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FLUORSPAR INVESTIGATIONS

PRELIMINARY REPORT ON THE GEOLOGY OF THE COLUMBIA MINE AREA, CRITTENDEN COUNTY, KENTUCKY*/

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ABSTRACT

The Columbia mine area in Crittenden County, Ky., was the site of the first mining operations in the western Kentucky fluorspar district. Development of the area began in 1835 when Andrew Jackson started mining lead ore for its silver content. The area has since supported several mines and many prospects that have produced fluorspar as well as lead and zinc ores. Most of the land is owned by the Krausse estate, but part of the Mary Belle property lies within the area mapped. Although the Columbia and Mary Belle workings are now inactive, some work is being done currently at smaller mines.

Limestones, sandstones, and shales of the Meramec and Chester groups of Mississippian age are exposed on the surface and in the underground workings. One lamprophyre dike trends northwestward across the area, and a parallel intrusive body is reported. The relatively flat-lying sedimentary rocks are broken into a mosaic of fault blocks. In general one set of faults strikes N. 20° E. and the other set N. 20° W. Of the 12 faults that were mapped in the area, 7 are known to be mineralized.

The ore bodies are mainly fissure fillings, but in some places the adjacent wall rock was replaced. Vein widths range from 6 inches to 12 feet. The ore consists principally of fluorite, sphalerite, and galena in a gangue of calcite and brecciated limestone. Most of the ore below the oxidized zone is a fine-grained mixture that can be separated only by selective flotation. Much of the fluorspar mined in the area has

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*/ Accompanied by three illustrations:
Plate 1. Property assemblage in the Columbia mine area.
2. Preliminary geologic and topographic map of the Columbia mine area.
3. Workings on the Columbia mining property.

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come from residual deposits in the overburden, and most of the zinc ore produced has come from smithsonite deposits formed by the alteration of sphalerite at shallow depths.

At least 35,000 tons of ore has been produced from mines other than the Mary Belle. An additional 65,000 to 75,000 tons has been mined from the Mary Belle workings parts of which are within the mapped area. Although measured reserves are negligible, indicated ore in the three principal mines on the Columbia property is estimated to total 10,000 tons, and more than 20,000 tons of ore are inferred at the Columbia mine alone. These reserve figures do not include an estimate for the Mary Belle property.

Faults crossing the area total more than 2½ miles in length. Only about 15 percent of this length has been prospected below a depth of 50 feet, and half of the total length is unprospected. In spite of the relatively small amount of exploration that has been done in this complexly faulted area, the production record is good. Systematic prospecting along the unexplored parts of the faults can reasonably be expected to reveal new ore bodies.

INTRODUCTION

The Columbia mine area is a tract about half a mile square in the vicinity of the Columbia mine. The area mapped extends nearly 700 feet south of the Mary Belle shaft and approximately the same distance north of the Columbia shaft. The land belongs mainly to the Krausse estate but includes also part of the Mary Belle property and small extensions of the Klondike, Jr., and Old Jim properties. (See pl. 1).

The Columbia mine area is 4½ miles west-northwest of Marion, Ky., and is reached by travelling west from Marion along United States Highway No. 60 to a point 2.4 miles from the Marion courthouse. At that place a graveled road turning off north from the highway provides access to the area, which is 3 miles farther northwest along the road.

The mapped area is complexly faulted and lies between Weller's faults No. 31 (Crittenden Spring fault) on the east and No. 59 (faults Nos. 6 and 11 in this report) on the west.[1] Seven of the faults crossing the area are known to be mineralized.

Examination and study of properties along the Crittenden Spring fault system was recommended by Currier and Williams[2] who made a preliminary

1/ Weller, Stuart, Geology of the Cave in Rock quadrangle: Kentucky Geol. Survey, ser. 6, vol. 26, pp. 104, 108, and 114, 1927.

2/ Currier, L. W., and Williams, J. S., Report on the fluorspar situation in the Kentucky-Illinois field: U. S. Geol. Survey Fluorspar Inv. Confidential Rept., p. 28, August 16, 1942.

study of the Kentucky-Illinois district for the purpose of encouraging the development of fluorspar reserves and suggesting favorable areas for future exploration.

The area was mapped by G. C. Hardin, Jr., W. H. Hass, and R. D. Trace from July 15 to 30, 1943. The geology and underground workings were studied by G. C. Hardin, Jr., at various times between July and November 1943.

History of mining in the area.3/--The Columbia mine is probably the oldest mine in the western Kentucky fluorspar district. In 1835 Andrew Jackson sank a shaft near Hurricane creek and southeast of the present Columbia shaft. In 1863 or 1864 the mine was purchased by the Columbia Silver Mining Co. The main shaft was nearly 80 feet deep but no drifts had been driven in 1873 or 1874 when the mine was leased to Halliday and Green, of Cairo, Ill. Halliday and Green worked the mine 15 months, drifting 40 or 45 feet southwestward on the 50-foot level. This drift is said to be on the vein. Henry, James, and Tom Glass then took an option on the property, retimbered the old shaft and sank to to a depth of about 85 feet, and drifted for a short distance on the 80-foot level. In 1876 Page and Krausse of St. Louis bought out the Glasses, deepened the shaft, and drifted on the 80-foot level for some distance both northeast and southwest along the Columbia fault, and southeast along the Eureka fault. The pig lead that Page and Krausse produced was hauled to the Ohio River at Fords Ferry for shipment. These operations were discontinued in 1877 owing to a decline in the value of lead. The property is owned at present by the Krausse estate of St. Louis, Mo.

In 1899 Blue and Nunn leased the property from Page and Krausse. The lease was sold in 1900 to the Western Kentucky Mining Co., who cleaned out the old mine, sank the shaft to a depth of 135 feet, and did some work at that level but was forced to abandon the mine because of water. The Columbia Mining Co. operated the mine on the 135-foot level during 1902 and 1903. In 1906 the mining rights were acquired by John D. Dresher, who assigned them to the Southern Lead and Zinc Co. in 1907. After a short period of operation, this company closed the mine, and it was not operated again until 1941.

Several shallow shafts were sunk on the Eureka vein (fault No. 9) prior to 1900. The Dresher open cut on this vein was examined by Smith4/ in 1903. Most of the ore removed consisted of smithsonite containing galena and some fluorite.

3/ History prior to 1903 abstracted from Ulrich, E. O., and Smith, W. S. T., The lead, zinc, and fluorspar deposits of western Kentucky: U. S. Geol. Survey Prof. Paper 36, pp. 169-176, 1905.

4/ Ulrich, E. O., and Smith, W. S. T., op. cit., p. 175.

The Mary Belle mine was opened in 1901 and was worked intermittently until 1930. Approximately 20,000 tons of ore, mainly fluorspar, was removed through the Mary Belle shaft. Veins in the Mary Belle fault (No. 3) and in fault No. 5 were worked to a depth of 350 feet. From about 1920 to 1925, the Krausse estate was under lease to the Aluminum Ore Co., owners of the Mary Belle property. Near the intersection of the dike and fault No. 4, this company sank the Rock shaft to a depth of 100 feet. Some drifting was done, and local miners reported that fluorspar averaging 1 foot in width was found. This observation is supported by the presence of some fluorspar on the dump.

Since 1930 many shallow shafts have been sunk on the faults in the area by various individuals and companies. The total quantity of fluorspar ore removed by these operations probably does not exceed 5,000 tons.

In 1937 Mr. Eugene Guess leased the Columbia property from the Krausse heirs, and the lease is now held by his son, N. G. Guess. In 1941 part of the property along the Columbia (No. 6) and Eureka (No. 9) faults was subleased to R. P. Davidson (see pl. 2), who reopened the Columbia mine by sinking a new shaft in the vein. Mr. Davidson became associated subsequently with the Corod Minerals Corporation, and the lease was assigned to that organization. Operations through the Davidson shaft were discontinued in December 1942 pending the installation of new equipment. Total production of fluorspar, zinc, and lead ore from the Columbia mine probably does not exceed 10,000 tons.

In 1937 part of the property along faults Nos. 4 and 5 was leased to the Craighead Bros. (see pl. 2), who are working faults Nos. 4 and 4a from a shaft 150 feet deep in fault No. 4a. A small shaft on fault No. 5 is worked intermittently by the Craighead Bros.

The Corod Minerals Corporation is now conducting mining operations at a depth of 50 feet from the Eureka shaft on the Eureka fault (No. 9), and plans are being made to reopen the caved Columbia shaft.

The fluorspar ore mined heretofore has been washed in a log washer, run through a jig mill, or hand picked and shipped directly to the consumer from Marion, Ky., as metallurgical grade fluorspar. A considerable quantity of lead (galena) and zinc (smithsonite and some sphalerite) ore has been marketed from the property. Most of this ore was hand sorted, but some was jigged. Below the oxidized zone, most of the ore is a fine-grained mixture of fluorite, sphalerite, and galena that can be separated only by selective flotation. A mill to handle ore of this type has recently been constructed in Marion, Ky.

Acknowledgments.—Thanks are due to Dr. A. H. Sutton, geologist of the Aluminum Ore Co., and to Mr. A. H. Reed, Sr., consulting mining engineer and geologist, for invaluable assistance. Dr. Sutton made several short trips into the field with the writer. The area was rather thoroughly discussed with Mr. Reed, who has done considerable work in the vicinity of the Columbia mine.

GEOLOGY

The sedimentary rocks exposed in the area are limestones, sandstones, and shales of the Meramec and Chester groups of Mississippian age. These beds are broken by a complex network of faults, which displace the sedimentary formations as much as 500 feet. A lamprophyre dike, reportedly striking about N. 20° W., was penetrated by workings from the Rock shaft, and a parallel dike has been reported by local miners.

Sedimentary rocks

Rocks of Mississippian age are at the surface in this area. With the exception of some silicification in the immediate vicinity of the faults, these rocks have not been altered. The formations in the area are outlined in the accompanying table.

A disconformity exists between the Ste. Genevieve limestone and the Renault formation. At the Franklin mine, half a mile south of the area, the Levias limestone member (Lower Ohara limestone member of some reports) of the Ste. Genevieve is absent. It is possible that the rock mapped as the Levias limestone member in the Columbia mine area is actually the Fredonia limestone member of the Ste. Genevieve. As the Rosiclare sandstone member of the Ste. Genevieve is known to be present in the Columbia mine area, however, the Levias limestone member appears to be correctly identified and mapped in this locality.

Igneous rocks

A lamprophyre dike contains the only igneous rock known in the area. The dike does not crop out, but considerable quantities of dike rock are to be observed on the dump of the Rock shaft. On the Old Jim property, zinc ore, consisting principally of smithsonite but containing some sphalerite, has been mined from an open cut along this dike and a parallel intrusive body, which has been reported also on the Krausse estate.

Most of the dikes in the district are known to have been intruded prior to the period of major faulting. The dikes in the Columbia mine area are believed to be contemporaneous with others in the district and must therefore have been offset by the faults. As field data showing such displacement could not be secured during the course of mapping, the dike is shown as a continuous body (see pl. 2).

The dike rock is a fine-grained dark-gray to black lamprophyre containing brown to gold-colored biotite in "books" as much as 1 inch long.

Generalized section of formations in the vicinity of the Columbia mine

	Formation	Character	Thickness (feet)
CHESTER GROUP	Palestine sandstone	Massive sandstone with sandy shale,	50 (partly eroded
	Menard limestone	Dark-gray to black shale and dark-gray fine-grained limestone,	100
	Waltersburg sandstone	Thin-bedded blocky sandstone and sandy shale.	20
	Vienna limestone	Massive dark-gray limestone; shaly in upper part.	50 - 60
	Tar Springs sandstone	Massive sandstone and sandy shale,	80 -100
	Glen Dean limestone	Medium-gray crystalline limestone.	30 - 40
	Hardinsburg sandstone	Massive sandstone; sandy shale in middle part.	110
	Golconda formation	Dark-gray dense limestone with black shale; 20 feet of fine-grained sandstone in middle.	140
	Cypress sandstone	Massive sandstone; dark sandy shale in middle part.	90
	Paint Creek shale	Dark shale containing thin limestone beds.	40
	Bethel sandstone	Massive sandstone; dark sandy shale in middle part.	70 - 80
	Renault formation	Dark shale containing marl and limestone beds.	70
MERAMEC GROUP	Ste. Genevieve limestone		
	Levias limestone member (Lower Ohara limestone member of some reports)	Light-gray coarse-grained oolitic limestone.	25
	Rosiclare sandstone member	Greenish calcareous sandstone.	20
	Fredonia limestone member	Light-gray coarse-grained oolitic limestone.	200
	St. Louis limestone	Medium-gray fine- to medium-grained limestone containing abundant blue-gray chert nodules.	350

On weathered surfaces the rock is greenish brown in color and appears to be stained with iron. A similar igneous rock5/ was noted along the "Dike" fault (not to be confused with the dike in the Columbia mine area) 2 miles south of the Columbia mine. A specimen of this rock was examined petrographically by J. J. Glass, who submitted the following statement:6/

> The dark vein rock is a greatly altered lamprophyre dike rock in which the only remaining original mineral is pale reddish-brown biotite. The replacement minerals now present are largely calcite where crystals of olivine and pyroxene once were; fringes of serpentine and chlorite are common; grains of black opaque material, once magnetite, now are a black stain that reacts for manganese.

Structure

The area studied lies between two faults mapped by Weller7/—fault No. 31 (the Crittenden Spring fault) on the east and fault No. 59 (composed of the two faults designated Nos. 6 and 11 in this report) on the west. The area is complexly faulted. Twelve faults have been mapped from information available at the surface and in workings underground. The two major faults in the area (faults Nos. 1 and 4) and several minor fractures strike N. 20° E., whereas the dike and faults Nos. 9, 5, and probably 7 and 8 strike about N. 20° W. Fault No. 11 strikes N. 10° E. Fault No. 6 strikes N. 40° E., but its trend changes to approximately N. 20° E. north of the Columbia shaft. The courses of the faults are shown on plate 2.

The most persistent fault in the area is the Crittenden Spring fault (No. 1). This fault was mapped regionally as the Levias and Crittenden Spring faults8/ whose combined lengths are about 8 miles. In the area studied the fault strikes about N. 20° E. The attitude of the fault plane, where known, ranges from the vertical to a westward dip of 75°. Downthrow along this entire fault is to the west. The Ste. Genevieve limestone forms the footwall. Stratigraphic displacement along this fault in the area mapped is about 150 feet in the locality south of fault No. 5, 100 feet in the block between faults Nos. 5 and 9, but is not known in the area north of fault No. 9. It seems probable, however, that at least a fracture extends northward from this point.

5/ Hardin, G. C., Jr., Preliminary report on the geology of the Eaton fault system, Crittenden County, Kentucky: U. S. Geol. Survey Fluorspar Inv. Confidential Rept., pp. 7-8, May 1943.

6/ Glass, J. J., personal communication to R. W. Lemke, May 3, 1943.

7/ Weller, Stuart, op. cit., pp. 104, 108-109, and 114-115.

8/ Weller, Stuart, op. cit., p. 104, 108-109.

Along fault No. 2 the displacement is small. The fault lies between the Bethel sandstone and the Renault formation at the north end and apparently dies out in the Bethel at the south end. The strike is about N. 20° E. This fault is cut off on the north by fault No. 5. Sheared silicified sandstone ledges, or "quartzite reefs," with prominent slickensides are exposed just south of the Mary Belle road on the nose of the hill.

In a crosscut driven 250 feet east from the Mary Belle No. 1 shaft, a vein containing a 1-foot thickness of fluorspar was found. This vein may be either in fault No. 2 or in a fault lying between faults Nos. 1 and 2 that is not discernible on the surface.

Fault No. 3, the Mary Belle fault, is unique in this area in that it is a thrust fault. As shown by a map of the underground workings, the fault dips 75° NW. At the surface the southeast side or footwall is Bethel sandstone with some limestone of the Renault formation toward the north end; the northwest side or hanging wall consists of limestones of the Ste. Genevieve and Renault formations. This fault strikes N. 20° E.; and it has a stratigraphic displacement of 70 feet and a strike length of about 2,000 feet. It is cut off at the north by fault No. 5 and at the south by Weller's fault No. 60[9], which is not shown on plate 2. Mining has been carried on to a depth of 350 feet on both faults Nos. 3 and 5. The workings are now inaccessible though mine maps exist.

Fault No. 4 strikes N. 20° E. and has a strike length of 1,800 feet in the area mapped. It lies between the Tar Springs sandstone on the northwest and limestones of the Renault and Ste. Genevieve formations on the southeast. Downthrow is to the northwest, and the stratigraphic displacement is about 500 feet. The fault plane dips slightly westward where it has been observed. The fault is cut off on the north by fault No. 8, but continues southward for a distance of 1½ miles to a point where it is cut off by the Siloam fault of Weller[10] (south of the area shown on pl. 2). The silicified sandstone ledges or quartzite reefs, forming the northwest wall of the fault as well as outcrops of the limestone in the footwall, are exposed at several places along the hillside south of fault No. 5. Several small shafts, one of which is now being worked, have been sunk on or near fault No. 4 north of the point where it joins fault No. 5. Fault No. 4 is well exposed in a caved area near the Rock shaft.

Fault No. 5 was mined to a depth of 350 feet through the Mary Belle shaft. This fault may be actually a series of closely spaced small faults. The large number of shallow pits from which "gravel spar" has been mined along this fault support this interpretation. The fault strikes about

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9/ Weller, Stuart, op. cit., p. 104.

10/ Idem.

N. 25° W. Its strike length is 750 feet, and stratigraphic displacement along the fault is about 50 feet, the southwest being the downthrown side.

South of its juncture with fault No. 9, the strike of the Columbia fault (No. 6) is N. 40° E. but it swings around to N. 20° E. north of this juncture. This change in strike was suspected from surface evidence and was confirmed by Fohs' description[11] of the workings in this part of the Columbia mine (now inaccessible even in workings from the Davidson shaft). Eighty feet northwest from the Columbia shaft the fault, according to Fohs, curves northward; and at the point where it turns, a cross fracture is present in the shale forming the west wall. In this fracture a 3-inch seam of galena and sphalerite was deposited. The opposite wall at this locality also shows some cross fracturing. This fault is exposed in the road 550 feet S. 35° E. from the Davidson shaft. It has been mined from the Davidson and Columbia shafts for a distance of 275 feet along the strike. Pits and caved areas north of the Columbia shaft expose the sandstone hanging wall and indicate that the fault swings northward.

At the Davidson and Columbia shafts the northwest wall of fault No. 6 is Hardinsburg sandstone at the surface, but the Waltersburg sandstone is well exposed in a ravine 350 feet N. 45°W. from the Davidson shaft. These stratigraphic relations indicate the existence of fault No. 12. The footwall of fault No. 6 is Tar Springs sandstone in the area north of fault No. 7, limestone and shale of the Golconda formation in the block between faults Nos. 7 and 8, and Ste. Genevieve limestone north of fault No. 8. Downthrow along fault No. 6 is to the northwest throughout its length, the amount of stratigraphic displacement north of its juncture with fault No. 8 being about 75 feet, and south of this point about 400 feet. Near the Davidson shaft, the fault dips slightly eastward.

Fault No. 7 has brought the Tar Springs sandstone on the south against shale and limestone of the Golconda formation on the north. The Tar Springs sandstone is exposed in a small pit beside the road near the Davidson shaft. Just north of this exposure, shale and limestone of the Golconda formation have been thrown out of a rather shallow pit. The exact strike of fault No. 7 is not known but is assumed to be about parellel to fault No. 9—N. 25° W. Stratigraphic displacement on fault No. 7 is about 175 feet.

Fault No. 8 brings shale and limestone of the Golconda formation against the Ste. Genevieve limestone, which is exposed at the surface of the Davidson shaft. The fault cuts off fault No. 4. The exact strike is not known, but fault No. 8 is assumed to be parallel to faults Nos. 9 and 7. The stratigraphic displacement along the part of the fault northwest of fault No. 4 is about 300 feet. Fault No. 8 dies out southeastward in the Ste. Genevieve limestone.

11/ Ulrich, E. O., and Smith, W. S. T., op. cit., p. 171.

Fault No. 9 (the Eureka fault) strikes N. 30° W. As Ste. Genevieve limestone is at the surface on both sides, the stratigraphic displacement is not definitely known. Several shafts and pits, including the Eureka No. 1 (the only shaft now being worked) were sunk along this fault, and a drift was driven along the fault on the 80-foot level from the Columbia shaft for a distance of 125 feet. Fohs and Smith12/ believed that the Eureka shaft was on a fault parallel with the Eureka fault and not in the same fracture followed by the drift from the Columbia shaft. This interpretation may be correct, but, as the workings from the Eureka shaft lie almost in line with the workings from the Columbia shaft, the writer believes that both drifts are on the same fault.

Fault No. 10 lies within the Ste. Genevieve limestone and has been mapped solely from the evidence offered by the abundant gravel fluorspar found in the overburden. It is probable that this fault really consists of a series of closely spaced fissures. This interpretation is supported by the fact that gravel spar has been mined from a wide strip.

Movement along fault No. 11 brought the Menard limestone on the west against the Waltersburg sandstone and Vienna limestone on the east. The fault is well exposed in a small shaft on the north side of the road about 400 feet west of the point where fault No. 6 is exposed in the road. This fault is probably cut off by fault No. 6 in the small stream valley south of the road.

Intense brecciation accompanied the faulting in most of this area, and in some places the ore is a limestone breccia cemented with ore minerals. On the 80-foot level of the Columbia mine south of the Davidson shaft, a 6-foot width of limestone breccia cemented with fluorite is minable. In surface outcrops and in caved areas where sandstone adjacent to the faults is exposed, the rock has been much sheared and brecciated.

The hanging walls, and in some places the footwalls, of the faults bear indications of considerable drag. Drag and gouge are more strongly developed where faulting has brought sandstone or shale against limestone than where two limestone formations have been faulted against each other. Between the 80- and 135-foot levels in the Columbia mine, the northwest wall is shale and the footwall is limestone. The shale beds stand almost vertically, and there is considerable gouge in the fault. Drag is very apparent in the footwall of the Columbia fault where it is exposed in the road southwest of the Columbia mine. Both drag and brecciation are pronounced in the hanging wall of fault No. 4.

12/ Ulrich, E. O., and Smith, W. S. T., op. cit., pp. 166, 176.

Slickensides along fault No. 4 are almost vertical, but in fault No. 4a the striae are inclined about 30° from the vertical thereby indicating that the movement had a horizontal component. As few fault surfaces could be observed, either underground or in outcrops, the inclination of slickensides ordinarily could not be measured. In such a complexly faulted area, however, movement along many of the faults probably had a horizontal component.

Some post-mineral movement took place, as the brecciated ore in the Columbia and Mary Belle mines indicates.

ORE DEPOSITS

Considerable fluorspar along with some zinc and lead ore has been produced from the mines in this area. The ore contains several minerals but consists principally of fluorite, sphalerite, and galena in a calcite and limestone gangue. Commercial utilization of this complex ore, which is usually fine-grained, has been greatly hampered by lack of selective flotation milling equipment in the district.

Mineralogy

The deposits contain relatively few minerals.

Fluorite.—The most abundant mineral is fluorite. It is found in many colors—principally white to brown, purple, or yellow—and no certain color seems to be restricted to any one fault. Purple fluorite appears to have been the latest variety deposited; it often coats fluorite of another color.

Small cubic crystals of purple and of clear fluorite are common in vugs in the vein material and the country rock. Crystals of galena as much as 1 inch on a side, together with very small crystals of sphalerite, are associated with the fluorite in some vugs. In these crystal aggregates, the sulfides appear to have been deposited later than the fluorite.

Clear to yellow fluorite and calcite have cemented limestone breccia in several places, and in the Columbia mine this variety of fluorite forms a network of veinlets in a clayey gouge. The calcite and limestone in these breccias have been replaced to some extent by fluorite.

In the zinc-free "coon-tail" ore mined from shallow depths near the southeast end of the Eureka fault, bands of relatively pure purple and clear fluorite alternate with fine-grained bands of impure fluorite containing silica and calcium carbonate. Bands of fluorite also alternate with sphalerite-rich bands in the high-zinc "coon-tail" ore that is now being mined from a depth of 60 feet along the Eureka fault through the Eureka shaft.

The "gravel spar" in the overburden usually consists of iron-stained, very cellular fluorite in lumps less than 4 inches in diameter. Vugs retaining the outline of leached-out particles offer abundant evidence of the removal of calcite and limestone fragements from the fluorspar in ore of this type. Galena remains practically unaltered where it is associated with the "gravel-spar", but may be stained with pyromorphite. Sphalerite is usually altered to smithsonite.

Sphalerite.--The second most abundant ore mineral in the Columbia mine area is sphalerite (zinc sulfide), and in parts of the area, this mineral predominates. The sphalerite is largely bright reddish brown in color. It is commonly well developed near the outer margins of fluorite veins. Sphalerite also fills small fractures in the limestone wall rock or is disseminated through and replaces the wall rock. In some places it is the predominant ore mineral associated with calcite. The zinc rich bands in the "coon-tail" ore are high in sphalerite; the mineral is also found in small veinlets in or disseminated through veins composed chiefly of fluorite.

The sphalerite usually is very fine grained. Small crystals of sphalerite, generally distorted tetrahedrons, also occur in vugs in the vein material and in the country rock. Most of the sphalerite above a depth of 50 feet has been altered to smithsonite.

Galena.--Considerable galena (lead sulfide) is present in the area; indeed, the Columbia mine was first opened in search for galena that was reported to contain silver.[13] Several tons of galena were mined from the Columbia mine and from the Eureka vein and sold as pig lead after smelting.

Galena is segregated in crystal aggregates as much as a foot across. It also is found intimately associated with sphalerite in ore composed principally of the zinc sulfide. Cleavage faces on galena are generally slightly curved. The galena is reported to contain from 2 to 5 ounces of silver per ton.[14] There may be some relationship between the silver content and the curved cleavage faces. Some of the galena in the oxidized zone (above 50 feet) is stained with pyromorphite.

Other Minerals.--The principal gangue mineral is milky-white to gray massive calcite. Barite is relatively rare. Quartz is rather scarce in the veins, but small dark gray to black doubly terminated crystals about 1 millimeter long are abundant in the Ste. Genevieve limestone along the footwall of the vein at the Columbia mine. A specimen dissolved in hydrochloric acid left a residue of quartz which constituted 15 percent of the rock.

13/ Ulrich, E. O., and Smith, W. S. T., op. cit. pp. 20, 169.

14/ Ulrich, E. O., and Smith W. S. T., op. cit. p. 18.

Small crystals, nodules, and veinlets of marcasite and pyrite are scattered throughout the ore and fractured country rock. The amounts of both minerals are small, but marcasite is the more abundant.

Massive gray smithsonite (zinc carbonate) and greenish pyromorphite (lead chlorophosphate) occur in the oxidized zone along most of the faults in this area. Considerable quantities of smithsonite have been mined and marketed. Yellow-green greenockite (cadmium sulfide) was observed in close association with sphalerite in ore on the dump at the Craighead No. 2 shaft.

The veins

The ore deposits are fissure fillings accompanied by some replaced wall rock along the faults. Vein widths range from 6 inches to 12 feet. Much of the fluorspar mined from this area has come from residual deposits concentrated in the overburden. Where no work has been done beneath these deposits, the relations of the vein and the wall rock are not known.

According to mine maps, the Mary Belle vein (in fault No. 3) averaged 3 to 6 feet in width. In a drift that was driven for a distance of 350 feet along fault No. 5 on the 350-foot level, the vein, according to Mr. A. H. Reed, Sr., averaged about 1 foot in width and the main ore was galena. In the Craighead mine, the vein width in fault No. 4a averages about $3\frac{1}{2}$ feet, whereas, the widths along the part of fault No. 4 that has been explored range from 6 inches to 12 feet and average 6 feet over a linear distance of 100 feet.

In the workings from the Eureka shaft the vein along the Eureka fault ranges from 6 inches to 3 feet in width. Replacement of the wall rock was greater than usual along this fault, however, and minable ore widths therefore range from 2 feet to 8 feet. The vein material consists chiefly of fluorite with some sphalerite and calcite, but the material replacing the limestone wall rock is principally red sphalerite.

Vein widths in the Columbia mine range from 3 to 12 feet. Large parts of the vein are composed of brecciated limestone cemented and partly replaced by ore minerals. The limestone wall rock has been replaced to a considerable extent by red sphalerite. In some places in the Columbia mine, veinlets of fluorite and sphalerite ramify in a network through the clayey gouge. South of the Davidson shaft, fluorspar is the chief ore mineral but north of the shaft and below the 150-foot level, sphalerite and galena predominate.

The wall rock is strongly silicified in the area. Silicification is especially common in the Columbia mine where the footwall of porous oolitic limestone contains as much as 15 percent of doubly terminated quartz crystals about 1 millimeter long. Along other faults in the area both sandstones and limestones are highly silicified near the fault, but limestone containing quartz crystals was not observed elsewhere.

A lamprophyre dike traverses the area, and some fluorite and zinc ore is reported to be associated with it. None of the workings cutting the dike are now accessible, but dike rock on the dump of the Rock shaft contains traces of sphalerite and fluorite.

Access to underground workings in the area is at present too restricted to reveal enough data for making generalizations about mineralization in the vicinity of fault junctures.

Origin

The vein material is believed to have been deposited by ascending solutions derived from a deep seated magmatic source. The lamprophyre dike was intruded prior to mineralization, but it is possible that the same magmatic source in a later stage of differentiation furnished the fluorine-rich solutions.

The "coon-tail" fluorspar along the Eureka fault closely resembles the bedded deposits of the Cave In Rock district, Ill. The Kentucky ore apparently had the same mode of origin—that is, replacement of the favorable Ste. Genevieve limestone with retention of the banding and cross-bedding of the limestone.15/

Abundant evidence of replacement both of the wall rock and of the vein calcite is available. Sphalerite in considerable quantity occurs as the result of replacement, particularly in the Columbia and Eureka mines. No microscopic studies have been made as yet, so a detailed description of this phenomenon is reserved for a later more detailed report.

Considerable amounts of "gravel spar" have been mined from the overburden above faults Nos. 4, 2, 1, 8 and 6, and smithsonite has been mined from the upper parts of faults Nos. 6 and 8. Weathering was the dominant process in the concentration of these ores. The porous oolitic limestone

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15/ Currier, L. W., Origin of the bedding replacement deposits of fluorspar in the Illinois field: Econ. Geology, vol. 32, No. 3, pp. 364-386, 1937.

that formed one or both walls of the veins in areas along which "gravel spar" has been found had comparatively little resistance to weathering and was decomposed to a considerable depth. Fluorspar is very resistant to chemical decomposition but breaks down mechanically into large lumps and gravel. As a result the fluorspar becomes a residual concentrate in the overburden left by the weathering of wall rock and vein material. The calcite and other more readily soluble minerals in the vein are leached and leave a relatively pure fluorspar concentrate. In this way, the fluorspar content of a deposit originally extending 100 feet or more in depth may be concentrated in a residual deposit 20 or 30 feet thick.

Smithsonite is believed to have been formed through the reaction between sphalerite and ground water containing carbon dioxide. The smithsonite deposits are usually considerably wider than the associated sulfide deposits.

Localization of ore bodies

The ore bodies lie along the faults of the system, but mineralization is not uniform, and the cause of its localization in certain parts of the faults is not fully known. Exploration in the Columbia mine area is not extensive enough to warrant any generalizations regarding the structural control of ore deposits. Because the faulting is unusually complex, future development and testing in this area should yield pertinent data as to whether fault junctures were an important controlling factor in ore deposition.

In the Kentucky flurospar district, if shale forms one of the walls of a fault, conditions usually have been found to be unfavorable for the accumulation of ore; however, even though the northwest wall of the Columbia fault is composed of shale from the 80-foot level through the 135-foot level, ore widths of as much as 12 feet are known. Along this wall, a rather siliceous "crust" ranging from 6 inches to 1 foot in thickness holds back the more plastic shale. Possibly the character of the wall rock has less effect than heretofore believed on the localization of ore bodies, or else not all the factors that may affect the character of the wall rock--for example, silicification and brecciation--have been given adequate consideration.

Sphalerite, which has replaced the limestone wall rock in considerable quantity, may be seen in the workings from the Eureka shaft. Occasional pockets of "coon-tail" ore have been found in these workings. A small deposit of zinc-free "coon-tail" ore was mined from the Eureka vein south of these workings, at a depth of 20 to 40 feet. These deposits closely resemble the bedding-replacement ore bodies of the Cave In Rock district, Ill., which are generally considered to be the result of

replacement of the Ste. Genevieve limestone at a "favorable horizon". The presence of banded ore in the Columbia mine indicates that replacement was an effective process in the formation and localization of some of the ore bodies.

Deposits of "gravel spar" and smithsonite are concentrated in the oxidized zone.

Reserves

The reserves of measured ore are negligible in the mines of this group. The practice has been to mine the ore as development progressed. Any estimate of reserves, therefore, must necessarily include only indicated and inferred ore.

Columbia mine.--The writer's examination of the Columbia mine was not extensive enough to warrant computing reserves solely from the data obtained in course of this investigation; however, by using data taken from mine maps and other sources, including assays of samples cut by Fred Meek, 8,000 tons of indicated ore is estimated. Of this 8,000 tons, 6,000 tons is ore containing 30 percent of CaF_2, 6 percent of zinc, and 2 percent of lead; the remaining 2,000 tons of ore contains 5 percent of fluorite, 20 percent of zinc, and 6 percent of lead. Development of the deposit is not extensive enough to warrant a really adequate reserve estimate, but from the information at hand, it is believed that more than 20,000 tons of ore may be inferred.

Craighead mine.--In the Craighead No. 1 mine, operations have been carried on by underhand stoping, and no appreciable amount of ore has been developed ahead of production. Because of this fact and because of the very spotty nature of the ore, reserves of any kind are difficult to estimate. The ore in fault No. 4a ranged in width from 3 to 5 feet through a distance of 110 feet, but the ore body pinched at each end. No attempt has been made to drive through these pinches. A pocket of ore having a maximum width of 12 feet and a length of 80 feet has been mined from fault No. 4. This ore shoot pinched at both ends. By conservative estimate, 1,000 tons of indicated ore probably remain in this mine.

Eureka mine.--As at the Craighead No. 1 mine, no appreciable reserves are blocked out in the Eureka mine. Ore widths range from 6 inches to 8 feet through the 100 feet of vein that has been worked. The ore in the floor of the drift is wider and more persistent than that above the level now being mined. The estimated reserve is 1,000 tons of indicated ore.

Mary Belle property.--The workings on the part of the Mary Belle property mapped in this area have not been in operation since 1930 and were not accessible for study. Inasmuch as the part of the property shown in plate 2 is generally considered to be depleted of ore, and as a mine examination could not be made, no reserves are estimated. The reserves on the part of the property lying south of the Columbia mine area (see pl. 1) are to be considered in a later report.

Production and possibilities in the area.--Excluding the Mary Belle property, about 35,000 tons of ore has been produced from the Columbia mine area even though less than 15 percent of the lengths of the faults on the property has been prospected below a depth of 50 feet and at least half of the fault lengths remain untested. As previous prospecting in this area has been so fruitful, exploration along the unprospected lengths of faults reasonably may be expected to reveal new ore bodies.

Because of the geologic factors involved, faults Nos. 1, 4, 6, and 9 are believed to offer the best chance of yielding new ore bodies.

INDIVIDUAL MINES AND PROSPECTS

Columbia mine

The Columbia mine has been operated at various times from 1835 until the present. The Columbia shaft is now caved from the surface down to about 50 feet, but the mine can be worked through the Davidson shaft, which has been sunk on the vein to a depth of 200 feet. At present the workings are filled with water and are inaccessible. This mine was examined in February 1903 by Mr. F. J. Fohs and the results of his examination were published by W. S. T. Smith.16/ At that time the entire 80-foot level could be examined, and the description of the now inaccessible part of the 80-foot level north of the Columbia shaft is taken from Fohs' description. The mine was examined by F. J. Meek in July 1942, six samples were cut, and a private report written.17/ The writer made a very brief examination of the mine in the company of J. S. Williams in December 1942 just before it was closed.

16/ Ulrich, E. O., and Smith, W. S. T., op. cit., pp. 169-175.

17/ Meek, F. J. Mine examination and ore utilization report of the Columbia Mines group, Marion, Ky. (Manuscript of report on private investigation) 8 pp., 2 pls., July 5, 1942.

On the 80-foot level (see pl. 3), the drift is in the fault and for about 75 feet trends N. 35° E. from the Columbia shaft; it then swings sharply to a course of N. 20° E. and continues for about 30 feet. At the point where the fault turns, a cross fracture in the shale of the west wall contains a seam of sphalerite and galena 3 inches thick. The opposite wall also shows cross fracturing at this point. In the part of the drift northeast from the shaft, except for the sphalerite in the west wall, ore was noted by Fohs only near the shaft, where medium-grained sphalerite with little or no galena is disseminated in limestone.

A drift southeast along the Eureka fault from the 80-foot level (see pl. 3) extends for a distance of about 125 feet. Fohs noted no ore in this drift except near its mouth where a small body of disseminated sphalerite ore 2 feet wide occurred. Occasional patches of ore are said to have been encountered while driving the drift.

On the 80-foot and on the 135-foot level, the ore in that part of the vein southwest of the Davidson shaft contains from 20 percent to 70 percent of fluorite and a considerable amount of sphalerite and galena, but the ore north of the Davidson shaft contains very little fluorite. The analyses of samples in the accompanying table are taken from Meek's report.[18] (See pl. 3 for location of samples.)

Analyses of samples from Columbia mine

Location	Sample No.	Length of Cut		Content			
		Ft.	In.	SiO_2 (percent)	CaF_2 (percent)	Zn (percent)	Pb (percent)
80-foot level NE.	101	3	0	42.70	2.38	18.0	5.01
do.	102	4	3	44.94	.86	17.97	8.85
do.	103	4	10	46.40	1.40	16.67	7.14
135-foot level SW.	201	10	0	11.16	56.06	2.11	2.67
do.	202	11	6	8.90	45.76	2.31	.53
do. NE.	301	7	6	57.36	2.46	20.28	2.77

These analyses show that the sulfide content varies greatly throughout the mine, but that in general the ore contains more fluorspar south of the Davidson shaft than to the north. The ore is very siliceous particularly where it is composed of limestone breccia cemented with ore minerals.

18/ Idem.

In the southeast drift on the 135-foot level the writer observed 10 feet of fluorspar ore composed of 3½ feet of very high-grade yellow fluorite and 6½ feet of disseminated fluorite in a clay and limestone gangue. This locality is probably the source of Meek's sample No. 201. The face at the south end of this drift is massive limestone in practically flat-lying beds. At the time of the writer's brief visit a later, more comprehensive examination was contemplated, so this part of the mine was not examined in detail. The closing of the mine unfortunately prevented further observation. It is believed, however, that fault No. 8 probably joins the Columbia fault (No. 6) near this point. The complex fracturing and possible offset of fault No. 6 resulting from such a juncture may be a cause that contributed to the miners "losing the vein." A chip sample cut by O. W. Greenman, Corod metallurgist, from the southeast wall where a small jack stall was shot into the wall (see pl. 3), analyzed 45.76 percent of CaF_2 and 2.31 percent of Zn. When the mine is reopened, a more detailed examination is planned.

The 170-foot level was not accessible to Meek but was seen by the writer. The vein is about 5½ feet wide, and the ore consists primarily of sphalerite in a calcite gangue. This ore is estimated to contain about 20 percent of Zn.

Mary Belle mine

The Mary Belle No. 1 and No. 2 shafts are located on the Mary Belle property but mining on the Columbia property was carried on through both shafts. These shafts were closed in 1930, but mine maps show the extent of the workings. A more comprehensive discussion of this mine is reserved for a later report which will cover the Mary Belle and other properties lying southward along the Crittenden Spring fault system.

The Mary Belle vein (fault No. 3) was mined to a depth of 350 feet from the Mary Belle No. 1 shaft. The ore consisted chiefly of fluorspar with some sphalerite and galena and ranged from 6 inches to 8 feet in width. The ore in the northern part of the workings contained more sulfides than that in the southern part. A drift was driven northwest along fault No. 5 for a distance of about 300 feet but probably never reached fault No. 4. According to Mr. A. H. Reed, Sr., as far as this fault was explored it contained about 1 foot of high-grade lead ore associated with calcite. About 40,000 to 50,000 tons of ore was mined from this shaft, about 40 percent of which came from the Columbia property. A crosscut driven east on the 300-foot level from the Mary Belle shaft cut a small fluorite vein about 1 foot wide at a point 250 feet from the shaft. This vein may be in fault No. 2 or possibly is in another small fault lying between faults Nos. 1 and 2.

Fault No. 1 was mined to a depth of 200 feet for a distance of 500 feet southwest from the Mary Belle No. 2 shaft. Above the 200-foot level the ore ranged from 2 to 9 feet in width but pinched to a few inches in the floor of this level. About 25,000 tons is estimated to have been mined from this fault. No exploration below a depth of 50 feet has been carried out on the fault No. 1 on the Columbia property.

Craighead mine

The Craighead shaft is 150 feet deep and was sunk in fault No. 4a. Crosscuts on the 90- and 120-foot levels have been driven west to fault No. 4, and both faults are being mined from the shaft. The mining is done by underhand stoping.

The ore in fault No. 4a ranges from 3 to 5 feet in width and consists chiefly of fluorite and calcite with some sphalerite and occasional lumps of galena. The ore mined from fault No. 4 was in a large pod-shaped pocket having a maximum width of 12 feet, but it narrows and pinches both northward and southward.

A short extension called the "zinc" drift was driven southwest from the south end of the drift on the 120-foot level in fault No. 4a to mine a fissure containing about 3 feet of sphalerite-rich ore. This drift was abandoned because of the high zinc content.

The accompanying table presents analyses of samples taken by O. W. Greenman, metallurgist for the Corod Minerals Corporation, on October 15, 1943. The locations of the samples are indicated on plate 3.

Analyses of samples from Craighead mine

Sample and location	Constituents (percentage)				
	CaF_2	Zn	Pb	$CaCO_3$	SiO_2
A-Composite grab sample from 2 muck piles at north and south ends of drift in fault 4	39.7	3.54	.25	43.61	10.89
B-Chip sample from east wall of fault 4 south of shaft on 120-foot level	17.02	3.54	.25	61.79	14.63
C-Chip sample from west wall of fault 4a 120-foot level south of shaft	22.41	2.08	.31	59.67	15.08
D-Grab sample from muck pile at face of zinc drift	34.89	4.58	.25	45.32	3.06

No work is being done at the Craighead No. 2 shaft at present.

Eureka mine

The Eureka shaft was sunk in the Eureka fault (No. 9) to a depth of 50 feet, and drifts were driven northwestward and southeastward.

The ore consists of fluorspar with some sphalerite and galena in a vein ranging from 6 inches to 4 feet in width along with a zone of limestone wall rock replaced by sphalerite on each side of the narrow vein. Ore widths range from 6 inches to 8 feet. In the northwest level, the fluorite-bearing vein is about 4 feet wide but it pinches to 6 inches at a point 40 feet from the shaft; however, the ore in the floor of this level is wider than that mined.

Occasional pockets of "coon-tail" ore have been found in the Eureka workings.

SUGGESTIONS FOR FUTURE EXPLORATION

With the exception of the mine workings and a large number of relatively shallow shafts sunk in search of "gravel spar", the faults in the mapped area have not been prospected. Fault No. 4 has not been tested south of the Reed shaft and several other faults are relatively untested.

Diamond drilling is believed to be the cheapest and quickest way of exploring the faults of this area. Faults Nos. 1, 4, 6, and 9 appear to offer the best possibilities for locating ore. The following general suggestions are based on geological conditions that appear to be favorable for exploration.

Fault No. 1.--Fault No. 1 has brought the Renault formation against the Ste. Genevieve limestone south of fault No. 5 and lies within the Ste. Genevieve north of fault No. 5. The Franklin, Ada Florence, and Keystone mines, which are south of the area mapped, are on this fault, and so far approximately 200,000 tons of ore have been shipped from them. On the Columbia property, the fault has not been tested below a depth of 50 feet, but a rather large amount of "gravel spar" has been mined above this depth. It is suggested that the fault be tested at depths of 150 and 300 feet south of fault 9, the intervals between holes being about 150 feet. About 3,000 feet of drilling would be required for this work.

If fault No. 1 is found to persist beyond fault No. 9, 1,500 feet of drilling could be used to test the fault at a depth of 150 feet, and 3,000 feet could be used to test it at a depth of 300 feet.

Fault No. 2.--The movement along fault No. 2 was not great, and the fault apparently dies out southward. Drilling on this fault is not recommended on the Columbia property.

Fault No. 3.--Fault No. 3 has been mined to a depth of 350 feet. The ore pinched at that level. No drilling is recommended on this fault at present.

Fault No. 4.--Along fault No. 4a the Tar Springs sandstone on the west lies opposite limestone of the Renault formation on the east. The stratigraphic displacement is about 500 feet. About 5,000 tons of ore has been mined over a strike length of 200 feet near the Craighead shaft, and some "gravel spar" has been removed north of this shaft. About 2,000 feet of drilling would be needed to test this fault at a depth of 150 feet if the holes were spaced at intervals of 150 to 200 feet. An additional 3,500 feet would be needed to test the fault at a depth of 300 feet.

Fault No. 5.--A drift on the 350-foot level driven along fault No. 5 from the Mary Belle Shaft showed about 1 foot of lead ore. Fluorspar containing zinc and lead has been mined from shafts less than 75 feet deep. Testing the fault at a depth of 150 feet might prove profitable. About 800 feet of drilling would be required.

Fault No. 6.--The Columbia fault has been mined to a depth of 150 feet, and the Davidson shaft is now 200 feet deep. About 10,000 tons of high-zinc fluorspar ore with some lead has been produced from the Columbia mine. Shallow shafts north of the Columbia shaft have yielded excellent lead and zinc (largely smithsonite) ore with some fluorspar. About 600 feet of drilling would be needed to test the fault length north of the shaft at a depth of 150 feet, and about 1,200 feet more would be needed to test the fault at a depth of 300 feet.

South of the Davidson shaft, the fault continues for some distance, but this southward extension has not been tested. About 2,500 feet of drilling could be used to test this part of the fault at depths of 150 to 250 feet.

Faults Nos. 7 and 8.--Faults 7 and 8 and the lamprophyre dike could be tested at depths of 100 and 140 feet respectively by one drill hole about 200 feet in length. A higher-angle hole from the same place would test the faults at 275 and 325 feet respectively.

Fault No. 9.--About 1,500 tons of ore have been mined from this fault, but mineralization has not been tested below 80 feet. About 1,000 feet of drilling could be used to test the fault at a depth of 125 feet, and about 2,000 feet to test at a depth of 250 feet.

Faults Nos. 10, 11 and 12.--No drilling is recommended on these faults at the present time.