Geology and Fluorspar Deposits, Big Four Fault System, Crittenden County, Kentucky

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GEOLOGY AND FLUORSPAR DEPOSITS OF THE BIG FOUR FAULT SYSTEM, CRITTENDEN COUNTY, KENTUCKY

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ABSTRACT

The Big Four fault system, near Marion, Ky., in the Kentucky-Illinois fluorspar district, is a complex northeastward-trending system of steeply dipping normal faults. Mining activity started in the area at the LaRue mine in 1874, and as of January 1945 about 35,000 tons of metallurgical grade fluorspar had been produced; most of this was from the Big Four mine. A small quantity of lead and zinc ore also has been produced.

The deposits are localized along the faults which displace nearly flat-lying shales, sandstones, and limestones of the Meramec and Chester series of Mississippian age and the Caseyville sandstone of early Pennsylvanian age. Displacements in the area mapped range from a few feet to more than 1,500 feet.

Detailed geologic mapping of the surface and data from underground workings have revealed at least 19 faults. Only a few of these faults are known to contain economic deposits of fluorspar.

The most abundant vein minerals are fluorite and calcite with subordinate quantities of sphalerite, galena, smithsonite, pyromorphite, anglesite, cerussite, marcasite, and quartz. More than half of the mined fluorspar came from veins composed mainly of fluorite and calcite. The ore bodies are the result of fissure filling with some replacement of the early vein material and wallrock. Residual concentrations of high-grade fluorspar in the overburden along faults also have yielded considerable quantities of "gravel" fluorspar.

INTRODUCTION

LOCATION AND GENERAL FEATURES

The Big Four fault system, also known as the LaRue fault system, is a group of mineralized faults in the Kentucky-Illinois fluorspar district, which straddles the Ohio River in southern Illinois and western Kentucky. The Big Four fault system is in the south central part of the district and is one of several major northeast-trending fault systems that have sliced the area into a complex fault block pattern, the largest of which are northeast-trending slivers 5–20 miles long and 1–2 miles wide. For a general description of the Kentucky-Illinois fluorspar district, see J. M. Weller and others (1952), Weller, Stuart, and Sutton, (1951), and Williams and Duncan (1955).

The Big Four fault system is about 7 miles west of Marion, Crittenden County, Ky., and crosses State Highway 297 about half a mile southeast of Sheridan, Ky. (fig. 62). The principal mine along this

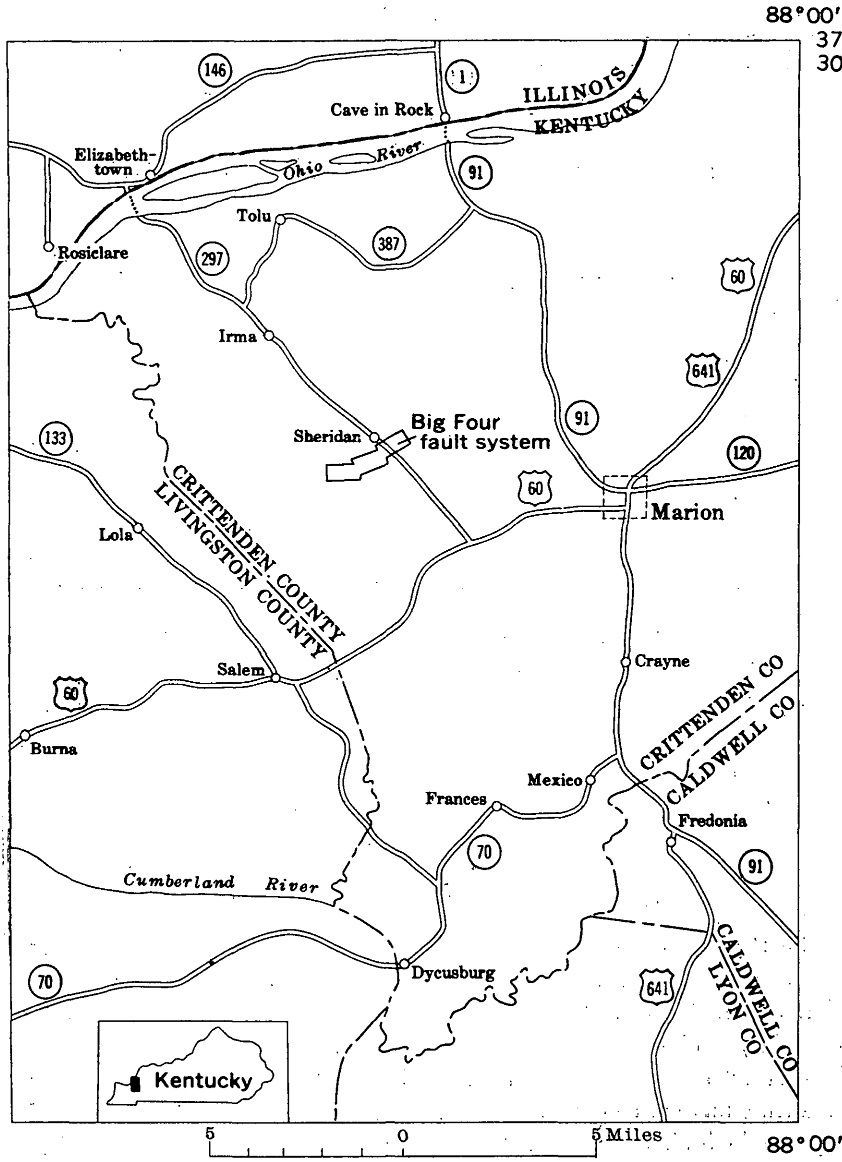


FIGURE 62.—Index map of western Kentucky, showing location of Big Four fault system, Crittenden County.

fault system is the Big Four mine, from which the system takes its name.

Mining activity apparently started in the Big Four area in 1874 when the LaRue mine was opened. Despite this early start, only a relatively small amount of fluorspar has been mined from the faults of this system; the total amount of fluorspar mined before January 1945 probably did not exceed 35,000 tons of metallurgical-grade fluorspar. The lack of mining activity along the Big Four fault system was mainly the result of the purchase of the entire area in 1924 by the Lafayette Fluorspar Co., a subsidiary of the United States Steel Corp., which held the area as a reserve until 1944, when the Big Four mine was reopened.

Like most of the Kentucky-Illinois fluorspar district, the area in the vicinity of the Big Four fault system is hilly and has wide valleys; the maximum relief in the Big Four area is about 160 feet. In general, the higher hills are capped by sandstones of the Chester series, and the broad valleys are underlain by limestones of the Meramec series.

FIELDWORK

EARLIER WORK

Norwood (1876) made a reconnaissance study of the Big Four area in 1875 and described two shafts of the Deer Creek Mining Co. on Robert LaRue's land. These two shafts were probably in the vicinity of the present Incline shaft of the LaRue mine, but it is not certain whether one of these shafts is the present Incline shaft.

Ulrich (Smith, 1905, pl. 8) mapped the LaRue and Glendale faults, and Smith (1905, p. 205) described the Cartwright mine on the Glendale fault. The locations of the Heywood prospect (now known as the Macer mine), the Moore prospect (probably the Zinc prospects of this report), and the LaRue mine are shown on plate 8 of the report by Ulrich (Smith, 1905), but no description of the prospects is given. Ulrich's LaRue fault roughly corresponds to the Big Four fault (fault 1) of this report), and his Glendale fault corresponds to a combination of fault 16 and the Commodore fault.

Fohs (1907) studied the Kentucky part of the fluorspar district in 1906 and included the Big Four and LaRue mines in his tabulation of mines in the district.

Currier (1923) studied the mines in the Kentucky part of the fluorspar district and described briefly the Big Four and LaRue mines and the Deer Creek, Heywood, and Mitchell prospects. None of these mines or prospects were accessible at that time.

In 1922–23 Weller (1927; see also Weller and Sutton, 1951) mapped the area around the Big Four mine on a scale of 1 inch to 1 mile. The interpretation of the geology given in the present report is in general agreement with Weller's interpretation, although there are differences in detail.

RECENT WORK

A study of the Kentucky-Illinois fluorspar deposits was begun in 1942 by the U. S. Geological Survey because of the increased demand for fluorspar during World War II. Before a specific program for fieldwork was planned, the Kentucky-Illinois field was visited in June 1942 by L. W. Currier and James Steele Williams, of the U. S. Geological Survey. As a result of this preliminary investigation, they recommended that detailed studies be made of the highly mineralized areas in the fluorspar district.

As a part of the program of detailed study, the Big Four fault system was mapped on a scale of 1 inch to 100 feet by George C. Hardin, Jr., assisted by Robert T. Russell and Donald A. Warner, in July and August 1944, and Robert D. Trace in May 1945. After the Big Four mine was reopened in July 1944, developments were followed closely, and a geologic mine map was kept up to date. Work was continued intermittently to May 1945.

Much of this report was written by George C. Hardin, Jr., in 1945-47 and is based entirely upon data obtained from areal and mine mapping during 1944–45 and the logs of two diamond-drill holes put down in 1911 by the LaRue Mining Co. Robert D. Trace, who has described the area adjoining the Big Four fault system toward the northeast (Trace, 1954), completed the report. The work was done under the general supervision of James Steele Williams and Ralph E. Van Alstine.

In order to facilitate location of points in the Kentucky district, a system of coordinates was established. The U. S. Geological Survey bench mark set in the concrete sidewalk approximately 40 feet west from the southwest corner of Grassham's garage at the corner of North Hayden and Broadway Streets (U. S. Highway 60) in Salem, Ky., was chosen as the zero point, and coordinate lines extended north, south, east, and west from this point. The coordinates used on the geologic map of the Big Four area (pl. 61) refer to this point.

ACKNOWLEDGMENTS

Thanks are due to the operators in this area for their assistance and cooperation, particularly to K. A. Johnston, of the Lafayette Fluorspar Co., and to Messrs. Loyd and Perry, operators of the Big Four mine during 1944–45. A. H. Reed, Sr., consulting mining engineer and geologist of Marion, Ky., furnished considerable information about the inaccessible workings of the LaRue mine, Macer mine, and Lead shaft mine.

GEOLOGY

The rocks exposed in the Big Four area are limestones, sandstones, and shales of the Meramec and Chester series of Mississippian age and sandstone of the Pottsville group of early Pennsylvanian age (pl. 61). The formations are nearly horizontal except near faults, where the beds dip as much as 55°. No igneous rocks were found in the mapped area, although lamprophyre (or peridotite?) dikes are exposed in the Crystal and New Holly mines (not in mapped area), about half a mile northwest of the Big Four mine.

The sedimentary rocks are broken by at least 19 normal and vertical faults. In general, the fault pattern of the Big Four system consists of a series of parallel and subparallel northeastward-trending faults; four northwestward-trending faults, the Crystal-Holly system, join the fault system southwest of the Big Four mine. The displacement ranges from a few feet to 1,000 feet on faults of the Big Four and Crystal-Holly systems and more than 1,500 feet on the Commodore fault (fault 18), which cuts off the Big Four fault system on the northeast.

SEDIMENTARY ROCKS

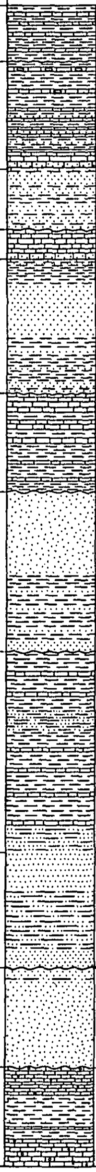
The formations present in the Big Four area include the sequence of beds from the St. Louis limestone of the Meramec series of Mississippian age to the Caseyville sandstone of early Pennsylvanian age. The paucity of outcrops in the mapped area makes it very difficult to determine with accuracy the local characteristics of any formation as a whole. Where outcrops are present they commonly represent only a small and more resistant part of the total rock sequence. Outcrops are numerous enough, however, to permit the identification of the surface formations in many of the fault blocks. The exposure of bedrock by prospect pits and the contents of the dumps of many of the now-caved pits greatly facilitate the accurate location of faults and the determination of the surface formations of the respective fault blocks. Little information on the thickness and lithology of the formations in the area was available from either underground workings or diamond-drill holes. A large number of diamond-drill holes, however, have been drilled through these formations along the Levias-Crittenden Spring fault system, about 2 miles southeast of the Big Four area. Information obtained by study of the cores from these holes has been utilized in compiling the following data on the character and thickness of the formations in the Big Four area.

The St. Louis limestone, the oldest formation exposed in the Big Four area, constitutes the surface of the large fault block bounded on the southeast by fault 1 and on the southwest by faults 12 and 14. In the Big Four area, the St. Louis limestone is a medium-gray fine-to medium-grained limestone containing many blue-gray chert nodules. Most of the block underlain by the St. Louis limestone is covered by red clay soil containing abundant brown nodules of leached chert.

The Ste. Genevieve limestone of the Meramec series constitutes the surface of the block bounded by faults 2, 10, and 11, of the block bounded by faults 2, 11, 12, and 13, and part of the block bounded by faults 2, 12, and 14. The Ste. Genevieve formation is composed of three members: the Fredonia limestone member, the Rosiclare sandstone member, and the Levias limestone member. In the first two of these blocks, the Levias limestone member has been removed by erosion where the Ste. Genevieve limestone constitutes the surface. Outcrops of the Fredonia limestone member are fairly abundant. This member is approximately 200 feet thick and consists of light-gray medium- to coarse-grained oolitic limestone with some beds of light-gray sublithographic limestone. The overlying Rosiclare sandstone member is approximately 20 feet thick and consists of greenish-gray fine-grained calcareous sandstone which becomes brown upon weathering. The Rosiclare sandstone member is exposed in a small outcrop in the old road about 1,200 feet west of the Big Four shaft, and weathered remnants of this member are present on the hillside along the northeast or upthrown side of fault 10. The Levias limestone member is present in the block bounded by faults 2, 12, and 14. Throughout the fluorspar district the lithologic character of the Levias limestone member is almost identical with that of the Fredonia limestone member.

Overlying the St. Louis and Ste. Genevieve formations of the Meramec series is a sequence of 8 limestone and shale formations alternating with 7 sandstone and shale formations which constitute the Chester series in the region. Of these 15 formations, 11 crop out in the mapped area (fig. 63); several of the sandstone and shale formations are similar lithologically, and some of the limestone and shale formations are difficult, if not impossible, to distinguish unless their characteristic fossils (Jillson and others, 1931) are found. These formations and their observed or inferred thicknesses are shown in figure 63.

Overlying the Chester series of Mississippian age in the Big Four area is the Caseyville sandstone of early Pennsylvanian age. In the northeast part of the area, this formation constitutes the surface of much of the block southeast of the Commodore fault (fault 18), where it is well exposed. Most of the sandstone has been removed by erosion, and only the lower 50–60 feet remains. This formation consists of medium-grained sandstone with a small amount of conglomerate composed of water-worn quartz pebbles in a sandy matrix.



Formation	Thickness (feet)	Lithology
Kinkaid limestone (base not exposed)	40+	Limestone, gray, crystalline; and black shale
		Degonia sandstone, Clore limestone, and Palestine sandstone not exposed in mapped area
Menard limestone	80	Limestone, medium- to dark-gray; sandy at base and few chert nodules near top; medium- to dark-gray shale; some thin beds of limestone, shale, and sandstone near middle of formation
Waltersburg sandstone	35-55	Sandstone, dark-gray with numerous shaly partings; and dark-gray shale with numerous thin sandstone lenses; upper 5 feet commonly calcareous shale.
Vienna limestone	15-30	Limestone, light- to medium-gray, fine- to medium-grained; slightly sandy at base locally
Tar Springs sandstone	100±	Sandstone, light-gray, fine- to medium-grained; and dark-gray shale, with thin sandstone beds; uppermost part of top shale unit is calcareous
Glen Dean limestone	55-90	Limestone, medium- to dark-gray, fine- to medium-grained, with interbedded dark-gray shale; and dark-gray thin-bedded calcareous shale with interbedded limestone; upper half dominantly limestone; lower half dominantly shale
Hardinsburg sandstone	120±	Sandstone, medium-grained, massive; and black thin-bedded shale with numerous thin sandstone lenses; upper half dominantly sandstone; lower half dominantly shale
Golconda formation	150±	Shale, black, thin-bedded, with interbedded limestone; thin sandstone lenses and sandy shale near middle; and sandy shale near base
Cypress sandstone	85-90	Sandstone, medium- to light-gray, fine- to medium-grained; and sandy dark-gray to black shale
		Paint Creek shale not exposed in mapped area
Bethel sandstone	70-80	Sandstone, fine- to medium-grained, mostly massive.
Renault formation	75±	Limestone, medium- to dark-gray, fine-grained, generally argillaceous with a few oolites; and calcareous shale; upper and lower thirds dominantly limestone; middle third dominantly shale

FIGURE 63.—Section of Chester formations exposed in the Big Four area, Crittenden County, Ky.

STRUCTURE

The Big Four fault system (faults 1, 2, 3, 3A, 4, 5, 6, 7, 8, 13, 14, 15, 16, and 17) consists mostly of a series of parallel and subparallel northeastward-trending faults (pl. 61). Northeast of the Big Four mine, the system is simple, consisting of two subparallel faults (1 and 16) trending approximately N. 50° E. These two faults are joined by a fault (17) trending N. 35° E. at a point about half a mile northeast from the Big Four mine. The entire Big Four fault system ends against the Commodore fault (fault 18) 1½ miles northeast of the Big Four mine.

Southwest from the Big Four mine, the Big Four fault system becomes intricate and is joined by four parallel northwestward-trending faults known as the Crystal-Holly system (faults 9, 10, 11, and 12). The Big Four fault (fault 1) continues through this complexly faulted area and, according to Weller and Sutton (1951), retains its identity for about 12 miles southwest of the mapped area.

Displacement along the faults of the Big Four and Crystal-Holly systems ranges from a few feet to 1,000 feet and along the adjacent Commodore fault to more than 1,500 feet. The displacement along the faults rarely is along a single fracture plane; commonly the displacement is within a zone from a few to as much as 50 feet wide that contains several fractures, fault gouge, and strongly dragged and brecciated country rock. The direction of displacement along faults in the Big Four area is believed to be nearly vertical. In other places in the fluorspar district, however, both horizontal movement and vertical movement have occurred, and along the Dike fault near Levias, Ky., 2–3 miles southeast of the Big Four area, much of the movement is believed to be horizontal.

The dip of the most of the faults ranges from 75° to vertical. Generally only a few of the faults are exactly vertical; typical normal faults are much more common, where the dip is about 80°–85° and generally the hanging wall is downthrown in reference to the footwall. Occasionally, however, a steeply dipping fault will reverse its direction of dip in places, and then the terms "hanging and foot walls" are meaningless locally.

Geologic data for mapping the faults were obtained from several sources: underground workings that cut or follow the faults; exposures of fault walls or veins, rarely on the surface or more commonly in the walls of caved pits; outcrops or large boulders of brecciated and silicified sandstone ("quartzite reefs"); stratigraphic studies that revealed juxtaposition of formations not in normal sequence; and where formations of the Chester series are present, the topography caused by the juxtaposition of a resistant bed (sandstone) to a more easily eroded bed (limestone or shale).

Fault 1, the Big Four fault, is the only fault that is continuous throughout the entire mapped area (pl. 61). The general strike of this fault is N. 50° E., and the dip of the fault plane, where determinable, ranges from 70° SE to nearly vertical. The downthrown side of the fault is on the southeast throughout its extent. The Big Four, LaRue, Cartwright, Macer, and Mitchel mines are on the Big Four fault. Considerable fluorspar has been mined from veins occurring in this fault, and most of the known fluospar reserves of the Big Four area are along it.

Although fault 1 does not crop out, numerous exposures of "quartzite reefs," a local term for small ridges of silicified sandstone or quartzite, and large boulders of slickensided and silicified sandstone reveal the position of the fault throughout the area mapped. Southwest of the Woods shaft at the Big Four mine, the fault cuts formations of the Chester series at the surface and is well marked by outcrops of quartzite and silicified sandstone in the gullies it traverses. Here the displacement along this fault is about 250 feet.

In the vicinity of the Big Four mine, fault 1 lies between the St. Louis limestone on the northwest and a sandstone of Chester age, tentatively identified as the Hardinsburg, and the Vienna limestone on the southeast. The displacement ranges from 650 to 1,000 feet in this vicinity.

Fault 1, where observed in the Big Four mine, consists of a sheeted and brecciated zone ranging in width from 5 to 35 feet. The Big Four mine is in the complexly faulted area where faults 1, 3, and 16 join; the intense brecciation along fault 1 in this vicinity is probably partly the result of movement near these junctions. In places in the Big Four mine, ore shoots as much as 20 feet wide were observed in stopes along fault 1.

Northeast of the Big Four mine, fault 1 lies between the Hardinsburg sandstone or Glen Dean limestone of the Chester series and the St. Louis limestone and has been cut in workings of the LaRue, Cartwright, Macer, and Mitchel mines. (See Mines and prospects.) None were accessible in 1944–45. The displacement along fault 1 probably is about 700 feet.

Fault 2 lies between the Golconda and Hardinsburg formations of the Chester series on the southeast side and Ste. Genevieve limestone to the Cypress sandstone of the Chester series on the northwest. The downthrown side of this fault is on the southeast throughout the area mapped, and the displacement ranges from 200 to 500 feet (pl. 61). The strike of fault 2 ranges from N. 55° E. to due east; the dip was not determinable. The fault does not crop out in the area, but the many prospect pits along the trend of this fault help locate it with considerable accuracy. Pits on the upthrown, or footwall side, of the fault are largely in the Fredonia limestone member of the Ste. Genevieve limestone, but those on the downthrown, or hanging wall, side are in the Golconda and Hardinsburg formations.

Approximately 600 feet southwest from the Big Four shaft, faults 2, 7, and 14 join fault 1. No outcrops were found here, but slickensided and brecciated quartzite is abundant along the hillside southeast of the junctions of these faults. This quartzite is not in place, however, and hence does not mark the fault traces accurately. A deep pit (pit A on pl. 61) sunk wholly in brecciated and sheeted silicified sandstone (probably the Hardinsburg sandstone) is between faults 1 and 2 near their junctions.

The waste dumps of several shallow prospect pits sunk along the trend of fault 2 (pl. 61) contain stringers of fluorspar in brecciated country rock, but no commercial body of fluorspar has been found along this fault. The deepest exploratory opening along fault 2, however, is probably not more than 25 feet.

Fault 3 (pl. 61) is exposed only in underground workings of the Big Four mine; where seen, both walls of the fault are probably St. Louis limestone. Fault 3 strikes approximately N. 35°–40° E.; the displacement along this fault was not determinable but probably does not exceed 100 feet.

Fault 3 dips southeastward toward fault 1 at approximately 60° at the Big Four shaft and 75° near its junction with fault 1; near the Big Four shaft faults 3 and 1 probably intersect at a depth of approximately 250 feet. On the 100-foot level at the Big Four shaft (pl. 62), faults 1 and 3 are distinct, and each contains a vein or breccia zone with fluorspar. On the 160-foot level at the shaft, however, the two faults are represented mostly by a calcite vein about 50 feet wide; the entire brecciated limestone block between the two faults at this level has been replaced by calcite. The northwestern part of this calcite vein, corresponding to the projection of the plane of fault 3 from the 100-foot level, consists of 8 feet of zinc ore containing as much as 10 percent of sphalerite. The remainder of the calcite vein is nearly barren of zinc ore.

Fault 3A (pls. 61 and 62) is exposed only in underground workings of the Big Four mine; on the 100-foot level northwest of fault 1 both walls of fault 3A are probably St. Louis limestone. Fault 3A dips about 65° N. and strikes about east; the displacement along the fault was not determinable but probably is small.

Faults 4 and 5 do not crop out, but their location was determined by exposures in prospect pits shown on plate 61. Fault 4 strikes N. 35°

E., dips 55° SE., and separates Tar Springs(?) sandstone of the Chester series exposed in three pits called pits B from the Glen Dean limestone of the Chester series and Tar Springs sandstone on the northwest, or upthrown, side of the fault. The trend of fault 4 is parallel to the strike of the steeply dipping Tar Springs(?) sandstone exposed in pits B. The displacement along fault 4 is estimated to be about 100 feet; the dip of the fault was not determinable.

The sandstone beds exposed in pits B are rather massive, which is not characteristic of most sandstone in the Tar Springs. The Vienna limestone of the Chester series, however, was identified on the dump of the shallow pit designated pit C, which is about 300 feet northeast from pits B. Possibly a short northwestward-trending fault separates the Vienna limestone in pit C from the sandstone exposed in pits B. If so, the sandstone exposed in pits B may be the Hardinsburg.

Fault 5 lies between pits C and D (pl. 61). The strike of this fault is approximately N. 25° E., parallel to the strike of a number of small calcite veinlets in Glen Dean limestone cropping out in the gully between pits C and D. The downthrown side of fault 5 is on the northwest; the dip of the fault was not determinable. The displacement along fault 5 is estimated to be about 50 feet southwest of its junction with fault 8 and about 125 feet northeast of this junction.

On the dump of pit D, considerable vein calcite was found. This calcite contains only traces of fluorspar, and the calcite veinlets in the outcrop of Glen Dean limestone to the northeast contain none.

Fault 6 does not crop out in the area mapped, and there are no pits or other exploratory openings along it. Its strike, however, is indicated by a westward-trending outcrop of quartzite about 40 feet south from the small creek half a mile southwest from the Big Four shaft (pl. 61). At the point where fault 6 crosses this creek, thinly bedded Tar Springs sandstone dipping 20° S. crops out. Fault 6 is downthrown on the south, with the displacement ranging from a few feet to 75 feet; the dip of the fault was not determinable. Fault 6 is about 1,200 feet long and is terminated on its west end southwest of the mapped area by a junction with fault 1; it is terminated on its east end south of the mapped area by a junction with fault 7. Faults 4 and 5 end against fault 6.

Fault 7 is not well exposed, but the fault trace may be located with reasonable accuracy throughout its extent. The strike of this fault ranges from N. 35° E. to N. 60° E. The downthrown side is on the southeast, with the displacement ranging from 100 to 150 feet; the dip of the fault was not determinable.

The dump of pit F (pl. 61) consists largely of clay and overburden but contains much slickensided sandstone, suggesting that this pit is within a few feet of fault 7. The dump of pit G consists largely of brecciated slickensided sandstone, indicating that fault 7 passes within a few feet of this pit. An outcrop of sheeted quartzite about 15 feet northeast of pit G indicates the trend of fault 7 to be about N. 35° E. in this vicinity. Between pits G and F, a small outcrop of slickensided quartzite trending N. 35° E. suggests that fault 7 is present here. Near the junction of fault 6 with fault 7, 150 feet south of the mapped area, fault 7 may be located with reasonable accuracy; here fault 7 lies between steeply dipping thinly bedded to massive Tar Springs(?) sandstone on the northwest and relatively flat-lying Menard limestone of the Chester series on the southeast.

Fault 8 is not exposed but has been mapped on the basis of topographic expression and on the presence of many large boulders of brecciated sandstone found along a northeastward-trending hillslope (pl. 61). The fault strikes N. 60° E. and is downthrown on the southeast; the displacement is estimated to be about 50 feet. No pits or other exploratory openings are present on fault 8.

Fault 9, called the Weller fault, and fault 10, called the Jones fault, trend about N. 30° W. at approximate right angles to the general strike of the Big Four fault system (pl. 61). These two faults are about 100 feet apart and, along with faults 11 and 12, constitute what is commonly called the Crystal-Holly fault system. Neither fault 9 nor fault 10 is exposed in the mapped area, but the New Holly mine about half a mile northwest of the mapped area, fluorspar has been mined from veins along both faults 9 and 10. At the New Holly mine, a crosscut connects the two faults; about halfway between the two faults this crosscut penetrated four closely spaced 6- to 12-inch-wide parallel lamprophyre (or peridotite?) dikes. The strike of these dikes is parallel to that of faults 9 and 10. No evidence was found that these four dikes extend southeastward into the mapped area.

The displacement along fault 9 at the New Holly mine is about 30 feet; the displacement along fault 10 in this vicinity is about 75 feet. Both faults, as exposed in the New Holly mine workings, are approximately vertical.

Fault 11, the Holly fault, strikes about N. 30° W., paralleling faults 9 and 10. This fault is the third member of the Crystal-Holly fault system. Although fault 11 does not crop out in the mapped area, several pits and caved shafts mark its trend. The Old Holly mine is on fault 11, about half a mile northwest of the mapped area. A narrow but persistent vein of high-grade fluorspar was mined at the Old Holly Mine, where Ste. Genevieve limestone constitutes the surface on both sides of fault 11. The amount of displacement was not determinable but probably does not exceed 50 feet. The dip of the fault is reported to be approximately vertical.

Fault 12, the Crystal fault, strikes N. 30° W., paralleling faults 9, 10, and 11, and is the fourth member of the Crystal-Holly fault system. The Crystal mine, about half a mile northwest from the Big Four mine, is on fault 12. At the Crystal mine, the fault is associated with a lamprophyre (or peridotite?) dike ranging from 3 to 15 feet in thickness. According to Mr. A. H. Reed, Sr. (oral communication, 1944), the continuation of the dikes exposed at the Crystal mine was penetrated by exploratory work somewhere in the Big Four area; none are shown on plate 61, however, as no outcrop of dike material was found and all exploratory openings are inaccessible.

In the mapped area fault 12 could not be traced by surface indications south of its junction with fault 2; A. H. Reed, Sr., however, reports that a faulted dike trending in the same direction as fault 12 was found in prospect pits just south of the mapped area. Weller (1927, p. 105) also reports that fault 12 and a dike "cross the Big Four fault together and continue to the Hardin Knob fault," or fault 17, which is about half a mile to the south.

Fault 13 strikes N. 20° E. and separates a small block of massive sandstone, thought to be Cypress sandstone of the Chester series, on the southeast or downthrown side from a block of the Fredonia limestone member of the Ste. Genevieve limestone on the northwest or upthrown side (pl. 61). This fault is not exposed, nor is its trend well marked. The presence of abundant large sandstone boulders on the hillside and the presence of sandstone on the dump of pit H indicate the existence of a small wedge-shaped block of massive sandstone here.

Fault 14 strikes about N. 50° W. and separates a block of the Ste. Genevieve (Meramec), Renault, and Bethel (Chester) formations on the southwest or downthrown side from a block of St. Louis limestone on the northeast or upthrown side (pl. 61). This fault is not exposed, and the trend was determined largely on the basis of topography. The displacement along fault 14 is estimated to be about 300 feet. The Rosiclare sandstone member of the Ste. Genevieve limestone, constituting a part of the fault block between faults 2, 12, and 14, is exposed in the road about 1,200 feet west from the Big Four shaft. Some of the large blocks of massive Bethel sandstone near the top of the hill north of fault 2 are probably bedrock.

Fault 15, the Hayshed fault, strikes N. 30° E. As St. Louis limestone constitutes the surface on both sides of this fault (pl. 61), the amount of displacement was not determinable; however, the displacement probably does not exceed 50 feet. The fault plane is not ex-

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posed, but miners who have worked in the numerous small shafts along this fault report that it is approximately vertical.

Fault 16 strikes about N. 50° E. This fault, one of the main branches of the Big Four fault system, is called the LaRue fault by some miners, although the term also has been applied to both faults 1 and 3. The term "Glendale" also has been used to designate this fault, but this is not the Glendale fault of Ulrich (1905) or Trace (1954). Fault 16 lies between northwestward- and southeastward-dipping upper formations of the Chester series on the southeast or downthrown side and Hardinsburg sandstone and Glen Dean limestone on the northwest or upthrown side. The displacement along this fault ranges from about 50 feet near its intersection with fault 17 to about 250 feet near the Big Four mine; the dip was not determinable.

The trace of fault 16 is well marked northeast from the Big Four mine to its intersection with fault 17. A large outcrop of brecciated sandstone (probably Hardinsburg sandstone) marks the fault in Coefield Creek about 200 feet east from the Big Four shaft. Northeast from this outcrop, the trace of the fault is shown by small outcrops of quartzite in the gullies. Near the intersection of faults 16 and 17 (pl. 61), a northeastward-trending slickensided quartzite ridge marks the location of fault 16.

Fault 16 probably is offset slightly by fault 17. Southeast of the Cartwright mine area and about 1,000 feet northeast from the intersection of faults 16 and 17, an outcrop of Waltersburg sandstone of the Chester series dipping 25° SE. suggests that fault 16 is only a short distance to the northwest. Northeast from this outcrop of Waltersburg sandstone, the fault is not exposed for more than half a mile. Farther northeast fault 16 crops out in an old road about 600 feet northeast of the Macer mine (pl. 61). About 600 feet northeast of this outcrop, fault 16 ends against fault 18, the Commodore fault, as the parallel Big Four fault to the north.

According to A. H. Reed, Sr. (oral communication, 1944), fault 16 was cut by a crosscut driven northwest from one of the Zinc prospects (pl. 61) near the intersection with fault 17. No other exploratory openings are known along fault 16.

Fault 17, the Hardin Knob fault, strikes about N. 35° E. in the area mapped. This fault continues to the southwest for about 4 miles, where it joins the Babb fault system probably about 600 feet northeast of the Howard shaft (Hardin, 1954). This fault is well exposed in Coefield Creek about 900 feet east from the Incline shaft (pl. 61), where the northwest wall of the fault is sandstone and shale of the Tar Springs and the southeast wall is shale of the Waltersburg. The displacement at this point is less than 50 feet. Northeast from the outcrop of fault 17 in Coefield Creek, the trace of the fault is well marked by small ridges of brecciated and slickensided sandstone. Fault 17 probably offsets fault 16 and ends against fault 1. In the area mapped the Zinc prospects (pl. 61) are the only exploratory openings sunk on fault 17.

Fault 18, the Commodore fault, strikes about N. 20° E. and crosses the northeastern end of the mapped area, where the faults of the Big Four fault system end against it. Fault 18 constitutes the major fault of the Commodore fault system, which has been described by Trace (1954) in the area bordering the Big Four fault system on the northeast.

At the northeast edge of the area mapped, the Lead shaft and the nearby Riggs shaft provide information that helps locate fault 18. The Lead shaft was sunk on this fault where the St. Louis limestone is faulted against the Kinkaid limestone close to the inferred junction with fault 1. In the nearby Riggs shaft, beds of Caseyville sandstone of the Pottsville group and Kinkaid limestone of the Chester series dip 35° SE. indicate that the trace of the fault is not far northwest from this shaft.

At the Lead shaft the country rocks of the Commodore fault are St. Louis limestone and Kinkaid limestone, and the displacement probably is more than 1,500 feet. To the southwest a large part of this displacement is taken up by the Big Four fault and fault 16, which join the Commodore fault. Southeast of these junctions the country rocks along the Commodore fault are the Caseyville and Kinkaid formations and the Vienna limestone, and the displacement is about 300 feet.

ORE DEPOSITS

GENERAL FEATURES

Approximately 35,000 tons of metallurgical-grade fluorspar was produced from the mines of the Big Four area before January 1945. In addition to fluorspar, small quantities of lead ore and oxidized zinc ore have been marketed from the mines and prospects of this area. No concerted effort has been made in the area to mine either zinc or lead ore, as the operators were interested primarily in fluorspar, and before 1946 adequate milling facilities for selective flotation of complex ore were lacking in the Kentucky part of the district. Because high-grade zinc deposits have been found elsewhere in the district and because several of the mines and prospects in the Big Four area reportedly contain zinc and lead, further exploration of the area for zinc and lead, as well as fluorspar, appears justified.

In the Big Four area more than half the fluorspar mined before January 1945 came from deposits in veins. However, most of the early mining operations were concerned principally with the production of high-grade "gravel" fluorspar, which is residual fluorspar concentrated in the overburden by weathering and removal of the gangue minerals and wallrock.

The vein material is believed to have been deposited by ascending hydrothermal solutions derived from a deep-seated magmatic source. It formed along the normal faults by fissure filling and replacement of wall rock and earlier vein minerals. Mine openings in the area are not extensive enough to warrant any definite conclusions concerning the causes of ore localization. Fault intersections may have helped localize the ore, but not enough fault intersections are exposed in the area for the extent of this control to be determined.

MINERALOGY

The fluorspar deposits of the Big Four area contain relatively few minerals, and the mineralogy is simple. The primary minerals are fluorite, sphalerite, galena, marcasite, calcite, and quartz; minor amounts of secondary minerals present are smithsonite, pyromorphite, anglesite, and cerussite.

The paragenesis of the minerals of the Big Four area has not been studied in either thin or polished sections. The deposits of this area, however, are similar mineralogically to the deposits of the Babb fault system, where the paragenetic relations have been given as follows (Hardin, 1954): Calcite, some quartz, fluorite, galena and sphalerite, some quartz, and marcasite.

ORE MINERALS

Fluorite.—The most important and abundant mineral produced from the Big Four area is fluorite. It is found in a great variety of colors—white, gray, yellow, tan, brown, blue, pink, and purple—but most of the fluorite from this area is gray to brown, with some of the massive fluorite commonly having a faint-purple tinge. In general, pink and dark-purple fluorite is more common in small fissures associated with the main faults. Some of the miners believe that the occurrence of pink or dark-purple fluorite indicates a pinch in the vein.

The veins at the Big Four mine, which are typical of those in the area, consist mostly of massive fluorite and associated minerals with some calcite and considerable shaly gouge. The fluorspar, as mined, is dirty grayish brown and has a somewhat greasy luster. Fluorite crystals are rare, but a few cubes, mostly dark purple or pink and from ½ to 2 inches on an edge, have been found in vugs.

Sphalerite.—The second most abundant ore mineral in the Big Four area is sphalerite, which is associated with the fluorspar. Only a small quantity of sphalerite was seen in the veins in faults 1 and 16 in the Big Four mine, but a considerable amount is present in the vein in fault 3. Sphalerite-bearing vein material and country rock were found on dumps in the vicinity of the LaRue mine, the Zinc prospects, and the Cartwright mine area. Sphalerite in the Big Four area is usually bright reddish brown and disseminated throughout masses of fluorspar, calcite, limestone, and sandstone; it is common in masses of porous limestone. The sphalerite is usually very fine grained but may occur in grains or crystals as much as 5 millimeters across. Above a depth of 50 feet, near surface oxidation produced by weathering has altered the sphalerite to smithsonite.

Galena.—Considerable galena is present in the ore from the Big Four mine, and some galena is present on the dumps of the LaRue mine, Cartwright mine area, Macer mine, and Lead shaft. Several tons of galena concentrated from the ore of the Big Four mine is reported to have been marketed, and galena and its oxidation products extracted from the Lead shaft were concentrated and sold.

The galena from the Big Four area occurs as crystal aggregates and small stringers in the fluorspar veins. In some places, the galena is fine grained and disseminated throughout the vein material. The distribution of galena generally is spotty, and, although pockets of galena locally form an appreciable part of the ore, galena probably constitutes less than 2 percent of the total material mined.

Alteration products.—Small quantities of smithsonite, anglesite, pyromorphite, and cerussite have been found in material on the dump of the Lead shaft. Most of this material is white to light gray and fine grained. With the exception of pyromorphite, which is yellowish green, it is almost impossible to distinguish the components of aggregates composed of these secondary minerals without the aid of a microscope.

OTHER MINERALS

Calcite.—Milky-white to gray massive calcite is the principal gangue mineral. Although calcite does not constitute as large a part of the veins in the Big Four area as it does elsewhere in the Kentucky-Illinois field, it locally forms much of the vein. Calcite crystals are rare.

Quartz.—Quartz is rather scarce in the veins but is present in the silicified wall rock in large quantity. The quartz is generally white or light gray, but a few crystals of smoky quartz have been found in fissures in the wall rock. Most of the quartz occurs as a cement filling the pore spaces of the country rock.

Marcasite.—A small amount of a pale-bronze-yellow mineral thought to be marcasite was noted. This mineral occurs as inclusions in the fluorite and as small stringers or veinlets in the wall rock.

VEINS, ORE BODIES, AND WALLROCKS

The fluorspar veins in the Big Four area are fissure fillings along faults and in fault breccia, accompanied by some wallrock replacements. A typical vein is well exposed in the workings of the Big Four mine, where it consists mostly of massive fluorite or massive white calcite largely replaced by fluorite. Considerable fault gouge is associated with the vein, and a film of gouge generally separates the vein from the wallrock. In the center of the vein, a surface along which vertical movement has taken place is marked by a gouge seam ranging in width from 1 to 6 inches. This surface is locally called the center slip. The fluorspar on the northwest side of the slip is generally of better quality than that on the other side; this difference in composition possibly was a factor in the localization of the slip. The better quality fluorspar consists largely of massive fluorite with considerable included wallrock and fault gouge derived from the shales where they constitute the hanging wall of the vein.

Vein widths range from a few inches to 20 feet and probably average 8–10 feet. The ore shoots in the Big Four mine range in strike length from 200 to 400 feet; these lengths are about average for the better fluorspar mines in the Kentucky-Illinois field.

The wallrock consists of silicified and brecciated limestone, shale, and sandstones of the Chester and Meramec series of Mississippian age. The footwall at the Big Four mine consists principally of massive cherty St. Louis limestone with considerable silica in the form of disseminated quartz crystals and quartz veinlets.

The limestone locally is brecciated and contains abundant veinlets and thin seams of white calcite. The hanging wall is largely sandstone and sandy shale with some limestone where exposed on the 100- and 160-foot levels. The shale has been strongly drag folded. The sandstone near the veins generally is silicified and altered to quartzite. The quartzite is considered to have formed both by pressure along the fault, forcing an intergrowth of individual quartz grains, and by later silicification when silica was added along small fractures and permeated the open spaces.

LOCALIZATION OF ORE BODIES

In another area in the Kentucky-Illinois fluorspar district (Hardin, 1954, p. 24–27), the effects of structural and lithologic controls in the localization of veins and ore shoots along the faults are apparent. In the Big Four area, however, data from mine openings and core-drill holes are inadequate for formulation of definite conclusions about the ore controls. In the 160-foot level of the Big Four mine (pl. 62), the vein at the junctions of faults 1 and 16 is no wider than it is at other points along fault 1. The large amount of gouge in the fracture before the deposition of the fluorite probably explains why the fluorite vein is not wider.

ORIGIN

The fluorspar deposits of the Big Four area are thought to have been deposited by ascending hydrothermal solutions derived from a deep-seated magmatic source. The vein openings were filled first chiefly with calcite; then renewed movement opened new fractures along which fluorine-bearing solutions moved. Fluorite replaced the calcite and limestone country rock and was also deposited in open spaces, possibly as a result of fluorine-bearing solutions reacting with waters containing calcium bicarbonate in solution (Schwerin, 1940). Most of the sphalerite and galena is younger than most of the fluorite.

MINES AND PROSPECTS

Although the area mapped has been prospected and attempts have been made to develop mines since 1874, the only mine of any consequence in the area is the Big Four. Much of the pre-World War II production was "gravel" fluorspar from various parts of the area, particularly the Big Four, Macer, and Hayshed mines. In 1944–45 vein fluorspar was taken from th Big Four mine.

Much of the area mapped has been prospected to some extent; before 1945, however, only a small part had been adequately prospected to a depth of 100 feet. Ore structures in much of the mapped area should be tested for fluorspar, zinc, and lead by diamond drilling to a depth of at least 500 feet.

BIG FOUR MINE

The Big Four mine (pl. 62) is owned by the Lafayette Fluorspar Co., a subsidiary of the United States Steel Corp. This company owns most of the property along the Big Four fault system.

Fohs (1907) states that the Big Four mine was opened in 1898 by J. C. Miller. According to A. H. Reed, Sr., geologist and mining engineer of Marion, Ky., ore was produced in 1900 by the Big Four Mining Co., which was composed of Messrs. Noe, Mosely, Roberts, and Noe. This company mined zinc-bearing "gravel" fluorspar from the opencut a few feet southwest of the present Big Four shaft (pl. 61). This opencut mine was shut down in 1905.

The Big Four mine was not operated again until 1917 when A. H.

Reed, Sr., acquired the property. Under Mr. Reed's ownership, the opencut was deepened, and the present Big Four and Airlift shafts were sunk to 100 feet. During the depression after World War I, the Big Four mine was closed but was reopened in 1922 when Mr. Reed organized the Big Four Fluorspar and Ore Co. Under the operation of this company from 1922 to 1924, the drifts on the 100-foot level of the Big Four mine were driven to the northeast and southwest. No work was done on this level from 1924 until 1945.

In 1924 the holdings of the Big Four Fluorspar and Ore Co. were sold to the Lafayette Fluorspar Co. This company deepened the Big Four shaft to 200 feet in 1924; the Big Four mine was then closed and remained idle until the summer of 1944 when Messrs. Perry and Loyd, of Marion, Ky., acquired a lease on the Big Four mine from the Lafayette Fluorspar Co.

Perry and Loyd drove a crosscut southeast from the Big Four shaft to the vein in the Big Four fault (fault 1, pls. 61 and 62) at a depth of 160 feet. From this 160-foot level a drift was driven southwest in the vein (pl. 62), and a raise was driven from the stope above the 160-foot level into the old 100-foot level. The airlift shaft was reopened and equipped for hoisting ore. A drift was driven southwest along fault 1 on the 160-foot level, and another drift was driven northeast along fault 16 from its junction with fault 1. Fluorspar veins in the mine range in width from a few inches to 20 feet; much of the better quality fluorspar is 10–15 feet wide.

In May 1945 work was in progress on the 100- and 160-foot levels, and ore was being hoisted from the Big Four and Airlift shafts.

The Woods shaft (pls. 61 and 62) was sunk about 400 feet southwest of the Big Four shaft to a depth of 100 feet by Perry and Loyd in the fall of 1945 and connected with the old 100-foot level from the Big Four shaft. Most of the mining from this shaft was from the 60-foot level, above which, however, considerable "gravel" fluorspar was extracted.

LARUE MINE

Fohs (1907) states that the LaRue mine (also locally known as the Incline Shaft mine) was opened in 1874 by James and Thomson, but little work was done at that time. In 1911 the LaRue Mining Co. sank the Incline Shaft (pl. 61) in the vein along fault 1 to a depth of 247 feet and drove drifts in the vein approximately 50 feet to the northeast and 50 feet to the southwest. Drifts also were made on the 60-, 90-, 140-, and 200-foot levels. The vein consisted primarily of sphalerite in calcite but contained some fluorspar. Little stoping was done from the drifts in this mine.

After purchasing this property in 1924, the Lafayette Fluorspar

Co. cleaned out and reconditioned the Incline Shaft. No mining was done, however, and this mine has been inactive since 1924.

HAYSHED MINES

Some "gravel" fluorspar has been taken from the Hayshed mines, a group of shallow shafts and propect pits that are along fault 15. None of the openings were accessible in 1944–45, but local miners report that, below the "gravel" fluorspar zone, the fluorspar vein is too narrow to be mined profitably.

ZINC PROSPECTS

The Zinc prospects consist of three shallow prospect shafts near the intersection of faults 16 and 17. None were accessible in 1944–45, and little is known about them. According to A. H. Reed, Sr. (oral communication, 1944), a large body of zinc-carbonate ore was found where a crosscut was driven northwest from one of the shafts cut fault 16. Some fluorspar- and sphalerite-bearing calcite is on the dumps of the shafts.

CARTWRIGHT OR DEER CREEK MINE AREA

According to Fohs (1907) the Cartwright or Deer Creek mine (pl. 61) was opened in 1900 by the Western Kentucky Mining Co., but little development work was done. When Smith (1905, p. 205) visited the mine, two shafts (not identified on pl. 61) had been sunk by the Deer Creek Mining Co., which had acquired the property. One shaft was 70 feet deep in the St. Louis limestone of the footwall of fault 1; no crosscut had been driven to fault 1 from this shaft at the time of Smith's visit. The other shaft, 20 feet south of the first, was sunk 62 feet in St. Louis limestone in the footwall of fault 1. A vein of zinc and lead ore 2 feet wide was cut near the bottom of the shaft and 12–14 feet of limestone containing small quantities of sphalerite, galena, calcite, and fluorite was found in a crosscut between the shaft and the hanging wall of fault 1.

In 1911 the LaRue Mining Co. sank a shaft in the Cartwright mine area to a depth of 90 feet. At a depth of 43 feet a crosscut was driven 30 feet southeast from the shaft to fault 1. At this place fault 1 contained no vein; St. Louis limestone is on the footwall, and black shale of the Golconda or Glen Dean formation is on the southeast, or hanging-wall, side. The fault plane dips 70° SE. At a depth of 90 feet, a crosscut was driven northwest from the shaft into the footwall of fault 1. A mud seam was penetrated, but no vein was found.[1] In 1945 5 large pits or caved shafts and 3 small pits were observed in the Cart-

[1] This information was obtained from a section through this shaft prepared in 1911 by Harold Linck, Engineer for the LaRue Mining Co.

wright mine area; the largest of these is thought to be the shaft sunk in 1911 and is designated as the LaRue Mining Co. shaft (pl. 61).

A caved pit known as the Quartz Wall pit (pl. 61) is about 200 feet southwest of the LaRue Mining Co. shaft. Brecciated rock is common on dumps in the vicinity of this pit, and several outcrops of brecciated and slickensided sandstone are present. On the northwest side of the Quartz Wall pit, a slickensided fault surface of massive sandstone can be seen. This fault is not numbered on plate 61 because it is thought to be a small slip in the hanging wall of fault 1. An alternative interpretation is that the Quartz Wall pit may be on fault 17, which may curve more to the east than shown on plate 61 and join fault 1 northeast of the Quartz Wall pit. Near the Quartz Wall pit a vertical core hole was drilled to a depth of approximately 50 feet; high-grade zinc ore was cut in the hole (A. H. Reed, Sr., oral communication, 1944).

In addition to performing the work described above, in 1911 the LaRue Mining Co. drilled six diamond-drill holes near the LaRue and Cartwright mine areas. The locations of these six holes were not determinable in 1945.

MACER MINE

In 1914 A. H. Reed, Sr. (oral communication), opened the Macer mine by sinking a shaft (pl. 61) to a depth of 100 feet in fault 1 and driving drifts northeast along the fault on the 50- and the 100-foot levels. High-grade fluorspar, ranging in width from 3 to 20 feet and approximately 100 feet in length, was mined from the 50-foot level. This fluorspar lens pinched about 10 feet below the 50-foot level, and the 100-foot level was largely barren. A crosscut on the 100-foot level was driven approximately 100 feet southeast from this shaft in steeply dipping limestone and shale of the Golconda or Glen Dean formation, but no faults or veins were found.

The Macer mine was purchased by the Lafayette Fluorspar Co. in 1924, and no work had been done on the property since that time.

MITCHEL SHAFT

The Mitchel shaft is reported (A. H. Reed, Sr., oral communication, 1944) to have been sunk by W. P. Mitchel to a depth of 100 feet in 1918. A crosscut was driven southeastward to fault 1, and some fluorspar was mined. Because the vein in fault 1 at this point was narrow and was not considered ore, the Mitchel shaft was abandoned.

LEAD AND REED SHAFTS

In 1916 A. H. Reed, Sr., (oral communication, 1944) sank the Reed shaft to a depth of 50 feet, entirely in overburden derived from weathered St. Louis limestone. A crosscut was driven in this overburden about 260 feet southeast to a lead-bearing vein along fault 18—the Commodore fault. At the intersection of the crosscut with this fault, a raise to the surface and a winze were excavated for a combined total depth of 100 feet; this combined raise and winze is known as the Lead shaft. The property was then sold to W. P. Mitchel, who drove a drift southwest along the Commodore fault for about 100 feet in a vein of galena-bearing calcite. Some of the lead ore was mined and sold, but the shaft was abandoned because of the lack of proper milling equipment to treat the ore. The property was sold to the Lafayette Fluorspar Co. in 1925.

RIGGS SHAFT

In 1944 the Riggs shaft was sunk on the John Bebout property to a depth of at least 90 feet, but no vein was found within that depth. The shaft passed through about 40 feet of Caseyville sandstone above 50 feet of Kinkaid limestone. The beds strike approximately N. 30° E. and dip about 35° SE.

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