Babb Fault System Crittenden and Livingston Counties

By GEORGE C. HARDIN, Jr.

FLUORSPAR DEPOSITS IN WESTERN KENTUCKY

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A detailed description of the geology and fluorspar deposits

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FLUORSPAR DEPOSITS IN WESTERN KENTUCKY

BABB FAULT SYSTEM, CRITTENDEN AND LIVINGSTON COUNTIES

By GEORGE C. HARDIN, JR.

ABSTRACT

The Babb fault system in the central part of the Kentucky-Illinois fluorspar field is a northeastward-trending complex of steeply dipping normal faults. It is one of the most highly mineralized fault systems in the field, having yielded more than 175,000 tons of fluorspar.

Movement along the faults displaced the relatively flat-lying limestones, sandstones, and shales of the Chester and Meramec groups of Mississippian age. Movement was principally vertical, and stratigraphic displacements range from a few feet to more than 750 feet. Detailed geologic mapping of the surface and rather extensive underground exploration and diamond drilling have revealed that the system includes at least 18 faults, 6 of them known to contain fluorspar deposits of economic value. Core drilling between 1942 and 1945 indicated 49,000 tons of commercial fluorspar, and an additional 100,000 tons is inferred from geologic data obtained from the drilling. Data obtained from the workings suggest an additional 125,000 tons of fluorspar.

The principal vein minerals are fluorite, calcite, sphalerite, and galena. Quartz, marcasite(?), barite, bitumen, smithsonite, limonite, gypsum, and sulfur occur in minor quantities. Fluorite and calcite were deposited thoughout the period of mineralization, whereas the other hypogene minerals were generally deposited rather late in the period.

Two general types of veins occur in the area; most of the veins are composed of calcite with fluorspar lenses; some veins are mainly fluorspar with little calcite. The two types intergrade. A few bedding-replacement deposits of fluorspar also have been mined in the Babb area.

The widths of the veins were influenced by both structural and lithologic features. Veins generally widen in the steeper segments of the normal faults. In the Babb area the widest veins are composed largely of calcite and may contain very little fluorspar. Sphalerite-rich fluorspar deposits appear to have been localized along fractures that were opened after the main period of fluorite deposition, and the later adjustments probably were partly controlled by cross and subparallel faults that intersect or join the main faults. In at least two places, vein widths are appreciably greater at fault junctions. The lithological character of the rocks to some extent influenced the dip of faults, thereby affecting vein widths. Veins are generally absent or very narrow where shaly gouge is abundant.

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Mining activity started in the Babb area about 1899, and fluorspar has been produced from 5 of the 7 properties that comprise the Babb group. Most of the fluorspar has come from the Kentucky-Babb, Delhi-Babb, and Guill mines, which are in the southwestern half of the mapped area.

INTRODUCTION

LOCATION AND GENERAL FEATURES

The Babb fault system in Kentucky is one of the six fault systems in the Kentucky-Illinois fluorspar field that prior to 1945 produced more than 100,000 tons of finished fluorspar. It includes a group of mineralized faults about 2 miles north of Salem, Ky. Several of the fluorspar properties in the area were owned formerly by the Raymon Babb heirs, hence the mines along this fault system are known locally as the "Babb" mines. Prospecting and mining activity in the Babb area apparently started about 1899, and the mines along this fault system are among the most productive in Kentucky. It is estimated that more than 175,000 tons of fluorspar has been produced from the area.

Like most of the Kentucky-Illinois field, the area in the vicinity of the Babb fault system is characterized by rolling hills, wide valleys, and moderate relief, the maximum being about 175 feet. The location of the area is shown on the index map (fig. 1). It is reached by a gravel road that leaves U. S. Highway 60 at Salem, Ky., and extends approximately north about 2 miles. Most of the fluorspar from the Babb mines was transported by truck to Marion, Ky., a distance of 13 miles, then shipped to market via the Illinois Central Railroad.

FIELD WORK

EARLIER WORK

Norwood (1876) studied the Kentucky fluorspar district in 1876 but did not describe the Babb area. The Babb area was first mentioned in geologic literature by Smith (1905, p. 201–202) who discussed briefly the Raymon Babb, Tom Babb, Morse, and Guill prospects. In Smith's descriptions, the Raymon Babb refers to two of the shallow pits just southwest from the Eagle No. 1 shaft on the Eagle-Babb property; the Tom Babb refers to two of the now caved pits just north of the Bachelor shaft on the Delhi-Babb property; the Morse refers to a shaft that was apparently near the Kentucky No. 1 shaft but could not be found by the writer; and the Guill refers to two of the pits southwest of the Guill No. 1 shaft. At the time of Smith's study, fluorspar had been shipped only from the Raymon Babb and Guill prospects. These prospects were then considered to be on a single fissure, but Smith attempted no specific interpretation of the geologic relations.

Currier (1923, p. 115) mentioned the Bachelor mine (then known

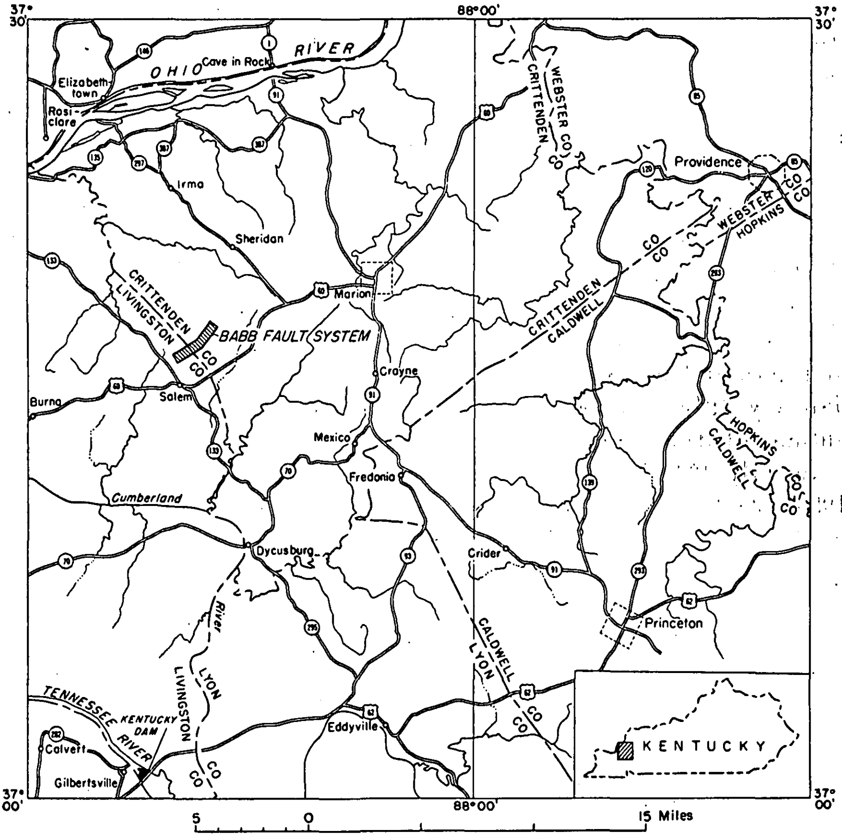

FIGURE 1.—Index map of western Kentucky showing location of the Babb fault system in Crittenden and Livingston Counties.

as the Two Bachelors or Babb mine) on the Delhi-Babb property, and the Guill mine. Both mines were inaccessible at the time of his visit.

In 1922–23 Weller (1927, p. 106–107; 1951) studied the geology in this area and, mainly on surface evidence, mapped 6 faults, 5 of which he designated Nos. 21, 22, 23, 25, 27. The sixth fault, a cross fault, was not numbered. The Babb group of mines is located on Weller's fault 22, which is actually a complicated fault system rather than a single fault. Weller's stratigraphic designations have been followed for the most part by the writer.

RECENT GEOLOGIC AND EXPLORATORY WORK

The Babb fault system was one of the areas in the Kentucky-Illinois field specifically recommended for detailed study by L. W. Currier and J. S. Williams as a result of their preliminary investigation of the fluorspar situation in June 1942. During the summer of 1942, O. M. Bishop of the U. S. Bureau of Mines, also visited the area and prepared a confidential engineering report on the mines.

The Babb fault system was one of the first areas to be mapped and studied by the Geological Survey field party stationed in Kentucky from 1942 to 1946, and the results obtained are described and interpreted in this report. Most of the mapping was done in September 1942 by G. C. Hardin, Jr., W. R. Thurston, R. D. Trace, and H. E. Rothrock. A preliminary report with maps was prepared in June 1943 and released for public inspection in open files in August 1943. The surface map (pl. 1) was extended somewhat in November 1944 by G. C. Hardin, Jr., R. T. Russell, and D. A. Warner. Underground mapping, study of drill cores, and general surface and underground studies of the area were made concurrently with drilling by the Bureau of Mines and private companies and continued intermittently until January 1945. Some data obtained from private drilling in the autumn of 1945 were added by H. J. Klepser of the Geological Survey.

In July 1943 the U. S. Bureau of Mines (Swanson and Starnes, 1950) started to explore by core drilling in some of the promising localities recommended by the Geological Survey in its preliminary report. The drilling was under the supervision of A. S. Swanson [1] until October 1943; from then until the completion of the project in May 1944, the work was under the supervision of X. B. Starnes.[1]

Twenty-eight holes totaling more than 8,000 feet in length were drilled (see pls. 1 and 2). According to the Bureau of Mines, data from this drilling indicated that there was 49,000 tons of fluorspar ore in this area. The Geological Survey has inferred from the drilling data that there is 100,000 tons of fluorspar in addition to this indicated ore. Data obtained from the workings suggest that additional reserves totaling approximately 125,000 tons of fluorspar in the measured, indicated, and inferred categories exist in the area.

The present geologic report is based upon surface, underground, and drill-core data and almost continuous observation over a period of more than 2 years. In contrast to the 6 faults previously believed to cross the area, recent study has revealed the presence of at least 18 faults, 6 known to be well mineralized. The fault system strikes approximately N. 50° E. and crosses the road from Salem to Irma 1.8 miles north of Salem, Ky. The deposits are being developed in active mines along the strike of the fault system for 1.4 miles.

Properties described in this report

Name of property	*Owner or lessee of mineral rights in 1949*
Guill	Inland Steel Corp.
Kentucky-Babb	Pennsylvania Salt Manufacturing Co.
Delhi-Babb	Ozark-Mahoning Co.
Eagle-Babb	Alcoa Mining Co.
Barnes	Inland Steel Corp.
E. Champion	Eli H. Brown.
Gid Taylor	Do.

[1] Mining engineer, U. S. Bureau of Mines.

The Guill and Kentucky-Babb properties are in Livingston County, and the other five properties are in Crittenden County. They are listed from southwest to northeast along the fault system.

In order to facilitate location of points in the Kentucky part of the fluorspar field, a system of coordinates was established. The U. S. Geological Survey bench mark set in the concrete sidewalk approximately 40 feet west of the southwest corner of Grassham's garage at the corner of North Hayden and West Broadway Street (US 60) in Salem, Ky., was chosen as the zero point, and coordinate lines were extended north, south, east, and west from this point. The coordinates used on the maps of the Babb area (pl. 1) refer to this point.

ACKNOWLEDGMENTS

Thanks are due to the operators in this area for their splendid cooperation, particularly to Mr. Robert Frazer, operator of the Kentucky-Babb property, and to Mr. L. F. Hearne with whom the geologic problems at the Eagle-Babb property were discussed in detail. Suggestions made by Prof. J. M. Weller in the field influenced the interpretation of the surface geology in several places. Mr. A. H. Reed, Sr., consulting mining engineer and geologist, furnished information about the inaccessible workings of the Delhi-Babb mine and certain historical information and property maps. The problems of ore localization were discussed with Prof. H. E. McKinstry, who offered helpful suggestions. Mr. C. S. Ross and Miss J. J. Glass checked the petrographic work on thin sections of wall rock and fluorspar. Mr. J. S. Williams and later Mr. R. E. Van Alstine supervised the Strategic Minerals Investigation program on the Kentucky-fluorspar project and, with the help of Miss Helen Duncan and Mr. C. P. Ross, assisted the author in collecting and compiling the data included in this report, and in preparing the report for publication.

GEOLOGY

The rocks exposed in the Babb area are limestones, sandstones, and shales of the Meramec and Chester groups of Mississippian age. No igneous rocks are known to occur in the Babb area. The sedimentary rocks are essentially horizontal but are broken by at least 18 normal faults. In general the fault pattern in the Babb area consists of several minor subparallel and cross faults associated with one main fault (fault 1, pl. 1) that splits into a complex series of 9 faults in the northeastern part of the area.

SEDIMENTARY ROCKS

The formations in the Babb area include the sequence of beds from the St. Louis limestone to the Palestine sandstone, all of Mississippian age. Over most of the area exposures are very poor, and few outcrops are available for study except in the northern part of the mapped area. Detailed information on the thickness and lithologic character of most formations was obtained from drill cores. Complete sections of the Hardinsburg, Golconda, and Cypress formations were not penetrated in the drilling, however, and none of the drill holes cut the Palestine sandstone, the youngest formation exposed in the Babb area.

The St. Louis limestone, the oldest observed formation in the area, is exposed only in mine workings. It is a medium-gray, fine- to medium-grained limestone containing blue-gray chert nodules. These lithologic features are typical of the formation throughout the region.

The Levias and Fredonia limestone members of the Ste. Genevieve limestone are mainly whitish-gray and oölitic, though they contain some light-gray sublithographic beds. The Fredonia member is about 200 feet thick in the Babb area, whereas the Levias member is not known to exceed 20 feet in thickness and may be entirely absent in some localities. The Rosiclare sandstone member, which separates the two oölitic members of the Ste. Genevieve limestone, is generally very fine grained and calcareous. It ranges from 10 to 15 feet in thickness. The rather massive Rosiclare sandstone member is exposed in a small sump northeast of the Guill No. 3 shaft. In holes drilled from the footwall side of fault 1 on the Eagle-Babb property, a sandy zone penetrated near the surface is considered to be Rosiclare. Although this sandy zone was not recognized in sinking the Eagle No. 2 shaft, it is probably present but not readily distinguishable. An oölitic limestone which may be either the Levias or the Fredonia member underlies the Renault formation in this shaft. As the Rosiclare sandstone member is known to be present elsewhere in the area, the oölitic limestone is believed to be the Levias member.

A sequence of limestone and shale formations alternating with sandstones constitutes the Chester group in the region. Several of the sandstones are very similar lithologically, and it is difficult, if not impossible, to distinguish some of the limestone and shale formations unless their characteristic fossils are found. The section of Chester formations that occur in the Babb area and the thicknesses observed are as follows:

	Feet
Palestine sandstone, partly eroded	30
Menard limestone	70
Waltersburg sandstone	15
Vienna limestone	50
Tar Springs sandstone	115
Glen Dean limestone	90
Hardinsburg sandstone	95–105
Golconda formation	120–130
Cypress sandstone	90–110
Paint Creek shale	10
Bethel sandstone	45
Renault formation	70

The Renault formation is composed of medium- to light-gray, commonly medium-grained, crystalline limestone containing some dark greenish-gray shale beds. The light-gray limestone beds are commonly slightly oölitic, and the shales are generally highly fossiliferous.

The Paint Creek shale is a thinly bedded medium-gray slightly sandy shale.

The Golconda, Vienna, and Menard formations consist of thinly bedded black shales and dense dark-gray limestones. The upper 25–30 feet of the Vienna formation is entirely black shale, and the lower 25 feet is dark dense limestone. In general the limestones of the Vienna and Menard formations are denser than the limestone of the Golconda, the latter formation also being distinguished by its greater thickness and by diagnostic fossils. In small exposures, however, if no diagnostic fossils are found, it is sometimes very difficult to distinguish among the three formations. Fortunately both the Golconda and Menard formations are very fossiliferous.

The Glen Dean limestone consists of light- to medium-gray medium-grained crystalline limestone with relatively thin beds of medium-gray shale. It is distinguished from the other limestone and shale formations in the area by its lighter color, greater crystallinity, and the presence of many small fossils. The Glen Dean contains very little dark limestone.

The Bethel, Cypress, and Hardinsburg sandstones cannot be distinguished by physical appearance. These three formations consist of light-gray medium-grained massive sandstone with a few thin shaly beds. Neither the Bethel nor the Hardinsburg sandstone contains appreciable quantities of shale, and no shale was observed in the Cypress sandstone in those places where it is exposed or in the drill cores. The sandstones are generally intensely silicified in the vicinity of the faults. As these three formations are essentially without fossils and cannot be differentiated on lithologic characteristics, positive identification depends upon determination of the underlying or overlying limestone and shale formations.

The Tar Springs sandstone consists largely of black shale, black sandy shale in thin layers alternating with bands of light-gray fine-grained sandstone, and thinly bedded fine-grained sandstone. The alternating beds of shale and sandstone generally are about a quarter to half an inch thick, and the effect of differential compaction is very well shown by the lenticularity of the beds.

The Waltersburg sandstone consists of fine-grained medium- to dark-gray sandstone interbedded with black shale. Both the upper and the lower contacts of the Waltersburg are gradational through a distance of 5 feet or more.

Only the lower part of the Palestine sandstone is exposed on some of the hills in the northern part of the Babb area, where it forms weathered iron-stained outcrops.

STRUCTURE

The Babb fault system is part of the same northeastward-trending faulted zone that contains the Commodore fault system (Weller, 1927, p. 104). The geology of much of the area along these fault systems has not been mapped in detail, but the structure of the whole zone is probably as complicated as the parts already mapped. As more detailed geologic work is done it becomes increasingly evident that the structure of the fault system is much more complex than was formerly believed. Many of the faults originally mapped as long simple fractures are really complex zones composed of several associated faults.

The main Babb fault (fault 1) strikes in general N. 50° E., but the associated subparallel and cross faults strike from N. 25° E. to N. 70° W. (See pl. 1.) The displacement on fault 1 at the point of maximum dislocation is about 750 feet. The stratigraphic displacement on auxiliary faults, however, ranges from a few feet to as much as 500 feet.

Outcrops are very poor in the area, so it is impossible to determine the detailed structure from surface exposures. The inaccessibility of the upper workings of several of the mines renders information unavailable that would be very helpful. Recent diamond drilling has done much to clarify the structure, however, and faults 3, 6, 7, 9, and 15, which were penetrated by drills, could have been found only by drilling or underground exploration.

The footwall block of the Babb system, that is, the block southeast of all mapped faults, consists mainly of the Ste. Genevieve limestone. In the northeastern and southwestern parts of the area, the higher hills are capped with Bethel sandstone, and the Renault formation forms the slopes. Exposures of the Ste. Genevieve limestone are excellent in the sinkhole area northeast of the Howard mine on the Barnes property. A few small outcrops of the Renault formation also are present in the same general locality.

On the northwest side in the hanging-wall block of the system (see pl. 1) the Glen Dean, Tar Springs, Vienna, Waltersburg, Menard, and Palestine formations are at the surface. Relatively good exposures of several Chester formations are found at the northwest end of the area near fault 14.

The main faults in the region were formed contemporaneously, though some of the branch and cross faults may have resulted from later adjustments along the faulted zones. Most of the dislocation occurred before the fluorspar veins were formed, but some of the movement was postmineral. The movement was essentially vertical. Stratigraphic separation is commonly of considerable magnitude;

horizontal offset is negligible; dragged beds dip in directions normal to the strikes of the faults; and wherever slickensides were observed underground, they are vertical or nearly so. In the Babb system, the stratigraphic displacement between the Ste. Genevieve limestone in the footwall and the Menard limestone in the hanging wall is approximately 750 feet. In many places this entire displacement was along fault 1, but in others the displacement was distributed among as many as five step faults. It is difficult to establish the continuity of some northeastward-trending faults through the structurally complex areas where auxiliary fractures branch from or rejoin the main faults and where cross faults interrupt the primary trends. In mapping the faults, therefore, segments that have the same general alinement on either side of junctions or intersections were arbitrarily identified as parts of the same fracture and are labeled so on the map (pl. 1).

Extreme brecciation accompanied the faulting. The rocks in the hanging-wall blocks were especially affected, and the broken zones bordering the faults are as much as 75 feet wide. The footwall blocks were generally more stable and are less broken. Considerable quantities of gouge are associated with the breccia in many places.

Geologic data for mapping the faults were obtained from several sources: underground workings that follow or cut the faults; diamond-drill cores; exposures of fault walls on the surface or in caved pits and shafts; outcrops or large boulders of highly brecciated, silicified, and slickensided sandstone (material of this type occurs only in the immediate vicinity of faults in this district); and stratigraphic studies that revealed juxtaposition of formations not in normal sequence. Many details are omitted in the description of the faults inasmuch as the information is presented graphically by maps and illustrations. Some specific details, however, are noted in the discussion of individual properties (pp. 28–36).

Fault 1 is traceable throughout the southwestern part of the area by rather extensive mine workings. South of fault 12, which apparently offsets fault 1, the presence of fault 1 is indicated by large exposures of silicified brecciated sandstone that is probably in place. On the Delhi-Babb property, the footwall of this fault is well exposed in the caved area between the Croft and Incline shafts. In that locality the fault dips 75°–80° NW. The sandstone hanging wall is exposed about 200 feet southwest of the Eagle No. 1 shaft in a caved pit where the fault is almost vertical. At the Eagle No. 2 shaft, a crosscut on the 200-foot level was driven southeast to fault 1 (pl. 4, sec. *E–E′*). At the place where the crosscut penetrated the fault, fault 1 lies within the Fredonia limestone member of the Ste. Genevieve limestone. The breccia zone is only 2 or 3 feet wide and contains a calcite vein 6–8 inches wide.

The location of fault 1 is uncertain in the area north of the Howard shaft on the Barnes property between coordinates 5,000 E. and 6,000 E. (see pl. 1). On the E. Champion and Gid Taylor properties and northeastward through the Barnes property, a fault was traced both by outcrops and by very large boulders of intensely brecciated silicified sandstone. This fault is inferred to be the northeast extension of fault 1, although it is possible that this fault dies out southwestward in the Ste. Genevieve limestone and is not actually continuous across the southern part of the Barnes property as shown on plate 1. If this interpretation is correct, fault 16 should be called fault 1 in this part of the area, and the fracture now labelled fault 1 should be given a different number. No outcrops were found in the southern part of the block between faults 1 and 16. If this alternative interpretation of the structure is found to be correct, the Renault and Ste. Genevieve formations must be present in this locality.

A small pit has been sunk in steeply dipping massive sandstone near the northeast end of the area mapped. Fault 1 passes within a few feet of this pit.

Fault 1*A*, a small fracture that diverges from the main fault, is exposed in the Kentucky-Babb mine workings. The fluorspar vein is found along fault 1*A* for a short distance into the hanging-wall block where it pinches.

Fault 2 diverges from fault 1 at some point between drill holes 1 and 3 on the Eagle-Babb property. It strikes northeastward and is offset slightly by fault 5. Fault 2 does not crop out in the area, but its presence is indicated by abundant brecciated sandstone along the hill near the Howard shaft on the Barnes property and by an exposure of highly dipping sandstone in a gully on the next hill north of the Howard shaft. The main mine workings from the Eagle No. 2 shaft and the Howard shaft are in this fault. The fault was cut by several drill holes on the Eagle-Babb and Barnes properties, and some fluorspar was found in it. The cross fault 2A is between drill holes 3 and 4 on the Eagle-Babb property, and although its exact position is uncertain, it lies between the Golconda and Tar Springs formations.

Fault 3 does not crop out and is known solely from diamond drill holes. It is sparsely mineralized and relatively short. Fault 4 diverges from fault 1 north of the Bachelor shaft on the Delhi-Babb property and joins fault 2 north of the Howard shaft. The fault does not crop out but has been cut by several diamond drill holes and a crosscut on the 125-foot level from the Eagle No. 1 shaft. Some fluorspar was found in these drill cores. Fault 5 is a cross fault known only from the underground workings from the Eagle No. 2 shaft. This fault slightly offsets fault 2, and the brecciated area near the intersection is highly mineralized with fluorspar.

Faults 6, 7, and 9 are not apparent at the surface and are known only from drill cores. Fault 8 is a cross fault lying between drill holes 31 and 38 on the Guill property. The strike of the fault is indicated by an outcrop of dipping Tar Springs standstone near the junction with fault 1.

Fault 10 shown on the Kentucky-Babb property does not crop out and has not been penetrated in drilling. An outcrop of Bethel sandstone on the hill southwest from the Kentucky No. 3 shaft indicates some displacement between that outcrop and the Kentucky No. 4 shaft, which was started in the Ste. Genevieve limestone. The C. Babb shaft was started in sandstone, and the limestone and shale on the dump at this shaft apparently came from the Renault formation. Fault 10, therefore, is inferred to be present here to account for the juxtaposition of the Bethel and Ste. Genevieve formations. The strike of the fault is uncertain but is suggested by the topography.

Fault 11 is a subparallel fault east of fault 1 between the Croft and Bachelor shafts on the Delhi-Babb property. This fault does not crop out, but its presence is indicated by the exposures of Bethel sandstone in the block between fault 1 and the Ste. Genevieve limestone of the footwall. Several drifts have been driven along this fault from the Incline and Croft shafts, and considerable fluorspar has been mined from it. The sandstone block between faults 1 and 11 is highly brecciated and contains many fractures filled with fluorspar.

Fault 12 offsets fault 1 on the Guill property near the southwestern end of the map area. Fault 12 is not exposed in the area mapped but was identified southwest of the area. It was cut by drill hole 39 on the Guill property. The fault is not mineralized in the Babb area, but the Eagle Fluor Spar Co. mined some ore from it southwest of the area near the point at which the road from Salem to Lola crosses the fault.

Fault 13 lies within the Menard limestone on the hanging-wall side of the system and is not apparent at the surface. It is exposed underground where it diverges from fault 1 in the northeastern end of the Kentucky-Babb mine workings (see pl. 2). The stratigraphic section in the New Delhi shaft is displaced about 50 feet with reference to the section exposed in mine workings from the Croft shaft.

Fault 14 is not exposed but was cut by a drill hole. Near the point where the fault leaves the area mapped, the Waltersburg and Tar Springs sandstones crop out about 200 feet apart; the fault is shown between these outcrops.

Fault 15 on the Barnes property was cut by two drill holes, but indications of it at the surface are lacking. The trace was plotted from topographic evidence.

Fault 16 apparently diverges from fault 1 east of the Howard shaft and rejoins fault 1 near the northern end of the area mapped. This fault crops out on the hill northwest of the Gid Taylor and E. Champion property corner, and its northeasterly trend is marked by abundant silicified brecciated sandstone. Northeast of these outcrops the course of the fault is not so well defined. If the strike observed persists northwestward, fault 16 should join or be cut off by fault 1.

ORE DEPOSITS

GENERAL FEATURES OF THE FLUORSPAR DEPOSITS

A large tonnage of fluorspar has been produced from the mines of the Babb fault system. A small quantity of galena also has been recovered as a byproduct in the milling of the fluorspar. Lack of adequate milling facilities for selective flotation in the district prohibited the utilization of ore containing fine-grained sphalerite that is found in some places. The small quantities of sphalerite and galena have been considered objectionable in the ore because of the lower price received when the finished product is sold for metallurgical-grade fluorspar.

In the Babb area most of the fluorspar has come from deposits in veins, but the Guill property and the southwestern part of the Kentucky-Babb property have yielded some so-called gravel spar, and elsewhere a little fluorspar has been mined from bedding-replacement deposits. The term "gravel spar" refers to residual fluorspar concentrated in the overburden by weathering and removal of the gangue minerals and wall rock.

The vein deposits have not been mined to any great depth, and only deeper exploration will determine the ultimate extent of the fluorspar ore. The fluorspar is believed to have been deposited by ascending hydrothermal solutions derived from a deep-seated magmatic source. There is evidence of fissure filling, wall-rock replacement, and replacement of minerals deposited earlier.

The attitude of the Babb fault system apparently exercised control over the width of the veins. In general where the faults steepen, the veins become somewhat wider, but the localization of fluorspar bodies cannot be correlated with vein widths because the veins may be composed almost entirely of calcite. The sulfides, which are distributed sporadically in faults 1 and 2, were deposited during the late stages of fluorite mineralization in fractures that were formed still later and were related to the cross and subparallel faults. The lithology of the wall rocks influenced the localization of the fluorspar along the faults, for the favorable wall rocks are competent rocks that are found only in certain formations.

MINERALOGY

The mineralogy of the fluorspar deposits is relatively simple. Fluorite, calcite, sphalerite, and galena are the most abundant minerals. Barite, marcasite (?), quartz, and bitumen are less common. Limonite, gypsum, smithsonite, and sulfur, are present in small quantities in the oxidized parts of the veins.

The following paragenetic sequence is based on underground observations in the Babb area and preliminary laboratory studies of specimens from the veins. Except for some early-formed quartz, calcite seems to have been the first vein mineral deposited, and its deposition continued throughout the period of mineralization. Fluorite deposition started early and was relatively persistent; some of the fluorite was deposited very late. The deposition of galena and sphalerite started sometime after the first fluorite was formed. The quartz and bitumen are of two generations; one was formed early in the mineralization period, the other late, but both are contemporaneous in part with the fluorite. Marcasite(?) and barite were deposited late. Smithsonite, limonite, gypsum and sulfur were formed as alteration products.

Calcite replaces limestone; fluorite replaces calcite, limestone, and, to a slight extent, quartzite; quartz replaces fluorite, calcite, and sulfides; sulfides replace calcite, limestone, quartz, and fluorite; and barite replaces fluorite and calcite. These observations agree in general with those of Currier (1920; 1923, p. 59–71) and Bastin (1931).

ORE MINERALS

FLUORITE

The most abundant ore mineral is fluorite (CaF_2). Much of the fluorite taken from the Kentucky-Babb mine has been clear or white, and considerable amounts of optical fluorite and almost chemically pure fluorite have been marketed. The fluorite in the other mines and to some extent in the Kentucky-Babb mine is generally light brown or clear, but fluorite having various shades of purple, yellow, and white, also occurs. The latest-formed fluorite, with the exception of some light-colored cellular material, is deep purple, and purple fluorite commonly is found in thin veinlets in the wall rock near the margins of the veins. Because of its marginal position the occurrence of purple fluorite is considered by some to indicate the beginning of a pinch in the vein.

Cubic crystals of purple and colorless fluorite are common in vugs in the vein material and the country rock. Many of the larger crystals contain inner phantom crystals indicating at least two distinct periods of growth. In the specimens noted, both the phantom crystal and the outer crystal had forms identical in minute detail. These shadow crystals may be composed of fluorite of different color or may be outlined by bituminous matter that accumulated before the second period of growth commenced. Some of the cubic crystals are incrusted with small crystals of calcite, sphalerite, and barite.

Etched fluorite crystals are common. In the Howard mine, several crystals incised with a complex network of small trenches about 1 millimeter deep were noted. Some of these trenches follow cleavage directions in the crystals, but others cut across and parallel the crystal faces of the cubes. Possibly a system of incipient fractures determined the orientation of these trenches; the etching probably was accomplished by the action of meteoric waters containing sulfuric acid derived from the oxidation of marcasite(?) and other sulfides.

Part of the colorless fluorite in the Kentucky-Babb mine contains small crystals of galena. Some of the fluorite is intergrown with sphalerite, and crystals containing inclusions of a mineral thought to be marcasite are frequently found.

A small amount of light-colored cellular fluorite was deposited as a coating on purple fluorite crystals. This cellular fluorite is believed to be supergene, probably having been dissolved and redeposited by circulating meteoric waters.

Bedding-replacement or "coon-tail" fluorspar ore occurs on the 135- and 200-foot levels of the Eagle No. 2 mine and has been noted on the 100-foot level from the Bachelor shaft. The term "coon-tail" is derived from the resemblance of the ore in cross section to the banded tail of a raccoon. The ore is composed of alternating light-colored bands of relatively pure fluorite and dark bands of fine-grained fluorspar containing fluorite, quartz, calcite, and locally sphalerite. The light-colored bands as a rule are fluorite combs—two sets of crystals growing toward each other from opposite directions—whereas the dark bands may be rich in sphalerite, thus forming zinc-rich coon-tail ore, or free of sphalerite in the zinc-free variety. The bands range in width from an eighth to half an inch.

SPHALERITE

Next to fluorite, sphalerite (ZnS) is the most abundant ore mineral. It is bright reddish-brown and occurs in veinlets and masses intergrown with calcite and fluorite and finely disseminated through them. It is commonly found near the margins of the fluorspar veins. Sphalerite also fills small fractures in the brecciated wall rock or is disseminated through and replaces the limestones. Most sphalerite is very fine grained; however, small crystals, generally distorted tetrahedra, were found at the Eagle No. 2 mine. Although most of the sphalerite occurs marginally, in some places it is finely disseminated throughout the fluorspar and constitutes as much as 25 percent of the total vein material. In the dark bands of the zinc-rich coon-tail ore, it is one of the main constituents, generally forming 5 to 15 percent of the ore.

GALENA

With the exception of sphalerite the only conspicuous sulfide mineral is galena (PbS). It is commonly found in the fluorspar in small masses and cubes. Some fluorite crystals contain inclusions of galena.

OTHER MINERALS

The most abundant mineral in the veins is milky-white to gray massive calcite ($CaCO_3$). It also fills many small fissures adjacent to the veins and replaces the country rock. Strongly brecciated zones generally contain considerable quantities in irregular masses. The calcite is, in general, coarsely crystalline and massive and commonly contains veinlets of fluorite and sphalerite. Distorted crystals, however, are commonly found in vugs.

Fine-grained quartz (SiO_2) and chalcedony are disseminated through the wall rock, but only one quartz vein is known in the Babb area. This vein is in the St. Louis limestone (footwall of fault 1) near the bottom of the Eagle No. 1 shaft. It is composed of massive white quartz intergrown with calcite and is about 18 inches wide at the bottom of the shaft, but pinches out at a point about 3 feet above. In the light-colored bands of coon-tail ore several small doubly-terminated clear quartz crystals a fourth to half an inch long were found between combs of fluorite, and perpendicular to the banding.

A pale bronze-yellow sulfide mineral believed to be marcasite (FeS_2) occurs sparsely in the veins and wall rock. It forms small veinlets and aggregates or coats fluorite crystals. In the Kentucky-Babb mine, it coats slickensided calcite surfaces. Infrequently, this mineral forms small clusters of crystals in comb structure. As no X-ray or mineragraphic studies have been made of this mineral, the possibility remains that it may be chalcopyrite or pyrite. Grogan (oral communication, November 1944) reports that sulfide inclusions in some fluorite crystals from Illinois give an X-ray diffraction pattern for chalcopyrite.

Barite ($BaSO_4$) was probably the last hypogene mineral deposited. It is not common but locally occurs in massive aggregates and small tabular crystals coating fluorite. It is white to light gray and generally somewhat granular. Barite replaces fluorite and calcite to a small extent.

A small amount of black sticky bitumen coats many calcite and fluorite crystals.

Smithsonite ($ZnCO_3$), limonite ($2Fe_2O_3.3H_2O$), and gypsum ($CaSO_4.2H_2O$), are found in the oxidized upper parts of the veins. The smithsonite is in massive and cellular cream-colored to gray aggregates and is commonly associated with the sphalerite from which it was derived. Limonite is formed by the oxidation of the mineral believed to be marcasite, and the two minerals are commonly associated. Gypsum occurs as tabular crystals that probably were deposited by circulating ground water.

Mine waters pouring through drill holes, cracks, and larger fissures in the walls of drifts are depositing small quantities of light yellow sulfur.

THE VEINS, ORE BODIES, AND WALL ROCK

The fluorspar veins in the Babb area are fissure fillings and in part replacement deposits along the faults. Vein widths range from 2 inches to approximately 30 feet and probably average 8–10 feet. The veins in the area are of two general types: those that are composed principally of calcite and are fairly continuous, and those in which calcite is much less prevalent and the ore is in pockets. In the first type the fissures are thought to have been filled first with calcite, then reopened by later fracturing that permitted the entrance of fluorine-bearing solutions. Deposits of the second type are thought to have been largely the result of replacement of the wall rock by fluorite. Throughout the southwestern part of the area, the vein in fault 1 is practically continuous. High-grade fluorspar lenses occur within the wider calcite vein, and fluorite replacing calcite is very common. In the northeastern part of the area, the vein in fault 2 seems to have been formed principally by replacement of the wall rock. The ore pinches out in short distances and in only a few places is continuous for more than 250 feet. The two types of veins are illustrated in plate 2. The map of the 450-foot level of the Kentucky-Babb mine illustrates the first type, and the map of the 200-foot level of the Eagle-Babb mine, the second.

The grade of fluorspar varies not only from one ore body to another but also within a specific ore shoot. Some ore from the Guill, Kentucky-Babb, and Delhi-Babb mines has been sold as acid-grade fluorspar (98 percent CaF_2 and less than 1 percent SiO_2) after being washed in a log washer, whereas other ore contains high percentages of sphalerite and calcite. Because of the wide range in composition, it would be necessary to take many closely spaced samples in order to determine accurately the grade of fluorspar in any one mine. In general the crude ore mined has averaged about 50 percent of CaF_2.

Though vein widths probably average 8–10 feet, ore widths probably do not average more than 5 feet. Ore bodies as much as 23 feet wide, however, have been mined. Fluorspar occurs throughout the veins in lenses that range in length from 15 to 350 feet but generally average about 200 feet. Because of the great variation in length and width of the veins (see pl. 3), it is difficult to make any generalization on the size of ore bodies.

As far as is known, the veins persist in depth. In January 1945 the deepest exploration in the area was the 550-foot level from the Kentucky No. 3 shaft. The vein on this level is 25–30 feet wide but contains much calcite. Between the 550-foot level and 450-foot level, however, the fluorspar is 3–10 feet wide and of high grade.

On the Kentucky-Babb property the fluorspar lenses generally have been found near the hanging wall of the fault; however, ore bodies are not confined to this section of the vein. Two lenses of fluorspar were cut by drill hole 35, one in the middle of the 30-foot vein and the other near the hanging wall.

The distribution of sphalerite in the veins is sporadic. In some places the veins contain as much as 25 percent of sphalerite, whereas other segments are essentially zinc-free. It is believed that the distribution of sphalerite is controlled to some extent by the cross and subparallel faults. In fault 1 southwest of its junction with fault 8, the fluorspar contains little or no sphalerite (see pls. 1 and 3). In the segment between fault 8 and the most southwesterly point at which fault 10 leaves fault 1, the ore contains 5–25 percent of sphalerite. Northeast of this point where fault 10 leaves fault 1, the fluorspar is practically zinc-free, and very little sphalerite occurs in the wall rock. In the section of the fault zone between the southwestern junction of faults 1 and 13 and the northeastern junction of faults 1 and 11, the fluorspar contains 3–15 percent of sphalerite, and the wall rock is impregnated with sphalerite for several feet on each side of the vein. Along fault 1, between its northeastern junction with fault 11 and its junction with fault 2, the vein material is essentially zinc-free. In the Eagle No. 2 mine, the fluorspar in fault 2 contains 3–10 percent of zinc, but the fluorspar in fault 5 northeast of its junction with the northeastern segment of fault 2 is practically zinc-free (see pl. 2). The change in zinc content is very abrupt at the junction of the two faults. On the Barnes property at the northeast end of the area studied, the fluorspar below the oxidized zone contains 3–8 percent of zinc. The deposition of sphalerite and the late-formed fluorite with which it occurs is believed to have been simultaneous.

Galena commonly occurs in small pockets distributed at irregular intervals throughout the vein material.

The vein walls consist of strongly brecciated and drag-folded rocks of the enclosing sedimentary formations. The shales of the Chester formations in the hanging wall generally are strongly drag folded and contributed to the formation of abundant gouge. In the mines, very little wall rock can be seen because of the abundant calcite gangue, gouge, and fault breccia. Shaly quartzitic sandstones of the hanging wall have been dragged more strongly than interbedded massive limestones and in many places lie between the fault and the limestones.

Much silica, both as fine-grained quartz and the cryptocrystalline variety, was seen in thin sections of the limestone wall rock. The quartz is in small doubly terminated crystals and clusters of small distorted crystals replacing the limestone and in crystal aggregates filling small fissures. Cryptocrystalline quartz (chalcedony) occurs in small masses replacing limestone and filling openings in it. It is estimated that 5–20 percent of silica has been added to most limestones within 10 feet of the veins.

Sandstones near the veins have been converted to quartzites. The sandstone grains interlock to a considerable extent, but secondary silicification appears to have been of more significance than pressure in the conversion of sandstone to quartzite. Fine-grained quartz and chalcedony were added along fractures in the sandstone as well as in the interstices between the grains. Silicification seems to have occurred before some of the fluorite was deposited because silica veinlets are cut by fluorite veinlets in many places.

LOCALIZATION OF ORE BODIES

The effects of both structural and lithologic control are apparent in the localization of veins and ore shoots along the faults of the Babb system. As has been noted in other mining districts, the attitude of the fault plane is one of the main factors controlling vein widths. Cross faults were effective in the localization of ore at junctions and to some extent controlled later movement along certain segments of the main veins. Lithologic control might also be regarded as stratigraphic control inasmuch as the formations have rather characteristic lithologic features.

STRUCTURAL CONTROL

CURVED FAULT PLANES

Studies of the structural features of ore deposits have shown that commonly where normal faults steepen, greater vein widths may be found along the steeper segments (McKinstry, 1941; Newhouse, 1942; Emmons, 1943). This condition is found in the Babb area. In most places where sufficient data were available to determine the dip of the fault plane, the vein was definitely wider in the steeper segments. Much of the early prospecting may have been unsuccessful because the shallow shafts were not deep enough to penetrate the steeper segments of the faults where the ore was localized. The localization of fluorspar bodies cannot be correlated with vein widths, however; some of the widest veins are composed almost entirely of calcite. The fluorine-bearing solutions evidently were introduced after the faults were reopened subsequent to the main calcite mineralization, and the fluorspar bodies were localized along new fractures principally within the calcite.

Veins increasing in width as the fault plane steepens were observed at the Croft shaft on the Delhi-Babb property and at the Eagle No. 2 shaft on the Eagle-Babb property (see pl. 4, secs. *C–C′* and *E–E′*). At the Croft shaft, the vein dips 80°–85° NW. from the surface to a depth of 350 feet where it steepens and becomes essentially vertical. Through this interval the vein ranges from 1 to 15 feet in width and averages between 5 and 6 feet, whereas on the 400-foot level, where the vein is vertical, vein widths range from 3 to 23 feet and average 10 feet. At the Eagle No. 2 shaft, the vein dips 80°–85° NW. to a depth of about 160 feet where it becomes almost vertical. No vein was found in the fault above the 160-foot depth, but where the fault plane steepened, 8 feet of fluorspar ore was found on the 200-foot level; a drill hole penetrated 12 feet of fluorspar ore at a depth of 325 feet.

Some exceptions are known to the general rule that veins widen in steeper segments of the faults. For example, drill hole 23 on the Barnes property cut 3 feet of fluorspar ore at a depth of 246 feet, but drill hole 36, which cut the fault 100 feet beneath drill hole 23, cut the fault at a point where the vein pinched, although the fault plane is essentially vertical between the two holes.

LATER-FORMED FRACTURES AND CROSS FAULTS

After the early period of calcite and fluorite deposition, new fractures were opened within the Babb veins along which both fluorine- and sulfide-bearing solutions rose. The fact that certain parts of the veins contain sphalerite, whereas adjacent sections are sphalerite-free, suggests that the fractures that were mineralized later were concentrated along segments of the main faults (faults 1 and 2) in which the adjustments took place. The ends of these segments appear to be at points where the main faults were intersected by cross faults or joined by subparallel fractures. For example, an abrupt change from zinc-rich to zinc-free fluorspar was noted at the exact line of the junction of fault 5 with the northeastern segment of fault 2 in the Eagle No. 2 mine (see pl. 2). Inasmuch as some fluorite was deposited simultaneously with the sphalerite, the localization of this later deposition of fluorspar was also affected by the later-formed fractures and cross faults.

As the cross faults in the area have scarcely been explored, the possibilities of ore bodies in them have not been determined.

FAULT JUNCTIONS

In the Babb area fault junctions are not always mineralized, but in at least two localities, one at the Eagle No. 2 shaft where faults 2 and 5 join, and the other south of the Kentucky No. 4 shaft where faults 1 and 8 join, very wide ore bodies have been found. In other places, as at the junctions of fault 1*A* and of fault 13 with fault 1, such structural relations seem to have had little effect on the localization of mineralized material within the vein. In general, however, fault junctions or intersections in the Babb area are considered by the writer to be more favorable sites for ore bodies than a single fault.

LITHOLOGIC CONTROL

Lithologic character was of considerable influence in the localization of some of the ore as it affected both structural features and chemicophysical factors. Inasmuch as certain types of sedimentary rock are confined largely to specific formations, however, the control is ostensibly stratigraphic. For example, shale which tends to pinch off the veins, is more abundant in the formations of the middle and upper Chester. Readily replaceable oölitic limestone occurs mainly in the Ste. Genevieve limestone, though replacement deposits are known in other formations as well.

COMPETENT AND INCOMPETENT BEDS

In the Babb area, the upper Chester formations are composed largely of shales and are rather incompetent. Lower in the Chester group, the formations contain less shale and are more competent. In general the faults tend to steepen as they pass from the shaly upper Chester rocks into the lower Chester and Meramec limestones. As lithologic character affects the attitude of the fault plane and this attitude in many places controls the vein width, the stratigraphic sequence is an important controlling factor.

EFFECTS OF SHALE AND SHALY GOUGE

In the mines of the Babb group and particularly in the Eagle No. 2 mine, where large quantities of shale or shaly gouge occur in the faults and fractures, veins are narrow or absent. This condition is particularly noticeable in the zone southwest of the ore body at the Eagle No. 2 shaft. In general the formations lying above the Bethel sandstone in the Babb area are incompetent and contain considerable quantities of shale as well as thinly bedded sandstones and shaly limestones. Fault fissures in rocks of this type ordinarily are filled with gouge and drag-folded rock and contain little vein material. Some competent rocks do occur above the Bethel sandstone, however, and where they form at least one wall of the fault, ore bodies may be found. This is true in fault 4 on the Eagle-Babb property where drilling revealed ore between the massive Hardinsburg sandstone and the shaly Golconda formation, both lying above the Bethel sandstone. Another example is in fault 1 at the place where ore occurs between the massive Ste. Genevieve limestone and the shaly Golconda and Tar Springs formations. Ore rarely has been found, however, where both walls of the fault are in shaly rocks.

SUSCEPTIBILITY OF FORMATIONS TO REPLACEMENT

In fault 2 much of the ore is probably the result of replacement of the limestone wall rock. The susceptibility of the wall rock to replacement by mineralizing solutions had a definite influence upon the localization of some of the ore bodies. A bedding-replacement deposit occurs at a depth of 135 feet at the Eagle No. 2 shaft in the top of the Levias member of the Ste. Genevieve limestone. A small amount of bedding-replacement ore was also noted in the Fredonia limestone member of the Ste. Genevieve limestone on the 100-foot level northeast of the Bachelor shaft. The Fredonia limestone member was replaced considerably on and above the 200-foot level from the Eagle No. 2 shaft where the fluorspar contains 3 to 8 percent of zinc. In general, replacement deposits are most common in the oölitic Fredonia and Levias limestone members of the Ste. Genevieve limestone, but they are known in other rocks in other areas.

Replacement deposits in the Babb area are very spotty, and it is impossible to predict their extent. Two winzes that started in ore from the 200-foot level from the Eagle No. 2 shaft penetrated unreplaced limestone beds a few feet beneath this level. Diamond drilling, however, has shown that high-grade ore exists at a depth of 125 feet beneath the 200-foot level.

CONCENTRATION IN THE OXIDIZED ZONE

Fluorspar commonly is concentrated in the oxidized zone by weathering, thus forming gravel spar. The porous oölitic limestone and brecciated shaly sandstone bordering the veins in some localities have comparatively little resistance to weathering and are decomposed and disintegrated to considerable depths. Fluorspar is resistant to chemical decomposition but breaks down mechanically into large lumps and small fragments. As a result it is left as a residual concentrate in the overburden. The fluorspar content of a vein that originally extended 100 feet or more in depth may be concentrated to a residual deposit 20–30 feet thick. Gravel spar is not formed to an appreciable extent in localities where the surface formations are very resistant to weathering.

Smithsonite has been found in the upper parts of the Howard mine on the Barnes property. No commercial deposits of this mineral are known in the Babb area, but it is not unlikely that they exist. The oxidation products of galena (cerussite, pyromorphite, and anglesite) have not been noted in the Babb area but are known elsewhere in the Kentucky-Illinois fluorspar field.

VERTICAL EXTENT OF THE ORE

There has not been enough deep exploration in the Babb area to warrant conclusions regarding the depths to which the ore bodies may extend. The apparent bottoming of a deposit should not necessarily be attributed to the depth factor as a fault may be filled locally by shaly gouge or calcite, or a decrease in dip of the fault in places may cause a pinch in a vein. At the Kentucky No. 3 shaft, the drift on the 550-foot level (the deepest workings in the Babb area when the field work was being done) was driven in vein material ranging from 20 to 30 feet or more in width but having a fluorite content of less than 30 percent. Fluorspar a few feet above this level was high-grade ore, and it is reported that fluorspar ore 5 feet wide was cut in sinking a sump in the vein. Only deeper exploration in this area will determine the limiting depth for fluorspar ore bodies. No relation between depth and concentration of sphalerite has been observed.

ORIGIN

The veins were filled first largely with calcite; then renewed movement opened new fractures along which fluorine-bearing solutions moved. Fluorite replaced the calcite and limestone country rock and was deposited in open spaces, possibly as a result of fluorine-bearing solutions reacting with waters containing calcium bicarbonate in solution (Schwerin, 1940).

The mineralizing solutions are believed to have been derived from a magmatic source. Lamprophyre dikes are exposed in the Kentucky-Illinois field but are not known in the Babb area; they appear to have been intruded prior to the period of fluorspar mineralization. It is possible that the dikes and the fluorine-rich solutions were derived from the same magma and that the mineralizing solutions were given off at a later stage of differentiation.

The bedding-replacement deposits of fluorspar in the Eagle No. 2 and Bachelor mines closely resemble those of the Cave in Rock area in Illinois and are believed to have had the same mode of origin; namely, replacement of favorable limestone (Currier, 1937).

DESCRIPTION OF PROPERTIES

GUILL

On the Guill property two shafts had been sunk 190 feet apart in fault 1 prior to 1905 (Smith, 1905, p. 201–202). The northeastern shaft was 85 feet deep, and the southwestern one was 60 feet deep.

These shafts are now caved, and their sites could not be located. Some shallow mining was done by the Eagle Fluor Spar Co. in 1900, but no attempt was made to mine on a larger scale until 1924, when this company started sinking the Hearne shaft in the footwall of the vein. The shaft, now caved, was abandoned at a depth of 225 feet before any crosscutting was done, and the Guill No. 1 shaft was started in the vein. The Guill No. 1 shaft was sunk to a depth of 300 feet, and a fluorspar body about 300 feet long was mined. A drift on the 300-foot level was driven in the vein (see pl. 3) about 310 feet northeast from this shaft; it is reported that the fluorspar in this drift was of too low grade to be mined under conditions then prevailing. A winze 40 feet deep was sunk in the vein 90 feet southwest from the Guill No. 1 shaft; it is reported that the vein pinched a few feet below the 300-foot level and that the winze was continued in black shale of the Golconda formation. Approximately 40,000 tons of fluorspar was produced from workings above the 300-foot level before mining stopped in 1929.

In 1928 the small prospect shaft (shown as a pit on pl. 1) northeast of the small creek was sunk to a depth of 40 feet and a crosscut driven to the vein, which was barren at that point.

In 1942 Perry and Loyd, a fluorspar mining company of Marion, Ky., sank the Guill No. 2 shaft to a depth of 100 feet in the hanging wall of fault 1 and mined the fluorspar disseminated in quartzite of the Tar Springs sandstone. In 1943, planning to mine the ore left in the walls of the abandoned stopes, they sank the Guill No. 3 shaft in the vein to a depth of 80 feet. The old stopes were found to be almost closed by subsidence and only small openings remained. Fluorspar ore averaging 5 feet wide was mined above the 80-foot level. The shaft was deepened to 120 feet, and a drift was driven about 200 feet southwestward. The property was then sold to Hillside Fluor Spar Mines of Rosiclare, Ill. This company sank the Guill No. 3 shaft to a depth of 170 feet, drifted 250 feet northeast on the 120-foot level, and was proceeding with development in January 1945 (see pl. 3). The property was held more recently by Inland Steel Corp., successor to Hillside Fluor Spar Mines in June 1945. Probably 3,000 tons of fluorspar has been produced from this mine between its reopening in 1942 and 1945.

Faults 1, 6, 8, and 12 cross the Guill property, but only fault 1 has been prospected extensively. The characteristics of faults 6, 8, 12, and of fault 1 south of fault 12 are not shown. Faults 6 and 8 and fault 1 south of its intersection with fault 12 were inferred to explain differences in altitude of the same stratigraphic horizon. The positions of the traces of these faults on plate 1 are uncertain. More detailed exploration in this vicinity probably will reveal the presence of more faults.

The fluorspar mined from the Guill No. 3 shaft is composed of colorless to brown fluorite in a calcite gangue. Much of the fluorite is clear but very dark and has a bituminous odor. The fluorite is largely massive and apparently replaced calcite to a considerable extent. The fluorspar ore contains very little sphalerite or galena.

On this property, the vein is essentially vertical (see pl. 4, sec. *A–A′*) and is 20–30 feet wide along that part explored by mine workings. Southwest of the mine workings, three core drill holes have explored about 400 feet of strike length along fault 1 and fault 12. In this section the brecciated zone is 20–40 feet wide, but with the exception of a few stringers of calcite and fluorite in the country rock, no vein was revealed by the drilling. Core recovery was so poor, however, that definite conclusions about the presence or absence of fluorspar bodies are not justifiable. The attitude of the fault marked by the breccia zone is not known.

Two drill holes explored that part of the vein between the mine workings and the Kentucky-Babb property line. Hole 44 entered a cavity in the fault, and hole 35 cut 20 feet of vein material including 4 feet of high-grade fluorspar.

KENTUCKY-BABB

The Morse prospect discussed by Smith (1905, p. 202) is a caved pit on the Kentucky-Babb property. Many shallow shafts and pits, among them the C. Babb shaft which was reported to be 80 feet deep, were sunk prior to 1930, but no fluorspar was marketed. In 1930 the Eagle Fluor Spar Co. sank the Kentucky No. 1 shaft to a depth of 40 feet and crosscut to the fault but found it barren. In 1935 the Kentucky Fluor Spar Co. reopened this shaft and sank it to a depth of 154 feet, where some fluorspar was mined. The Kentucky No. 2 shaft was sunk in 1936, and the Kentucky No. 3 and No. 4 shafts in 1939. The Kentucky No. 3 shaft, the deepest shaft in the Babb area, was the only one being used in January 1945 when mining was being done at a depth of 550 feet (see pl. 3). The property is now held by the Pennsylvania Salt Manufacturing Co.

Faults 1, 1*A*, 7, 8, 9, 10, and 13 cross the Kentucky-Babb property. In addition to the rather large production from fault 1, a small amount of fluorspar has been mined from faults 1*A* and 13 near their junctions with fault 1. At the junction of faults 1 and 1*A*, fluorspar is found along fault 1*A* for a short distance from the junction. At the junction of faults 1 and 13, the ore widens slightly but pinches in both faults a few feet from the junction. Faults 7 and 9 were cut by drill holes, but no vein material was penetrated. Fault 8 was not cut by a drill hole, but a hole penetrated fault 1 near its junction with fault 8 and revealed a 20-foot lens of fluorspar. It is reported that a horizontal hole was drilled southeast from fault 1 on the 340-foot level of the mine. This hole probably cut fault 10, but no fluorspar was found and no record of the hole is available. The locations of the faults and the geologic formations exposed are shown on plate 1, and the stratigraphic and structural relations at the Kentucky No. 3 shaft are illustrated on plate 4, sec. *B–B′*.

In general the fluorspar and the character of the vein are rather uniform throughout the accessible parts of the mine. The vein ranges from 10 to 30 feet in width and contains fluorspar lenses from 2 inches to 12 feet wide. The fluorspar is generally massive white to brown and of high grade; it contains a small amount of galena but essentially no sphalerite. Many of the fluorspar lenses contain very little calcite; furthermore the calcite, which constitutes most of the vein material, rarely contains more than 10 percent of fluorite. The contact between the high-grade fluorspar lenses and the almost barren calcite may be marked by a small fault or a thin film of gouge, or it may be gradually transitional.

That part of the 340-foot level southwest from the Kentucky No. 3 shaft was inaccessible in 1944, but a mine map of the drift was furnished by Mr. Robert Frazer, operator of the mine. According to this map and reports of miners who worked in the drift, the vein ranged from 1 to 10 feet in width and contained no fluorspar bodies wider than 4 feet (pl. 3). A series of assays shows that part of the drift was driven in 3–4 feet of vein material containing 8–10 percent of zinc occurring as sphalerite.

The distribution of zinc-free fluorspar ore and calcite in the fault zone on the 450-foot level from the Kentucky No. 3 shaft is shown on plate 2.

On the 550-foot level from the Kentucky No. 3 shaft, the vein ranges from 10 to 30 feet or more in width but consists largely of calcite with stringers of fluorite; however, fluorspar ore 6 feet wide was reported to have been found in a sump sunk in the vein near the shaft. In stopes immediately above the 550-foot level, high-grade fluorspar ore has been mined.

That part of the fault lying between the Kentucky No. 4 shaft and the Guill property line (pls. 1 and 3) was explored with 4 core drill holes. Hole 25 cut 8 feet of sphalerite-fluorspar ore averaging 13 percent of zinc and 20 percent of CaF_2. The other 3 holes penetrated veins ranging from 15 to 40 feet in width and indicated the presence of an essentially zinc-free fluorspar ore body ranging from 4 to 20 feet in width. The greatest width of the vein was cut near the junction of faults 1 and 8.

DELHI-BABB

The first reference to workings on the Delhi-Babb property was made in 1905 by Smith (p. 202) who mentioned that the Tom Babb prospect consists of two holes 200 feet apart; the northeastern hole was about 240 feet S. 54° W. from the Raymon Babb shaft, which is southwest of the present Eagle No. 1 shaft. These holes probably are represented by two of the caved pits northeast of the Bachelor shaft. The next recorded work on this property was done in 1918, when the Bachelor shaft was sunk and some fluorspar was mined. This shaft was not accessible when Currier (1923, p. 115) visited the property in 1921, but since then the mine has been operated intermittently from this shaft. Mr. A. H. Reed, Sr., acquired the Delhi-Babb property and in 1934 sank the Incline shaft in the vein of fault 1. The Delhi Fluorspar Co. next acquired the property and sank the Croft shaft in 1938. Mining from the Croft and Incline shafts continued until May 1943, when the mine was closed pending the sinking of the New Delhi shaft. Since that time, contractors did some mining from the Croft, Incline, and Bachelor shafts; none of this work went below a depth of 100 feet (pl. 3). The Delhi-Babb property in 1946 was sold to the Ozark-Mahoning Co.

The Delhi-Babb mine was examined by the writer before it was closed in 1943, but many of the mine openings were inaccessible because of caving. The vein in fault 1 was examined on the 350- and 400-foot levels from the Croft shaft, and high-grade fluorspar ore was observed. On the 350-foot level the vein ranges from 1 foot to 15 feet in width and on the 400-foot level it ranges from 3 to 22 feet; the maximum width occurs where a fracture striking N. 30° E. extends from fault 1 into the hanging wall. The vein consists largely of high-grade fluorspar that contains from 3 to 10 percent of zinc occurring as sphalerite. Drifts along faults 1 and 11 and in the brecciated block separating these faults were examined on the 70-foot level from the Incline shaft. Veins ranging from small stringers to as much as 8 feet in width consist chiefly of high-grade fluorspar containing some sphalerite, calcite, and wall rock. The fluorspar in the fissures in the brecciated block between faults 1 and 11 contains considerable quartzite.

Faults 1, 4, 11, and 13 extend across the Delhi-Babb property, but only faults 1 and 11 have been explored. Fault 1 dips approximately 80° NW. to a depth of 350 feet, where it becomes essentially vertical. Exploration along fault 11 has not been systematic enough to reveal the structural details of the fault. The surface trace of fault 11 joins fault 1 northeast of the Croft shaft. Fault 11 is exposed in the crosscut on the 270-foot level from the Croft shaft where it lies 15 feet southeast of fault 1, but it is not perceptible in the crosscut on the 350-foot level (see pls. 3 and 4, *C–C′*). The drift in fault 11 on the 270-

foot level passed through small pockets of fluorspar, but no ore bodies were found.

At the Bachelor shaft, the 100-foot level northeast of the shaft was mapped. A small fluorspar ore body about 40 feet long and averaging 4 feet in width occurs on this level. Banded ore of the bedding-replacement type was noted in the northeast face of this drift (see pl. 3).

EAGLE-BABB

Smith (1905, p. 201) stated that the Raymon Babb mine consisted of two shafts and several small prospect pits. These openings are identified by the writer with the series of pits lying southwest of the Eagle No. 1 shaft. Between June 1899 and August 1900, the group was worked by the Eagle Fluor Spar Co., and more than 1,000 tons of fluorspar was mined above the 80-foot level. Later, the present Eagle No. 1 shaft was sunk to a depth of 125 feet in the footwall of fault 1 and a crosscut driven 125 feet through fault 1 to fault 4. A vein consisting largely of calcite was found in fault 1, but no vein was present in fault 4 where is was intersected.

No more work was done on this property until 1942 when, following the discovery of fluorspar on the Barnes property, sinking of the Eagle No. 2 shaft and a program of core drilling were started (pl. 1). Six core holes totaling 2,300 feet in length were drilled. Two of the holes cut sphalerite-fluorspar ore in faults 3 and 4, and the crosscut to fault 2 from the Eagle No. 2 shaft cut sphalerite-rich fluorspar 8 feet wide. In 1943 the Eagle No. 1 shaft was reopened and sunk to a depth of 300 feet. A short crosscut was driven to fault 1, and a drift was started in the vein. Not much work was done from this shaft between then and 1945. About 6,000 tons of ore has been produced from this property during the two periods of operation.

Faults 1, 2, 2*A*, 3, 4, and 5 extend across the Eagle-Babb property, and fluorspar ore is known to occur in all except fault 2*A*, which has not been prospected. At the Eagle No. 1 shaft the vein in fault 1 is 10 feet wide but is mainly calcite. At the Eagle No. 2 shaft there is essentially no vein in fault 1. The veins in faults 2, 3, and 4 are lenticular, and their character changes within very short distances; they contain chiefly sphalerite-rich fluorspar. The vein in fault 5 is about 7 feet wide and is composed essentially of sphalerite-free fluorspar and calcite. In addition to the ore found in the veins, a bedding-replacement deposit of the "coon-tail" type of ore has been mined at a depth of 135 feet from the Eagle No. 2 shaft (pl. 3). The locations of the faults and the geological formations exposed are shown on plate 1. Two sections across the fault zone on the Eagle-Babb property are given on plate 4, secs. *D–D′* and *E–E′*.

Most of the ore occurring on this property is in pockets and was formed mainly by wall-rock replacement. The ore body in fault 2 at the Eagle No. 2 shaft is about 180 feet long but ranges from 1 foot to 16 feet in width. At the widest places, the fluorspar has replaced the Fredonia limestone member in the footwall. The drift southwest from the Eagle No. 2 shaft on the 200-foot level was driven in sphalerite-rich fluorspar for a distance of 110 feet to a point where the vein pinched abruptly. The drift was continued for 220 feet but was driven largely in black shaly gouge between slickensided limestone and quartzite walls (pl. 2). The drift northeast from the Eagle No. 2 shaft on the 200-foot level was driven in fluorspar ore for about 60 feet. The vein pinched abruptly in fault 2, northeast of the junction of fault 5 and the northeastern segment of fault 2, but continued in fault 5. Much of the vein material in fault 5 is calcite, and the fluorspar ore was spotty. Two winzes were started in fluorspar on the 200-foot level, but both penetrated unreplaced limestone beds and were abandoned later.

The bedding-replacement deposit mined on the 135-foot level was about 30 feet wide, and the thickness ranged from 6 feet near the fault to a feather edge southeast of the Eagle No. 2 shaft (pl. 3). The fluorspar was distinctly banded and closely resembled the ore from the bedding-replacement deposits of the Cave in Rock area, Illinois.

The U. S. Bureau of Mines drilled 10 holes from underground stations to explore faults 3 and 4 (pl. 4, secs. *D–D′* and *E–E′*). The cores showed that sphalerite-rich fluorspar occurs in faults 3 and 4, but the very pockety nature of the deposits renders it almost impossible to estimate the quantity of ore. One hole was drilled to intersect fault 2 at a point 125 feet below the 200-foot level and was continued to cut fault 4. This hole indicated the presence of a high-grade fluorspar vein about 12 feet wide in fault 2 on this level and some fluorspar in fault 4 (sec. *E–E′*).

In 1946 the Eagle Fluor Spar Co. sold the Eagle-Babb property to the Aluminum Ore Co., now the Alcoa Mining Co.

BARNES

In 1904 "Doc" Radcliff sank the shaft (shown as a pit on pl. 1) south of the Howard shaft to a depth of 90 feet. This is the first work known to have been done on the Barnes property. Short drifts were said to have been driven northeast and southwest from the shaft and fluorspar stringers found. In 1941 Claude Fletcher of Marion, Ky., sank the shaft now known as the Howard shaft approximately 50 feet; at about the same time, John Barnes sank the pit near drill hole

40 of the U. S. Bureau of Mines to a depth of about 30 feet. Both of these shafts were abandoned. Later in 1941 Ray Howard and associates leased the property, reopened the Howard shaft, and sank it to a depth of 130 feet. Some fluorspar was found in crosscutting to the vein at that depth. The shaft was deepened to 171 feet, and considerable mining was done on this level. In 1943 the shaft was deepened to 234 feet, but very little work had been done on this level by January 1945 (pl. 2). Later in 1945 the Inland Steel Corp. further explored the property by core drilling northeastward along the strike of the fault system.

On the 171-foot level from the Howard shaft the vein is weathered, and fluorspar occurs as large boulders in red clay. Considerable work has been done on this level and from a shallow winze, but the fluorspar ore has been spotty. On the 234-foot level faults 2 and 4 are clearly defined, and a 4-foot vein occurs in fault 2. The vein is largely calcite but contains about 35 percent of CaF_2.

Faults 1, 2, 4, 14, 15, and 16 extend across the Barnes property. With the exception of fault 16, all these faults were penetrated in recent diamond drilling by the U. S. Bureau of Mines. None of the Bureau's prospecting was done on the northeastern part of the property (pl. 1). Subsequent core drilling by the Inland Steel Corp. explored fault 16 at several points, as well as faults 1 and 2 farther northeast along the strike. Fluorspar ore has been mined from fault 2. The broken zone between faults 2 and 4 contains stringers of fluorite and sphalerite, but no ore had been found in the other faults on this property by January 1945. Because of the stratigraphy and the character of the fault, it is believed that fault 2 offers the best possibilities for prospecting farther northeast on the Barnes property. Section *F–F′* on plate 4 illustrates the structural and stratigraphic relations inferred to exist in the area northeast of the present mine workings.

Three diamond-drill holes explored the parts of faults 2 and 4 southwest of the Howard shaft. Hole 19 cut a calcite vein about 30 feet wide in the fault zone. Holes 21 and 40, however, cut a vein 3 feet wide containing sphalerite-rich fluorspar ore in fault 2 but no ore in fault 4. Six holes were drilled northeast of the Howard shaft by the Bureau of Mines. Approximately 3 feet of fluorspar was cut in holes 23 and 28; but the other holes, including hole 36, which was drilled beneath hole 23, cut the faults at barren places. The cores from drilling done by the Inland Steel Corp. in the autumn of 1945 were not studied by the Geological Survey. According to reports, however, some fluorspar was found, and the drilling revealed evidence of faults not shown on plate 1.

E. CHAMPION AND GID TAYLOR

As far as is known, only fault 1 extends across the E. Champion and Gid Taylor properties, and only a short length of it is within the property boundaries. This part of the Babb area is not known to have been prospected.

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