. The metallic sulfide mineralization occurs either along northwest- or north-trending mafic dikes or along northeast-trending faults that are near mafic dikes. Examples of zinc deposits along dikes include those of the Hutson (Burna quadrangle) and Old Jim (Salem quadrangle) mines. The Hickory Cane mine (Salem quadrangle) contains a zinc deposit along a northeast-trending fault, which crosses a mafic dike swarm. A major exception to the dike–zinc-deposit association is the Nine Acres mine (Salem quadrangle), which contained zinc deposits along a northeast-trending fault; the nearest known dikes are about two-thirds of a mile to the southwest. The mine, however, is within the 6- to 8-mi-wide belt of dikes described above. The Dike and Eaton veins and associated dikes in the Salem quadrangle (Trace, 1962b) are examples of mixed fluorspar-zinc deposits. Although detailed data are not available, substantial quantities of zinc and fluorspar appear to be associated with the Lasher-Robinson dike in the Golconda quadrangle (The Mining Record, Denver, Colo., Dec. 23, 1970).

STRUCTURE

Introduction

The rocks in the district (pl. 1) are complexly broken by a series of steeply dipping normal faults that strike dominantly northeast and divide the area into elongate northeast-trending blocks. Near the east border of the district, these faults trend more easterly and many terminate east of the district within the western part of the western Kentucky coal basin. Toward the southwest, these faults cut Paleozoic rocks that underlie the Mississippi River embayment. Some have displaced Cretaceous sediments and a few have displaced Tertiary sediments of the embayment (Rhoades and Mistler, 1941; Amos, 1967). Many cross faults that strike north to northwest are occupied at places by mafic dikes.

A few well-defined northeast- to nearly east-trending grabens and horsts dominate the structural pattern of the district (pl. 1; Hook, 1974, fig. 1; Pinckney, 1976, fig. 2). The best defined grabens are the Mexico, Moore Hill, Griffith Bluff, Lockhart Bluff, and Rock Creek grabens (fig. 3). Other less well defined grabens are also present in the district. Displacement along the bounding faults of some of the grabens terminates within or just outside the district.

Another prominent structural feature is the Tolu Arch, which enters Kentucky near Tolu on the Ohio River (pl. 1) and extends southeast for at least 6 mi. Northwestward in Illinois, the arch terminates against the Rough Creek–Shawneetown fault system (Baxter and others, 1967, p. 31).

Faults and Associated Features

Nearly all faults in the district are normal faults that dip 75° to nearly 90°; rarely are they inclined as low as 45°.

Fault zones consisting of several subparallel and sinuously intersecting fractures are present, especially along the edges of many of the larger grabens (Hook, 1974, fig. 3). Individual faults are step faults, antithetic faults that form small grabens within or along the edge of the fault zones, and cross faults (Hook, 1974, p. 79–81). The fault zones are commonly a few hundred feet wide, although at places they are more than 1,000 ft wide.

Along the major northeast-trending faults in the district, the vertical or dip-slip component of displacement appears to have been dominant. In general, stratigraphic displacement ranges from a few feet to a few hundred feet, but displacement is possibly as much as 3,000 ft in the southeast corner of the Smithland quadrangle (Amos, 1967) and in the adjacent corner of the Burna quadrangle (Amos, 1974). Where the Caseyville Formation (Morrowan, Pennsylvanian) is adjacent to the Fort Payne Formation (Osagean, Mississippian), the average thickness of Mississippian rocks above the Fort Payne is about 2,400 ft, the Fort Payne is about 600 ft thick, and the Caseyville is a few hundred feet thick; thus, minimum displacement is 2,400 ft and maximum displacement is as much as 3,000 ft.

Horizontal or wrench-type movement along faults in the district and surrounding areas was discussed by Clark and Royds (1948), by Heyl and others (1965, p. B9–B10), and by Hook (1974, p. 81–82). No positive evidence is known for major strike-slip displacement along the northeast-trending faults, although the local presence of horizontal slickensides indicates that some horizontal movement has taken place. As most of the strata are approximately horizontal or low dipping, the amount of vertical displacement is relatively simple to determine, but the amount of horizontal movement is difficult to determine. Possible evidence regarding horizontal movement, particularly along the northeast-trending faults, is discussed further in the section entitled "Origin."

Vertical movement along the northwest- to north-trending faults is rarely more than a few feet. Horizontal slickensides are common and indicate that some horizontal movement also took place (Oesterling, 1952, p. 321; Trace, 1962b, p. E12–13; Hook, 1974, p. 81). No criteria are known to determine the amount of horizontal displacement along the northwest- and north-trending faults before mineralization and dike emplacement. However, the general lack of districtwide continuity of these faults and the relatively weakly brecciated or otherwise disturbed wallrocks suggest that displacement has been small. In a study of the north-northwest-trending dike faults at the Hutson mine, Oesterling (1952, p. 327, 332, 336) concluded that the postfluorite-presphalerite movement was largely horizontal but involved only a few feet of displacement.

Information is limited regarding the amount of vertical or dip-slip fault displacement along the northeast-trending faults in the subsurface below depths of 1,000 ft. A few drill holes in the Crittenden Springs and Commodore areas in the Salem quadrangle (Trace, 1962a) indicate that the amount of displacement at depths of nearly 2,000 ft below the surface is on the same order as that at the surface. This drill-hole information suggests that the faults are not a near-surface phenomenon.

The major displacement along all faults probably was completed by middle Cretaceous time, although some movement continued through the Cretaceous and Tertiary to the present (Rhoades and Mistler, 1941; Heyl and Brock, 1961; Ross, 1963; McGinnis, 1963; Amos, 1967; York and Oliver, 1976).

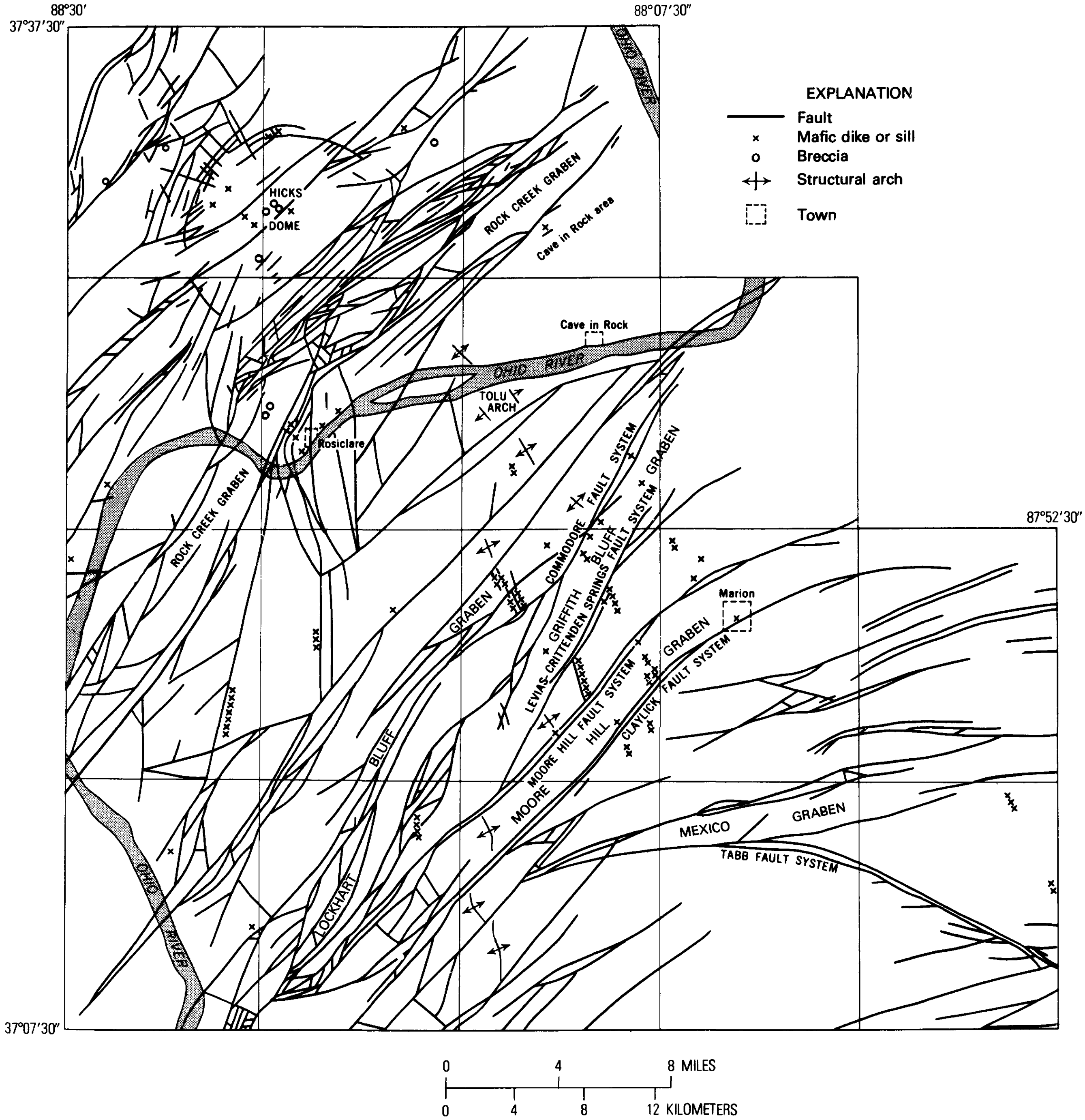


FIGURE 3.—Major structural features of the Illinois-Kentucky fluorspar district. Compiled from 17 geologic maps of 7½-min quadrangles, 1962–72, by the Illinois State Geological Survey and the USGS. Modified from Trace (1974a).

Locally, some fault movement may have begun during Early Pennsylvanian time. In the northern part of the Golconda quadrangle (Amos, 1966) in an oil test within the Rock Creek graben, the lowermost Pennsylvanian, the Lusk Shale Member of the Caseyville Formation, is about 130 ft thick; the same unit is only 50 ft thick a little more than a mile away where it is exposed along the eastern margin of the graben. The easterly thinning may be due to concurrent fault movement and graben filling that began in Early Pennsylvanian time.

The wallrocks along faults are commonly silicified to varying degrees. Sandstone that is adjacent to a fault commonly is altered to quartzite. Evidence suggests that these quartzites were caused either by the addition of interstitial silica or by compaction and the elimination of pore space in the sandstone during faulting (Trace, 1974a, p. 64). Limestone beds adjacent to faults are less altered than are sandstone beds although, in places, many small, doubly terminated quartz crystals and small masses of chalcedony are present in the limestone (Trace, 1974a, p. 64).

Faulting has intensely shattered and sheared the wallrocks within a few feet of faults although broken zones as wide as 75 ft have been reported (Hardin, 1955, p. 15). Generally, the width of the breccia zone appears to be related to the amount of vertical displacement along the fault and to the type of wallrock along the fault. Massive-bedded rock units tend to fracture, whereas thinner bedded rock units tend to be drag folded and sheared.

Grabens and Horsts

The internal structure of the grabens in the district is quite different from that of the horsts. In the grabens, most of the dips are inward as a result of tilt and associated drag folding parallel to the bounding faults, as shown by the structure contours (pl. 1). These grabens seem to have resulted from essentially vertical movement along the bounding faults. In the horst blocks, however, the beds commonly retain their regional northeast dip toward the western Kentucky coal basin. These differences in the structure of the graben and the horst blocks suggest that the actual block movement was confined to the grabens.

For example, the dominantly northeast regional dip has been interrupted in many grabens by northeast-striking beds that are parallel to the strike of the faults. The beds may dip either northwest, as in the Rock Creek graben, or both northwest and southeast, as in the Moore Hill graben, thus creating a syncline. A deep basin was formed in the Griffith Bluff graben by dip-slip displacement of more than 1,000 and 2,000 ft along the two bounding faults; this displacement is greater than that along any of the other grabens. The bounding faults of this graben essentially die out within 4 mi along strike and are substantially shorter than the faults along any of the other grabens.

The Rock Creek, Griffith Bluff, and Lockhart Bluff grabens are tilted northwestward, whereas the Moore Hill graben is tilted southeastward. The Mexico graben does not have a well-defined tilt. The Dixon Springs graben, entirely in Illinois and the most northwesterly of the well-defined grabens of the Illinois–Kentucky fluorspar district, also tilts to the northwest (Baxter and others, 1967, pl. 1; Weller and others, 1952, p. 78). According to Weller (1940, p. 49), the McCormick and New Burnside anticlines, in Illinois northwest of the Dixon Springs graben, "are asymmetrical anticlines with steeper flanks to the northwest ***." Hicks Dome in Illinois has steeper dips on the northwest and north flanks (Baxter and Desborough, 1965, p. 29; Baxter and others, 1967, p. 31–32).

Tolu Arch

The Tolu Arch, as mentioned above and as described by Trace (1974a, p. 66), enters Kentucky near Tolu and extends southeast for at least 6 mi where it is transected by the younger northeast-trending Griffith Bluff graben. Further southeast, the presence of the arch is uncertain. The block between the Griffith Bluff and Moore Hill grabens contains a shallow structural high near John Thomas Bluff and another high about 6 mi to the southwest near New Salem. The age and origin of these highs are uncertain because of the proximity of faulting. Along the arch's possible strike to the south near Pinckneyville, another dip reversal is present, but its age relative to the age of the arch is uncertain as it is present in the southern part of the Moore Hill graben. Further south, the southernmost dip reversal and a possible extension of the arch (Heyl and Brock, 1961, p. D6 and fig. 294.2; Heyl and others, 1965, p. B9) are present astride the Cumberland River near Dycusburg. South of the district, Cretaceous and Tertiary sediments conceal evidence for any further possible extension of the arch.

Schwalb (1969, fig. 6) showed the southwest limb of the Tolu Arch to extend into central Livingston County, north of Smithland. Dip reversals in this vicinity such as those in the south-central part and near the southwest corner of the Lola quadrangle (Trace, 1976a) may be part of this arch, but many faults in the area obscure the origin of the dip reversals.

Geophysical Data

On the basis of magnetic studies, Lidiak and Zietz (1976, p. 14–17, fig. 3) inferred that three basement faults or fault zones are in or very near the district (fig. 4). A recent aeromagnetic map of western Kentucky by Johnson and others (1978) shows the same magnetic trends. Two of the inferred faults trend west-northwest. The westernmost may be the subsurface extension of the Ste. Genevieve fault zone that is to the northwest in Illinois and Missouri (Heyl, 1972, fig. 5). This inferred fault, however, is not present at the surface in the district. The other west-northwest-trending inferred fault, which crosses the district in the vicinity of Marion, Ky., also is not expressed at the surface except possibly

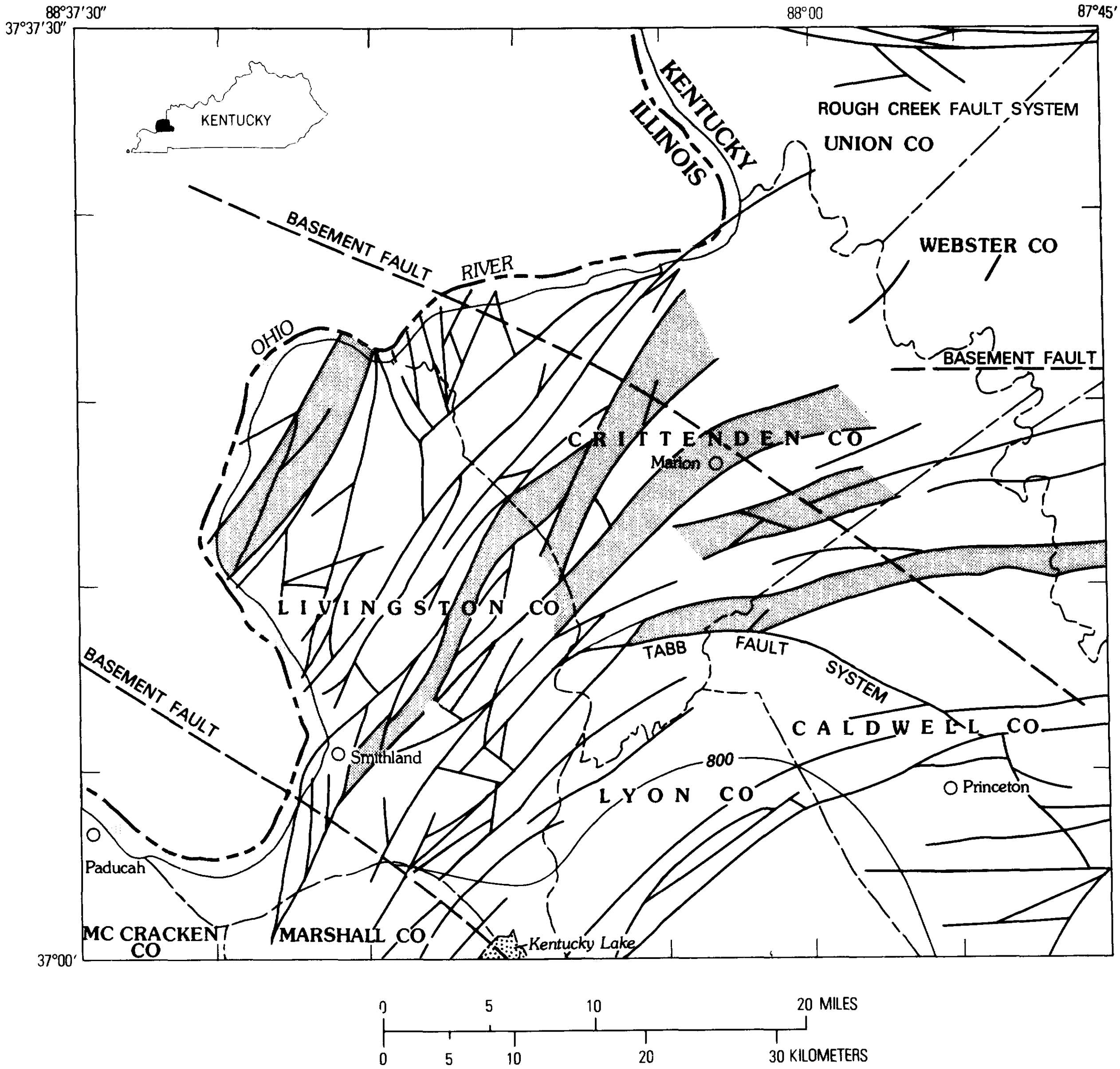


FIGURE 4.—Generalized fault map of the western Kentucky fluorspar district and surrounding area in Kentucky, showing major fault grabens (shaded). Inferred basement faults and the 800-gamma line are from Lidiak and Zietz (1976, fig. 3).

as a part of the Tabb fault system (pl. 1). In the area bordered by these two inferred faults, the anomalously trending west-northwest part of the Tabb fault system approximately parallels the 800-gamma line (Lidiak and Zietz, 1976, fig. 3), although the fault system is about 5 mi northeast of the line. The 800-gamma line may represent a deeply buried boundary of unlike rock types that was related to the formation of the anomalously trending Tabb fault system and its accompanying short west-trending fractures or faults (for example, the faults at the Marble mine and Senator–Black Sulphur mine complex) and the Farmersville Dome to the northeast.

The inferred east-trending basement fault is expressed at the surface by several east-trending surface faults (Trace and Palmer, 1971). These faults are east of and away from the influence of the presumably younger northeast-trending New Madrid fault system.

According to seismotectonic maps by Hildenbrand and others (1977, fig. 1) and Heyl and McKeown (1978), the boundaries of the New Madrid rift zone are alined with and encompass the entire Illinois-Kentucky fluorspar district. These maps suggest that the dominant northeast-trending faults of the fluorspar district are the surface expression of the New Madrid fault system. Heyl and McKeown (1978) pointed out, however, that conclusive evidence for the New Madrid fault system from the Paducah area to the New Madrid area is lacking. The mafic rocks in the district may be related to buried mafic intrusions shown along the boundary of the rift zone in southeastern Missouri, northeastern Arkansas, and western Tennessee.

Origin

Heyl and Brock (1961, p. D3) stated, "The Illinois-Kentucky mining district is centered in the most complexly faulted area in the central craton of the United States. Structural studies suggest that the mining district lies within a domal anticline that is located at and near the intersections of several major fault lineaments." The Illinois-Kentucky fluorspar district is just south of the intersection of the 38th parallel lineament (Rough Creek–Shawneetown–Cottage Grove fault systems) and the inferred New Madrid fault system (Heyl, 1972, p. 886).

The specific causes for and the direction of the stresses responsible for the complex structure of the district are not clearly understood. Many theories have been presented (Stuart Weller, 1927; J. M. Weller, 1940; Oesterling, 1952; Heyl and others, 1965; Grogan and Bradbury, 1968; Heyl, 1972; Hook, 1974). The basic problem is to determine the relative importance of and causes for horizontal and vertical stresses and fault movement; for example, we want to determine (1) what relationship the faults in the district might have to horizontal and (or) vertical movement along the Rough Creek–Shawneetown–Cottage Grove fault systems and along the New Madrid fault system, (2) the effects of movement along the inferred basement faults, and (3) the stresses caused by possible deep-seated igneous activity.

No new overall hypothesis is put forward here, but some relatively new pertinent data are discussed. New data have been obtained from the recently completed geologic mapping program, from magnetic studies along the 37th and 38th parallels (Lidiak and Zietz, 1976), and from recent aeromagnetic and gravity studies of the general midcontinent area (Hildenbrand and others, 1977; Johnson and others, 1978; Keller and others, 1978).

The geologic map (pl. 1) shows more information than the older and slightly smaller scale geologic map of Weller and Sutton (1951). The overall fault pattern of the two maps is essentially similar, but modern base maps and more subsurface data have resulted in many revisions of details, and several new faults and dikes are shown in plate 1. Mapping has more clearly defined the axis of the north-northwest-trending Tolu Arch, and perhaps most significantly, the new geologic map (pl. 1) delineates the interfault structure, especially within grabens, much more clearly by structure contours.

The dikes and associated fractures or faults are commonly generalized in the literature as having a northwest or north-northwest strike. In the 6- to 8-mi-wide zone of dikes (see "Igneous Rocks") extending across the district, the trends of the dikes are almost all from N. 20° W. to N. 30° W., and most are N. 25°–30°W. In the western part of the district, however, the Hutson dikes strike about N. 5° W., and the Sunderland and Lasher-Robinson dikes strike north. This strike change suggests that some of the dikes possibly were injected into tension fractures having a radial arrangement related to a central uplift, such as Hicks Dome in Illinois (fig. 3); some of the dikes probably were injected into tension fractures related to the more elongate Tolu Arch, as mentioned by Heyl and Brock (1961, p. D4) and Heyl (1972, p. 887), or tension fractures caused by lateral movement along the Rough Creek–Shawneetown fault zone, as suggested by Hook (1974, p. 84).

Possible evidence for major horizontal displacement along the northeast-trending faults was discussed by Trace (1974a, p. 67) who stated "preliminary mapping of the Hicks-Tolu structural high southward through the Cave in Rock quadrangle and the Dycusburg quadrangle suggests horizontal offsetting, or at least bending, of the axis of the structural high." This suggested extension of the Tolu Arch further than 6 mi south of Tolu, however, is difficult to evaluate and, therefore, is of limited value as evidence for horizontal movement along the northeast-trending faults. The origin of the shallow structural highs south of the Griffith Bluff graben may be related to the northeast-trending faults rather than to the apparently older Tolu Arch. The most convincing evidence against horizontal offset of the arch axis is that the north-northwest-trending zone of dikes crosses the axis and apparently has no substantial lateral offset across the district.

In summary, obviously some horizontal movement has taken place along the faults in the district, but no convincing evidence exists for horizontal movement of the same order of magnitude as the vertical movement.

Weller (1923, p. 100) was the first to propose that magmatic activity explains the arching, dikes, and faulting in the district. The structural pattern has also been related to stresses caused by the Rough Creek–Shawneetown and New Madrid fault systems, as summarized by Hook (1974, p. 83–85).

Possible evidence of magmatic activity is the fact that the deepest downdropped part of the Griffith Bluff graben is in the belt of abundant mafic dikes and is alined with the axis of the Tolu Arch. This combination suggests the possibility of magma upwelling and subsequent withdrawal and resultant arching and later fracturing due to collapse. Such a mechanism might be expected to create considerable fracturing and brecciation of the rocks within the graben. Exploratory drilling, however, revealed no such widespread collapse in rocks 1,500 to 2,000 ft below the surface, although the Commodore fault-zone breccias are still present at these depths. The depth to basement is probably more than 12,000 ft in this area, however, and such a collapse breccia could exist at depths below 2,000 ft.

MINERAL DEPOSITS

The mineral deposits were not studied during the mapping program, except to locate mines and prospects. Plate 1 shows only the mines that have had substantial production. Figure 5 shows the distribution of the known fluorspar deposits for the entire Illinois-Kentucky area. No underground examinations were made; logs of exploratory cored drill holes were used, however, for geologic mapping and stratigraphic information. The description of the mineral deposits that follows is a brief resume of general information from publications that describe in some detail certain deposits of the district (Norwood, 1876a; Ulrich and Smith, 1905; Fohs, 1907; Hoeing, 1913; Jillson, 1921; Currier, 1923; Oesterling, 1952; Klepser, 1954; Thurston and Hardin, 1954; Trace, 1954a, b, 1962b; Hardin, 1955; Hardin and Trace, 1959). Detailed recent information was given in several papers in a symposium on fluorspar (Hutcheson, 1974) and by Grogan and Bradbury (1968).

Most of the fluorspar-zinc-lead-barite ore bodies are steeply dipping to vertical vein deposits along faults or are "gravel deposits" that resulted from concentrations of fluorite as residuum above vein deposits. A few are very gently dipping to nearly horizontal bedding-replacement deposits in the Renault Formation or the upper part of the Ste. Genevieve Limestone of Late Mississippian age.

Most of the vein ore deposits are along northeast-trending faults; a few veins are along northwest- and north-trending fissures or faults that at places contain mafic dikes. The fluorspar veins are fissure fillings along faults and in fault breccia, accompanied by replacement of vein calcite and some limestone wallrock. A typical vein is lenticular, pinches and swells erratically, and is a mixture of fluorite and highly variable quantities of calcite and country rock fragments. Locally, the vein may be either entirely calcite or entirely fluorite. Commonly, a contact with vein walls is sharp; however, at places, veinlets of fluorite and calcite extend from a few feet to a few hundred feet beyond a vein into slightly broken wallrock. In many veins, sphalerite, galena, and barite are minor minerals; sphalerite or barite is the major constituent in a few veins. Mine run ore commonly contains from 30 to 40 percent fluorite; at places, it contains 2–3 percent zinc and ½–1 percent lead, and, in the northern part of the area, it contains a small percentage of silver in the galena and recoverable cadmium and germanium in the sphalerite.

The width of most veins is 3 to 10 feet, and mined ore shoots commonly range from 200 to 400 ft in length and from 100 to 200 ft in height. Several ore deposits are as deep as 700 to 800 ft below the surface, where the wallrocks generally are not older than the St. Louis Limestone. Rarely ore may occur where the Warsaw Limestone is the footwall, such as near the intersection of the Commodore and Sheridan faults (Salem quadrangle), or where both fault walls are Warsaw, as at the Hutson mine zinc deposit (Burna quadrangle). A small amount of drilling as deep as 2,000 ft has explored faults where the footwall was the Chattanooga Shale. No minable deposits have been found at this depth, although small quantities of fluorspar in cryptovolcanic breccia were found in a 2,944-ft oil test in the Illinois part of the fluorspar district in rocks of Ordovician age (Brown and others, 1954, p. 897–898).

A few bedding-replacement deposits are present in Kentucky. These include the Shouse, Clement, Ellis, and possibly part of the more recently opened Lasher-Robinson deposit. The bedding-replacement deposits are elongate bodies that trend north to northeast. The Shouse deposit is reported to be approximately 2 mi long and 150 to 250 ft wide, to have an average thickness of 7 ft, and to be about 30 percent CaF_2 (Trace, 1974a, p. 69).

Accurate dating of the age of mineral deposition is difficult. Stratigraphic relations indicate that the minerals were deposited after the Lower to Middle Pennsylvanian rocks were laid down. To the writers' knowledge, no fluorite has been found along faults where at least one fault wall is of Cretaceous or younger age. Thus, the age of mineralization is post-Early or Middle Pennsylvanian and pre-Late Cretaceous.

More than 2 million short tons, or about two-thirds of the district's total production of 3¼ million short tons of fluorspar, has been produced from five areas. The Tabb mine complex has produced more than 1 million short tons. This complex included mines on the Tabb fault system from the Tabb No. 18 mine on the west to the Pygmy mine on the east, a distance of about 4 mi. Four areas have produced a combined total of more than 1 million short tons. These areas are: (1) the Babb mine complex, from the Guill to the Barnes mines, about 2 mi along the Babb fault system; (2) the Dyer Hill mine, about 1 mi along the Dyer Hill fault

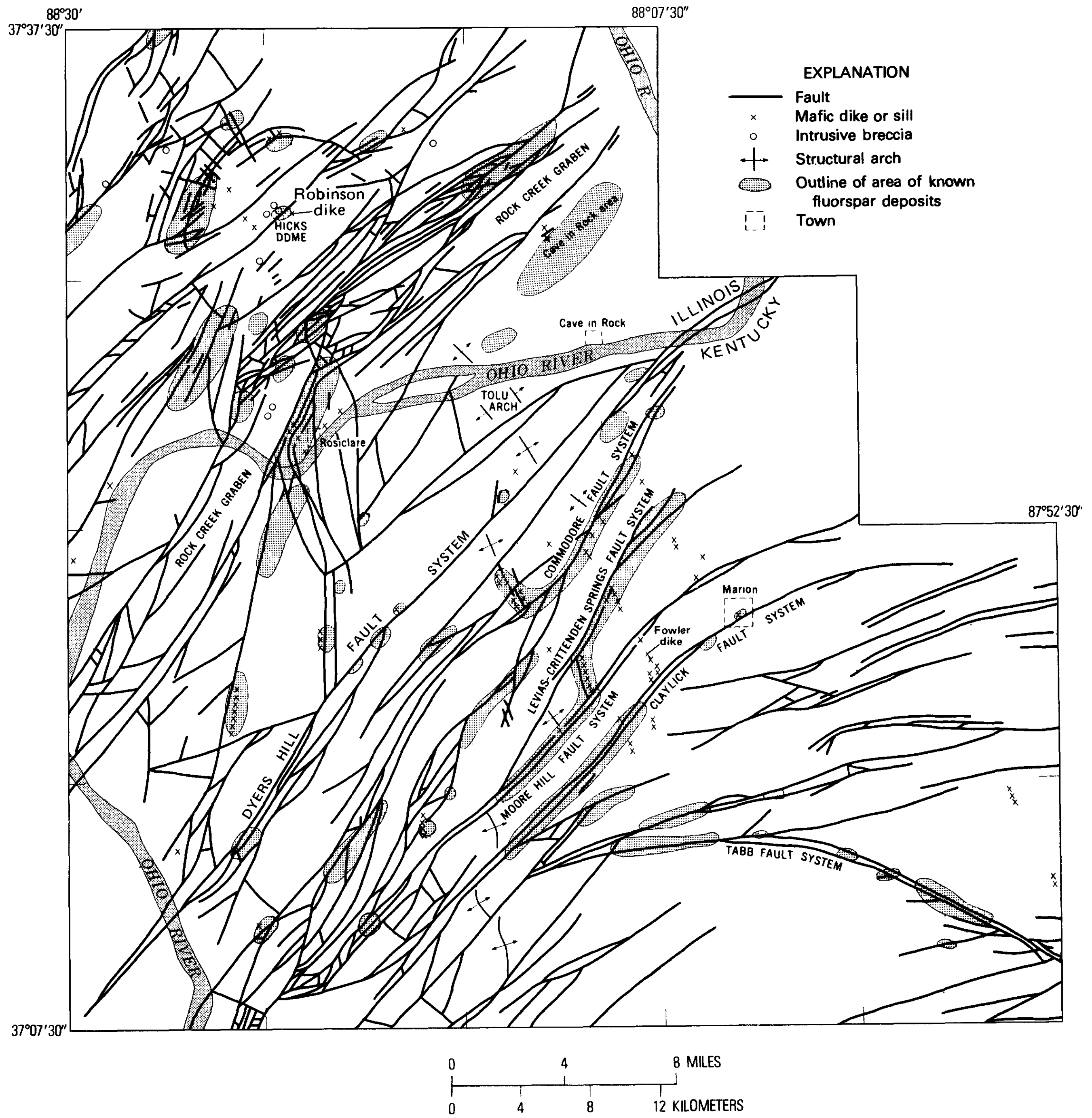


FIGURE 5.—Major structural features, igneous rocks, and distribution of known fluorspar deposits, Illinois-Kentucky fluorspar district. Compiled from geologic maps, 1962–72, by Illinois State Geological Survey and USGS (from Trace, 1976b, fig. 23).

system; (3) the Crittenden Spring mine complex, from the Keystone mines northeast about 3 mi along the Levias–Crittenden Spring fault system to the vicinity of Crittenden Spring; and (4) the Moore Hill mine complex, from the Shelby mine complex on the southwest to the Summers mine on the northeast, about 5 mi along the Moore Hill fault system.

Several mines or mine complexes have produced 10,000 to 100,000 short tons of fluorspar. These are the Commodore, Klondike, Mineral Ridge, Big Four, Lucile, Senator–Black Sulphur, Clement, Shouse, Bonanza, Dike-Eaton, Royal Silver, Atwood–Kibbler Hill, Kemper-Belt, Hodge, Susie Beeler, Memphis, Beard, and possibly a few others.

A few mines have produced only zinc ore. These include the Hutson, Nine Acres, Hickory Cane, and Old Jim mines. Also, a few mines have produced only barite or have produced substantial quantities of barite; these include the Mico, Ainsworth, part of the Pygmy, part of the Wright, and part of the Damron mines. Some mines have produced lead and silver ores as byproducts, but the production has always been small.

The main potential areas for the discovery of new vein fluorspar deposits in western Kentucky are along the many unexplored hanging-wall faults (Trace, 1979), where the ore would be from 500 to 1,000 or more ft deep. Few, if any, near-surface "gravel spar" deposits remain undiscovered, and many, perhaps most, of the deposits within 500 ft of the surface have been found.

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