GEOLOGY OF THE
FLUORSPAR DEPOSITS OF ILLINOIS

BY

J. MARVIN WELLER, ROBERT M. GROGAN, AND FRANK E. TIPPIE

WITH CONTRIBUTIONS BY

L. E. WORKMAN AND A. H. SUTTON

PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

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MANUSCRIPT COMPLETED FEBRUARY 1951
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GEOLOGY OF THE FLUORSPAR DEPOSITS OF ILLINOIS*

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WITH CONTRIBUTIONS BY

L. E. WORKMAN AND A. H. SUTTON

CHAPTER 1—INTRODUCTION

This report on Illinois fluor spar1 is based largely on a series of investigations by Weller, Grogan, and Tippie, of the Illinois State Geological Survey, made between 1942 and 1945 in connection with war industries surveys cooperatively with the United States Geological Survey, the United States Bureau of Mines, and the Reconstruction Finance Corporation, and by Sutton in his capacity as geologist of the Aluminum Ore Company (now the Alcoa Mining Company). During this time all the important and many of the less important fluor spar properties were examined and many confidential reports were prepared for the Federal agencies and owners. This bulletin includes material from those reports which is of general and more or less lasting interest.

Although responsibility for various parts of this report is shared by the authors, their general duties have been as follows:

J. M. Weller—General supervision of the field work of the Illinois Geological Survey; general geology (stratigraphy and structure) and paleontology of the area; detailed studies in the Rosiclare district; examinations in the outlying district; general supervision of the preparation of this report.

R. M. Grogan—General review of history, production, and uses of fluor spar; detailed studies in the Cave in Rock district; description of igneous rocks; collection of data concerning outlying properties and prospects; editing and revising of text.

F. E. Tippie—General subsurface geology of the ore-bearing formations; mining, milling, and prospecting methods; examination of several outlying properties.

L. E. Workman—Subsurface stratigraphy of the deeper formations.

A. H. Sutton—Detailed studies of the Alcoa Mining Company's properties.

The Illinois-Kentucky district is the most important fluor spar producing center in the world. From 1913 through 1947 (omitting 1940 and 1941), it produced 91.0 percent of the domestic and 33.5 percent of the world's supply. During these same years 60.6 percent of the district's production came from Illinois. This is equivalent to 55.2 percent of the domestic and 20.3 percent of the world's production. In spite of its outstanding position, however, many of the mining operations of the Illinois-Kentucky district are conducted on a comparatively small scale, and until recently the study of geology has played a very small part in both the development and operation of the mines.

Previous geologic studies of the Illinois portion of the district were made in 1904 by Bain,3 in 1917-18 by Weller and Currier,4 in 1926 by Bastin,5 and in 1934 by Currier and Wagner.6 Between 1935 and 1942, when the most recent investigations were begun, few geologic observations were made in the Illinois district. Most of the prospects and many of the smaller mines were never examined

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*This report is a contribution of the Industrial Minerals Division.

3 Following the accepted custom, the terms fluor spar and fluorite are used interchangeably throughout this report to denote the mineral form of calcium fluoride. Spar is a colloquial form of fluor spar.


by a geologist during the time they were open, and even in the larger and more permanent mines geologic study has been largely limited to active workings. Consequently much potentially valuable geologic information was not obtained at the only time that it might have been recorded. Altogether it is surprising how little reliable geologic information respecting many properties is now available. Many of the smaller operations were never surveyed, and reports regarding the extent of underground workings and character of the ore are commonly conflicting. Even for the larger mines, records are largely restricted to notations as to local widths of vein or workable ore, and information regarding character of the vein and wall rock is almost completely lacking. Likewise the data derived from past diamond drilling is inadequate because the cores were not examined by a geologist or were not saved.

Bain's observations were made before fluorspar production in Illinois achieved much significance, and consequently they were comparatively superficial. During the time of Stuart Weller's and Currier's studies, most of the production was obtained from the vein mines at Rosiclare, but the Hillside mine had not yet been fully opened. At the time of Bastin's investigation, only the Hillside mine and part of the Daisy mine were available for observation, and production in the Cave in Rock district was only beginning to become important. During the time of Currier's later investigation, the deposits of the Cave in Rock area had been extensively opened but production was at comparatively low ebb. Stuart Weller's studies were largely devoted to the surface mapping of the geology of the fluorspar region. Currier's earlier observations and those of Bastin were mainly directed toward determining the paragenesis of the vein-forming minerals. Only in Currier's later studies was attention directed importantly toward the geologic relations of the ore bodies, and such work was restricted to the Cave in Rock area.

During the period of latest study, large parts of the older Rosiclare mines were not accessible. Great expansion, however, had occurred in the Cave in Rock district and observations of the bedded deposits were possible on a scale never before equalled. Also the detailed prospecting by core drill and the rapid development of new workings in the Blue Diggings mine furnished much more complete data on this type of vein deposit. Consequently the most important parts of the studies here reported are those dealing with the Cave in Rock district and the property of the Alcoa Mining Company at Rosiclare. An attempt has been made throughout, however, to relate both types of deposits to details of the local stratigraphy and structure, and several important generalizations and conclusions have been reached.
CHAPTER 2—HISTORY OF MINING

EARLY HISTORY, 1839–1910

Prior to the advent of the white man, Indians or prehistoric peoples carved ornaments and images from colorless fluor spar. It is said that the small turtle was a favorite design. Although the exact source of the fluor spar so used is not known, probably most of it came from the weathered outcrops of veins in Illinois and Kentucky. Because of its softness and ready availability in beautiful colors, fluor spar has continued to the present day to be a favorite medium for the carving of small ornamental objects.

The recorded history of mining in the fluor spar-producing region of southern Illinois is largely that of the Rosiclare district where most of the important early mining ventures took place. The early accounts of mining contain only brief references to operations in Pope and Hardin counties.

For many years the deposits were worked for their content of galena, the sulfide ore of lead. The fluor spar mined with the galena was largely discarded as waste, for it had only a limited market, chiefly for the manufacture of hydrofluoric acid, the preparation of glass and enamels, and as a flux in the melting of iron for foundry use and the smelting of gold, silver, copper, and lead.

According to Norwood the first discovery of lead ore in the Rosiclare district was made in 1839 during the sinking of a well near the Ohio River on the farm of Mr. James Anderson, about a mile southwest of the village of Rosiclare, on what is now the property of the Alcoa Mining Company. This well and a second dug in 1841 encountered a vein subsequently termed the "Anderson's Well Lode" which many years later was mined as part of the Fairview-Rosiclare vein system.

Early in 1842 Mr. William Pell discovered fluor spar and galena on his farm about one-half mile northwest of Rosic'are. His findings resulted in the first known mining operation in the Illinois fluor spar district, post-dating by seven years the first important similar mining venture in Kentucky near the site of the present Columbia mines in Crittenden County. Development of the Pell mine, now part of the Rosiclare mine, continued until 1850 when operations were temporarily suspended. Galena was the principal mineral sought and recovered.

Mining on the Blue Diggings vein, on the land of James Anderson several hundred yards west of the Pell mine, began in 1843, and on the Good Hope vein, also on Anderson's land, in 1844. Work on the Good Hope vein was continued until 1851, during which time several shafts 40 to 80 feet in depth were sunk within a distance of 200 yards. Beginning in 1847, the Good Hope Engine Shaft was sunk to an ultimate depth of 130 feet. It is said that galena in fluor spar gangue was encountered throughout the whole depth, and that it became more abundant as the depth increased. Operations on the Good Hope vein were suspended in 1851. As in the Pell mine, the recovery of galena was the principal reason for these mining operations.

Regarding later mining on the Good Hope vein, Bain stated that operations were practically continuous from the time of the sinking of a new shaft in 1862 until 1874, the lead ore produced being smelted on the property. Three smelters were built, two of which were destroyed by fire, and the third was torn down about 1888. The dumps of fluor spar waste from lead mining were milled and sold in 1889 and 1890. From 1891 to 1895 the property was operated by the owners of the Rosiclare mine.

In 1852 Prof. G. J. Brush visited the Rosiclare district and apparently was able

[11]
to enter some of the mines. He obtained specimens of galena which assayed four ounces of silver to the ton.\(^8\)

The early records are confusing and incomplete, but apparently lead mining continued in a small way into the early seventies, stimulated for a while by the demand created by the Civil War and later depressed by a fall in the price of lead. The early period of lead mining resulted in the finding of three of the veins which later became the principal producers of fluorspar in the Rosiclare district. As indicated or suggested by Norwood's notes and by maps prepared under his direction before 1858, these veins were those now known as the Rosiclare (or Rosiclare-Good Hope- Extension) vein, Blue Diggings vein, and Argo vein. It is possible that by 1860 mineralization also had been discovered on the Eureka (or Clement) vein, as Worthen\(^9\) wrote of the McAllen diggings in the SW ¼, sec. 21, three miles northeast of Rosiclare, which could be on the northern extension of this structure.

Shipments of fluorspar from Illinois mines apparently began in the early seventies.\(^10\) It is said that in 1870 fluorspar was ground in buhrstone mills, and that in 1878 "gravel spar" too small for "lump" was shipped.\(^11\) It is probable that Illinois and Kentucky began shipping fluorspar at about the same time. Fobs\(^12\) stated that the first shipments from Kentucky were made in 1870 from the Royal mines, but according to Smith\(^13\) the first shipments were made from the Yandell mine in 1873.

S. F. Emmons visited the Rosiclare district in 1891 and found most of the mines inactive.\(^14\) He mentioned a recently opened shaft on the Daisy vein, 40 feet deep, and also workings on the Eureka vein northeast of the Daisy shaft; it thus appears that both of these veins were known before 1891.

Although principal attention was directed to the deposits in the Rosiclare district, occurrences of lead and fluorspar in other parts of Hardin and Pope counties also received early notice.

As early as 1819, Schoolcraft\(^15\) recorded the occurrence of "fluate of lime" about three miles back of Cave in Rock, 15 miles below Shawneetown, which was probably in the vicinity of Lead Hill. During his travels in 1821, he visited abandoned lead diggings at the same locality, where galena and fluorspar were obtained from an oolitic limestone.\(^16\)

In the second edition of Cleveland's Mineralogy\(^17\) fluorspar is reported to occur in alluvial soil and in veins in limestone at the three forks of Grand Pierre Creek,\(^18\) on Peters Creek, and for 30 miles southwest of Cave in Rock.

In a paper read in 1842,\(^19\) D. D. Owen stated that 30 to 40 miles west of Shawnee-town limestones are traversed by small veins of galena, "fluate of lime," and sulphate of barytes. He noticed a vein of compact fluorspar 18 inches wide cutting in a north-easterly direction across the bed of a tributary of Grand Pierre Creek.

The lead workings on Lead Hill were also mentioned by Worthen\(^20\) who stated that mining was in progress about the year 1850. He recorded that numerous holes were dug in limestone in the western slope of the hill, some 60 feet below the base of the overlying sandstone. The material mined was a mixture of decomposed limestone, fluorspar, calcite, and some galena, which was obtained from irregular openings in the limestone having a "general direction."

In Pope County the presence of fluorspar or of galena and fluorspar was observed by


\(^9\) Worthen, A. H., op. cit., p. 373.


\(^13\) Fobs, idem.


\(^16\) Schoolcraft, H. R., A view of lead-mines of Missouri, p. 191, New York, 1819.

\(^17\) Schoolcraft, H. R., Travels in the central portions of the Mississippi Valley, pp. 189-196, New York, 1825.

\(^18\) Cleveland, Parker, An elementary treatise on mineralogy and geology, 2nd ed., p. 202, Boston, 1822.

\(^19\) Possibly referring to the Empire district in northeastern Pope County.


\(^21\) Worthen, A. H., op. cit., p. 373.
Englemann\(^{22}\) in the vicinity of the present Compton mine near the mouth of Bay Creek; along Lusk Creek fault zone in the vicinity of the present Clay Diggings, Scott, and Lost 40 properties; on Big Grand Pierre Creek at the Stockton (or Stogdon) locality; and in the Empire district, which Englemann stated was explored by various persons in 1849 with unsatisfactory results.

At the time of Bain's study of the fluor spar area (1903) a number of outlying properties were known in Hardin and Pope counties which were not mentioned by earlier writers. Among these\(^{22}\) were the Hamp, Pell, Stewart, Oxford and Watson, Cook, Parkenson, Gordon, Lead Hill (including workings along the Spar Mountain escarpment east of Lead Hill), and Eureka (along Peters Creek fault in eastern Hardin County).

Thus by 1903 both the Rosiclare and Cave in Rock districts appear to have been well known, and many smaller deposits also had been discovered.

**LATE HISTORY, 1910–1945**

The year 1910 makes a convenient date for separating the early mining period from the later period. Milling capacity of the two most important plants, the Fairview Fluorspar and Lead Company and the Rosiclare Lead and Fluorspar Mining Company, was being increased by this time and the annual production of concentrates was rising rapidly. The Rosiclare district was entering the modern era of large scale production.

In 1905 the Fairview mine and remodelled mill were able to produce about 50 tons, and the Rosiclare mill was turning out about 25 tons of spar daily.\(^{23}\) In 1909 the Fairview mill was being rebuilt to increase its capacity to 300 tons a day, and the Rosiclare company completed its new mill of 500 tons crude ore capacity in the spring of 1911. In 1911, Illinois produced 68,817 short tons of fluorspar, some 45 percent more than was produced in 1910, and exceeded the 50,000-ton mark for the first time.

In 1910 work was begun on the Blue Diggings vein by the Fairview Fluorspar and Lead Company. An effort to use an old shaft was abandoned and a new shaft started. The same company began work on the Annex and Extension mines in 1911. World War I brought a hitherto unprecedented demand for fluorspar and greatly stimulated exploitation of existing deposits and the search for new ones. No new large deposits were found, but dozens of small mines and prospects were opened or explored.

In 1919 a branch of the Illinois Central Railroad was extended from Golconda to Rosiclare, permitting the shipping of fluorspar by rail. Prior to that time all shipments were made by barge on the Ohio River. Also in 1919, the Rosiclare Lead and Fluorspar Mining Company was formed through reorganization of the earlier Rosiclare Lead and Fluorspar mines. Former operators of the property included the Argyle Lead and Fluorspar Mining Company, which acquired title in 1892, and later the Pell Fluorspar Mining Company.

After several years of exploration, the operators began to sink the Hillside shaft of the Hillside Fluorspar Mines in 1919. Construction of the mill was begun in 1920, and production began in April 1922. As the result of a program of exploratory churn drilling, the Argo vein on the property of the Fairview company was opened by a prospect shaft in 1922.

In the three months from November 1923, to January 1924, practically all the mines along the entire Fairview-Rosiclare vein were flooded as the combined result of an unfortunate set of circumstances. In November the Annex and Extension workings were flooded by a large flow of water, apparently from Ohio River, which was encountered in a raise from the 200-foot level of the Extension workings near the Anderson Well shaft. Some 3,000 gallons per minute were being pumped when operations ceased.

In January the Rosiclare mine also was flooded. The mine had been pumping from
1,000 to 1,200 gallons of water per minute, about half of which was overflow from the Good Hope No. 4 mine on the property immediately to the south. As the 620- and 720-foot levels of the Rosiclare mine were driven northward, increasing amounts of water were encountered which taxed the capacity of the pumps. Heavy autumn rains had caused a cave-in from the surface north of the plant shaft. Surface water thus dammed at the 500-foot level finally broke through and entered the lower workings. High water in Ohio River increased the inflow from the Good Hope workings until on January 19, 1924. 3,500 gallons per minute were being pumped and bailed from the mine. This was too great a load for the pumps and bailers, and after as much as possible of the electrical and other equipment had been removed, the pumps were stopped and the Rosiclare mine allowed to fill. It remained out of production for 16 years until unwatered in 1940.

The Fairview Fluorspar and Lead Company was sold to the Franklin Fluorspar Company, a subsidiary of the Aluminum Company of America, on November 17, 1924. During the next 12 years, until the Blue Diggings mine was unwatered in June 1937, the Franklin Company mined little ore in the Rosiclare district. Although its Hamp mine in northern Hardin County produced briefly, the company's chief mining activity was centered in Kentucky. After many years' experimentation, in cooperation with the United States Bureau of Mines, the Franklin Company built the first froth flotation mill at Rosiclare, which was put into operation March 18, 1929. The mill was designed to produce acid-grade fluorspar concentrate from gravity mill tailings, and for a number of years operated on such tailings brought in chiefly from Kentucky.

With their Rosiclare mine flooded, the Rosiclare Lead and Fluorspar Mining Company maintained its large mill output by intensified mining on the Daisy vein and the Blue Diggings workings reached from the Daisy shaft. Additional ore was obtained from the Eureka property in the Rosiclare district and from the Empire mine in eastern Pope County. Throughout the long period when the Fairview-Rosiclare mine was flooded the Daisy and Hillside mines were the chief producers in the Rosiclare district.

In June 1936, the flotation plant of the Aluminum Ore Company, successor to the Franklin Fluorspar Company, resumed operations after being idle since 1931.

In January 1937, Ohio River rose to its highest known level, cresting at 67.1 feet, 54.1 feet above pool stage, and exceeding the crest level of the 1913 flood by approximately 6 feet. The river first rose above normal flood level of 26 feet on January 4 and did not return to that level until March 3, eight weeks later. The district's only means of communication with the outside world were by boat and short wave radio, as the flood closed all roads and a heavy sleet storm broke all telephone and telegraph connections. Although all possible precautionary measures were carried out by the mining companies, the surface installations suffered extensive material damage as a result of the inundation, which also affected the business and part of the residential districts of the town. The Rosiclare mill was shut down from January 22 to March 4 and damages were estimated at $40,000.24 The mill of the Aluminum Ore Company was shut down for 60 days. The Fairview-Rosiclare mines, flooded since 1924, did not suffer much damage. The Hillside Fluor Spar Mines plant, located on higher ground, was able to furnish electric power for the community but its mill was shut down for six weeks because of flooding of the company's Lee and Keystone mines in Kentucky.

The differential flotation mill of the Mahoning Mining Company was completed and started operation in June 1939. The mill feed was a combination of purchased jig tailings and ore from the company's W. L. Davis mine. The Hillside company also completed a small flotation plant for treating its own mill tailings.

The unwatering of the Rosiclare mine was begun on June 4, 1940.25 A 3,200 gal-
HISTORY OF MINING

lon per minute Pomona pump installed in the main shaft lowered the water level from 200 to 600 feet below the surface in 20 days and this level was maintained until October 1940, when the water was lowered about 10 feet below the 620-foot level. Four 1,000 gallons-per-minute centrifugal pumps were then installed in a station on the 620-foot level at the main shaft, and the Pomona pump was moved to the Rosiclare shaft. These, together with a 500 gallon-per-minute pump in a shaft at the south end of the property, gave a combined pumping capacity of 7,700 gallons per minute. Production from the mine was resumed in 1941. A small flotation plant was installed at the Rosiclare mill in 1940.

The capacity of the flotation mill of the Aluminum Ore Company increased in 1941, and then was doubled in 1942 as the wartime demands for acid-grade concentrate increased. A diamond drilling campaign, started in September 1941, was successful in locating additional ore reserves, and soon the Fairview shaft and three smaller shafts were started on the southwestward extension of the Blue Diggings vein. The three small shafts were completed to 300 feet and production from them began in 1942. The 775-foot Fairview shaft, largest in the district, was completed and began operating in June 1943.

The Rosiclare Lead and Fluorspar Mining Company completed construction of the first heavy-media separation plant in the Illinois-Kentucky district in February 1944.26 This mill uses finely ground ferrosilicon and is said to have definite metallurgical and economic advantages over the jiggling operation formerly employed. The second such plant in Illinois was placed in operation in 1946 by the Aluminum Ore Company.

In March 1945, the Rosiclare district suffered another flood but property damage was somewhat less than in 1937. The Ohio River reached a crest of 57.37 feet on March 15, about 10 feet short of the 1937 mark. The aluminum and Rosiclare companies' mills ceased operating and rail service was interrupted. Most serious of all, water rose above the level of the collar of the Recovery shaft on the Rosiclare vein and entered the workings of the Rosiclare mine. As pumping capacity was inadequate to meet this situation, the pumps were stopped and the mine once more allowed to fill. Water from the Rosiclare mine then broke into the Hillside mine and subsequently from the Hillside into the Daisy mine. After the flood subsided, however, these mines were immediately pumped out. Future economic loss to mines and town from floods will be relieved by the construction of a floodwall for which Federal and State funds were appropriated in 1949.

In 1949 the Rosiclare Lead and Fluorspar Mining Company applied measures designed to control and reduce the flow of underground water into its Rosiclare mine, which early in the year amounted to about 8,000 gallons per minute. An additional deep-well pump was installed, and in April an apparently unsuccessful attempt was made to seal off watercourses by pumping cement grout into them. The mine was closed in July, and after suitable preparations it was allowed to fill with water so as to induce a static condition of underground water flow. In October and November further attempts were made to seal the main watercourses with cement grout, this time through pipes from the surface. As of the end of the year the mine was still flooded.

As the result of merger, purchase, or transfer, the names of three companies now or formerly operating at Rosiclare have been changed since the war, namely Hillside Fluor Spar Mines to Inland Steel Company, Hillside Works (June 1, 1945); Mahoning Mining Company to Ozark-Mahoning Company, Mahoning Mining Division (December 1, 1946); and Aluminum Ore Company to Alcoa Mining Company (January 1, 1948). Mining and milling activities at the Hillside mine by the Inland Steel Company were terminated in April 1948, and the mineral rights were later bought by the Rosiclare Lead and Fluorspar Mining Company.

The Cave in Rock district attained its position as an important producer of fluor­spar since 1918. In that and the succeeding year the Spar Mountain Mining Com­pany acquired mineral rights to land along the Spar Mountain escarpment which, from earlier work by the Cleveland-Illinois Company and others dating back to about 1900, was known to contain bedded de­posits of fluor­spar.

Mining by the Spar Mountain Company began in 1919 and continued until 1925, when that company was succeeded by the Benzon Fluorspar Company, which con­tinued operations until 1939. A number of deposits were worked, including the Oxford-West Morrison, Lead Mine, 32-Cut, Cleveland, Green, Defender, and East Green mines. This group, collectively known as the Spar Mountain or Benzon mines, passed its peak productivity in the early thirties. In 1930 the group produced 25,995 short tons of crude ore, and was the nation’s largest shipper of fluor­spar.

In 1927, Outwater, Schwerin, and Barnett (later the Victory Fluorspar Mining Company) sank the Carlos (No. 1) shaft on the westward continuation of the Green and Defender ore bodies and reached the ore level in December. Production began in 1928. Prospecting in the fall of 1929 disclosed a second ore body on the Victory property, which was later developed by the Addison (No. 2) shaft sunk in 1930.

The Benzon company completed and put into operation its new mill on the mine property on May 1, 1929. Before that time the crude ore was hauled to a mill on the river at Cave in Rock. Also in 1929 the Crystal (then the Austin) mine was opened east of the Benzon property, and operations were begun just before the end of the year. Production and development work continued and in 1931 the company completed the installation of a mill at the mine. A second ore body north of the original deposit was soon discovered by drilling, and later de­veloped by long drifts. Three shafts were sunk to facilitate mining operations on these two deposits. In 1944 a fourth shaft was put down on a third ore body north­east of the earlier workings, and subsequent­ly a number of other shafts were sunk on the property. The company installed a heavy-media plant at their mill in 1949. This was the fourth such installation in the Illinois district, the third being at the mill of the Alco Lead Corporation.

The deposits on Lead Hill were known very early in the history of the region, but probably did not come into important commercial production until a few years prior to 1917, when ownership passed into the hands of the Basic Mineral Company. Intermittent mining by a succession of opera­tors continued until 1934, when the Fluorspar Products Corporation (later the Fluorspar Products Company) succeeded the Pittsburg Fluorspar Products Company as operator of the principal mines. Most of the production from the Lead Hill mines has occurred since that time.

Prospecting by A. J. Lay and others disclosed the presence of a fluor­spar deposit rich in zinc and lead on land north of the Crystal mine, and in 1937 options on some 2,000 acres were acquired by the Mahoning Mining Company. By April 15, 1939, 125 churn drill holes 300 to 400 feet deep had been drilled and three bedded replacement deposits of fluor­spar had been located in an area of about one square mile. Two shafts sunk by the Mahoning Company opened the W. L. Davis-Deardorff and A. L. Davis mines. The company’s differential flotation mill on the railroad at Rosiclare, 17 miles away, was completed in June 1939 to treat ore from these mines. Acid and metallurg­i­cal grades of fluor­spar and zinc and lead concentrates are produced. In 1942 the West Green mine was opened, and the East Green shaft completed. Development work on the East Green deposit was completed in 1943 and in the same year the capacity of the mill was increased 50 per­cent. A second deposit on the W. L. Davis tract was opened by a new shaft completed in 1945, and the Deardorff No. 1 shaft was sunk in 1946 to facilitate hoisting of ore from the W. L. Davis-Deardorff de­posit. The North Green shaft was com-

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completed in the first half of 1949 and a shaft on the Ida Oxford property was begun later in the year.

Following 18 months of exploratory drilling, during which over 100 holes ranging from 450 to 800 feet deep were drilled on a 3,000 acre tract northeast of the holdings of the Mahoning Company, the Minerva Oil Company in 1942 began the sinking of the Ledbetter shaft to develop ore bodies. It was completed to 644 feet in September 1943, and mine development was begun immediately. A differential flotation mill at the mine location, built by the Defense Plant Corporation, was placed in operation in February 1944. It produces zinc concentrate, as well as ceramic and acid-grade fluorspar concentrates. The company commenced sinking a second shaft in 1949, which was to be 580 feet deep and to serve purposes of escape and service.

SUMMARY

The fortunes of the mining industry in southern Illinois have varied with the interplay of business conditions and changing emphasis on uses for the minerals produced. Successive outstanding events and developments in the growth of the industry may be listed as follows:

1) Change in emphasis about 1880 from mining for lead to mining for fluorspar due to decline in market price for lead and increase in demand for fluorspar.

2) Development of the basic open hearth method of making steel, in which fluorspar is used as a flux. The first such steel was made in the United States in 1888 and the production of fluorspar for this "metallurgical" use thereafter gained accordingly as the steel industry grew until in 1912 and 1913 production was almost 30 times greater than in 1880. Mining and milling operations in the Rosiclare district expanded with this general movement.

3) Advent of World War I with unprecedented demand and high prices for fluorspar. This combination occasioned the search for and development of numerous deposits in districts outside the area of main production at Rosiclare, one of the principal results being the inception of large scale mining in the Cave in Rock district.

4) Growth in production of fluorspar for metallurgical use and marked increase in production for ceramic and chemical uses between World Wars I and II.

5) Development of flotation process for making acid-grade fluorspar concentrate in the late 1920's and the installation of the first flotation plant at Rosiclare in 1929.

6) Inauguration of commercial production of Freon and anhydrous hydrofluoric acid in 1931, both of which require acid grade fluorspar.

7) Extension of Cave in Rock district to northeast and discovery of fluorspar-zinc deposits from 1937 to present. This added considerably to the resources of the region and also permitted mining lower grade fluorspar ore than was formerly possible because the zinc (and lead) also could be recovered from the ore and sold.

8) Advent of World War II and the several years of high production preceding it. The production of fluorspar used to make steel for munitions and aluminum for airplanes gained enormously.

9) Development of anhydrous hydrogen fluoride as a catalyst in the alkylation process for making high octane aviation gasoline, and other military chemical uses spurred production of acid-grade fluorspar greatly during the war. The first alkylation plant using anhydrous HF was built in 1942.

10) Adaptation of the heavy-media process of concentration to the milling of fluorspar ore, by means of which plant efficiency is increased and costs per ton are lowered.

11) Increase in recent years in the proportion of fluorspar sold for making aluminum, fluorine chemicals, and ceramic products relative to that sold for making steel. If permanent, this means that fluorspar mining will be less dependent in the future upon variations in the requirements of any single major consuming industry.
CHAPTER 3—PRODUCTION AND USES OF FLUORSPAR

PRODUCTION

Illinois ranks first in the United States as a producer and shipper of fluorspar. In recent years Illinois has generally been the source of 40 to 60 percent of all fluorspar shipped from mines in this country; the figure for 1948 was 52 percent. Data showing shipments, aggregate value, and average price per ton for Illinois, Kentucky, other states, and the United States for the period 1880-1936 and for each later year to 1948 are given in table 1.

Table 1 shows that fluorspar shipments from Illinois passed 100,000 tons in 1940 (for the first time since 1920), rapidly rose to nearly 200,000 tons in 1943 under the impetus of wartime demands and then declined until 1945, but increased again each year thereafter. Total shipments for the state from 1880 through 1948 exceeded 3,800,000 tons having a market value of over $79,000,000. The long-time average selling price of $20.59 per ton for Illinois fluorspar is very close to the national average.

For detailed and comprehensive statistical analyses of the fluorspar industry the reader is referred to the works listed in the footnote.

In the present report the Illinois fluorspar mining field is subdivided into three general units, namely the Rosiclare district, the Cave in Rock district, and all outlying operations elsewhere.

From records of individual mine production gathered by the United States Bureau of Mines it is possible to estimate fairly accurately the relationship of production in each of the three units mentioned above to the total shipments from Illinois in years for which figures are available. Table 2 shows in round numbers and percentages the shipments of fluorspar by districts for the periods 1880 to 1947, 1917 to 1947, and 1940 to 1947.

The period 1880 to 1947 is approximately that during which fluorspar has been mined and for which reliable figures and estimates are available. The period 1917 to 1947 is that in which the Cave in Rock district has been an important producer, and the period 1940 to 1947 that in which the Cave in Rock district has been a really large producer.

Table 2 illustrates the dominance of the Rosiclare district in terms of aggregate long-time shipments, which amount to 73 percent of the total for the area, how important a source of fluorspar the Cave in Rock district has become since 1940, and how relatively small has been the aggregate contribution of mines in the area outside of the two principal districts. Calculations based on the figures in table 2 show that 99 percent of the shipments made from the Cave in Rock district have occurred since 1916 and that over 67 percent have been made since 1939, which indicates the very rapid growth of that district in recent years. For outlying districts, 94 percent of the tonnage was shipped since 1916 and 49 percent since 1939. By contrast, only a little more than 65 percent of the total shipments from the Rosiclare district have been made since 1916 and only 23 percent since 1939.

USES OF FLUORSPAR

Fluorspar is an essential raw material in the metallurgical, ceramic, and chemical industries, its principal uses being in the production of basic open-hearth and basic electric furnace steels, the manufacture of hydrofluoric acid, and the making of opaque glasses and enamels. Fluorspar has many...
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additional uses of industrial importance but...much smaller amounts.2

During and after the war years large quantities of the gaseous fluorine compound uranium hexafluoride were used in the preparation of uranium isotopes by the gas diffusion and electromagnetic methods.3 This use may become one of major peacetime importance if atomic energy is successfully exploited on a large scale for the development of industrial power.

Many of the metallurgical uses of fluorspar stem from its marked ability to flux silicates and other substances of high melting point which are present or combined with the metals being recovered or refined. This characteristic was known to Agricola (1529) but was not much utilized until the production of basic open-hearth steel became important in the nineties.

In the basic open-hearth process of steel making a fluid slag of properly basic composition is essential. The slag is basic because of its content of calcium and magnesium silicates. It serves the several purposes of protecting the molten metal from rapid or excessive oxidation, assisting the removal of phosphorous and sulfur impurities, and facilitating the transfer of heat to the furnace charge. Additions of small amounts of fluorspar are made to increase the fluidity of the slag at the desired operating temperatures, thus promoting its efficiency. The average consumption of fluorspar per ton of basic open-hearth steel decreased from 8.2 pounds in 1921 to 5.2 pounds in 1940, rose to 5.8 pounds in 1941 and 6.4 pounds in 1942, and then declined to 5.9 in 1943.4 The temporarily increased consumption is said to have resulted partly from the greater proportion of armor steel being made, poorer quality scrap, higher charges of lime, and the rushing of heats.5 Consumption dropped to a low of 5.4 pounds per ton of steel in 1946 and then rose to 5.5 pounds in 1947 and 5.85 pounds in 1948.6

In the basic electric steel process, employed in making large amounts of ferroalloys and alloy-steels, fluorspar performs much the same functions. An average of 12.8 pounds of fluorspar was used per long ton of basic electric steel in 1943.7 A small amount of fluorspar has been consumed recently in making bessemer steel, where it...

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2 General references on the uses of fluorspar include the following:


3 Chapters on fluorspar and cryolite in Minerals Yearbooks and Mineral Resources of the United States.


5 Minerals Yearbook, 1943, p. 1449.
6 Minerals Yearbook, 1942, p. 1398.
is said to be used in the acid bessemer process as one component of a cold dephosphorizing flux added as the molten steel is poured from the converter to the ladle.\(^8\)

In iron foundries fluorspar also serves as a flux and as an aid in dephosphorizing and desulfurizing the metal. Its use is particularly advantageous where cupola melting is continuous and in handling iron that has a relatively high sulfur content. In some foundries the fluorspar additions are made in the ladle. The quantity of fluorspar used in cupolas probably averages 15 to 20 pounds per ton of metal.

Small amounts of fluorspar are used in a number of other metallurgical operations, among which are the smelting of refractory ores of gold, silver, and copper; the refining of lead and silver; the production of nickel and its alloys such as monel metal; the melting and casting of aluminum and magnesium; and the extraction of tantalum and columbium.

Fluorspar is used in the glass industry in the preparation of light and dense white or colored opal glasses. The manufactured products include lamp globes, shades, and bulbs; vases, bowls, and other ornamental glassware; containers for liquids, foods, drugs, and toilet preparations and liners for fruit jars; bars, rods, and other fixtures for lavatories; table and counter tops, wainscoting, baseboards, shelves, and other similar articles. The fluorspar is ground and added in proportions ranging from 50 to 500 pounds per 1000 pounds of sand, according to the degree of opacity desired.

Fluorspar is also used in the enamel industry to make the dense opaque white or colored enamels used for coating steel and iron for bath tubs and sinks, kitchen and hospital ware, barber chairs, stove and refrigerator parts, reflectors and signs, and facings for brick and tile, structural materials, earthen cooking ware, and art pottery. Enamel batches for such products contain up to 15 percent of fluorspar.

Additional ceramic and miscellaneous uses of fluorspar include its employment as a flux in several manufacturing operations such as the making of portland cement and rock wool, the making of surface coatings for roofing materials, the manufacture of alundum and other artificial abrasives in the electric furnace, the making of basic refractory cements and brick, and the manufacture of calcium carbide and cyanamide; its use as a flux to deslag high pressure generators; and its uses as paint filler or pigment, in the making of carbon electrodes for flaming-arc lamps, and as a bonding material for abrasive wheels.

Small amounts of clear, colorless (or nearly so), and unflawed crystalline fluorite have long been used by optical companies in the making of specially-corrected lenses or prisms for microscopes, telescopes, and spectrosopes. The properties that make fluorite valuable for this purpose are its single refraction, low index of refraction, low dispersion, and high degree of transparency to rays in the ultra-violet and infra-red parts of the spectrum.

The importance of natural fluorite as an optical material has decreased somewhat in recent years owing to the perfection of a commercial method for the preparation of synthetic crystals of fluorite and of other compounds having similar optical properties. Single crystals of calcium fluoride, lithium fluoride, sodium chloride, potassium bromide, and sodium nitrate are made by the Harshaw Chemical Company, Cleveland, Ohio, by very slow cooling of pure molten salts in specially constructed electric furnaces.\(^9\) The availability of these crystals, some of which are as large as 8 inches in diameter, has permitted important advances especially in infra-red spectroscopy.

Pure calcium fluoride deposited in an exceedingly thin film on the polished surfaces of optical lenses and prisms serves to reduce reflections from those surfaces and thereby increases the percentage of light transmitted. Such “coated lenses” are being used extensively in photographic cameras and projectors, range-finders, binoculars, telescopes, and many scientific instruments. Calcium fluoride, or in some cases magnesium or sodium fluoride, is caused to

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8 The Foundry, vol. 69, no. 5, p. 146, 1941.

volatilize in an evacuated chamber containing the lenses. The resulting vapor is allowed to condense on and coat the lenses with a film of the proper thickness.

The key fluorine compound in the chemical industry is hydrofluoric acid, made by the reaction of fluorspar with sulfuric acid in heated iron or steel stills. Both batch and continuous stills are in use. The HF vapor formed is cooled and absorbed in water, forming aqueous hydrofluoric acid, which is sold in concentrations ranging from 30 to 80 percent HF. Anhydrous hydrofluoric acid is prepared from the strong aqueous acid by distillation, followed by cooling and condensation in a refrigerated condenser. Acid solutions containing more than 65 percent HF can be stored or shipped safely in steel containers, whereas weaker acids require special containers lined with lead, wax, rubber, or bakelite.

The two principal direct uses of anhydrous hydrofluoric acid are as a catalyst for producing the alkylate used in high-octane aviation fuel blends and as a raw material in the manufacture of the various Freon refrigerants, although it is also employed in the synthesis of numerous other organic fluorine compounds and nonfluorine-containing compounds.

In the alkylation process a mixture of olefins and isoparaffins is caused to react in the presence of anhydrous hydrofluoric acid which serves as a catalyst. The alkylate product after purification and fractionation is a mixture of branched methyl side chain isomers of heptane, octane, etc. The consumption of anhydrous acid is said to average probably about 1.5 pounds of acid per barrel of alkylate, with a probable low of 0.8 pound per barrel.

Of the several Freon compounds now manufactured, Freon-12 (dichlorodifluoromethane) is apparently the one in most common use. In its preparation carbon tetrachloride is treated with anhydrous hydrofluoric acid in a heated reactor in the presence of a suitable catalyst such as antimony trifluoride. The Freons are excellent refrigerants and in addition are non-toxic, non-inflammable, and non-corrosive. A recently developed large-scale use for Freon-12 is as the solvent and propellant in "bug-bombs" used for destroying insect pests such as flies and mosquitoes. The handsize bombs contain a solution of pyrethrum extract and sesame oil, or of D.D.T. (dichloro-diphenyl-trichloroethane), in Freon-12, and will efficiently fumigate a space of 150,000 cubic feet. Freon may also find future application as the propellant for spraying paint and other materials.

Aqueous hydrofluoric acid has a number of important direct uses including the etching and polishing of glass, pickling of steels, cleaning of sand from metal castings, enamel stripping, and as a laboratory reagent, but most of the aqueous acid made goes into the manufacture of a great variety of inorganic fluorides.

Chief among the inorganic fluorides, in terms of production and consumption, are synthetic cryolite (Na₃AlF₆) and aluminum fluoride (AlF₃) which during and after the war were used in increasingly larger amounts in the production of metallic aluminum. In this process, alumina (Al₂O₃) is dissolved in a molten bath of natural or artificial cryolite and other fluoride salts. Upon the application of an electric current, metallic aluminum collects at the bottom on the cell. It is said that the production of 1000 pounds of aluminum required the consumption of 37 pounds of acid-grade spar converted into aluminum fluoride in 1942 and 40.8 pounds in 1943 (8 months), and that if synthetic cryolite also was used an additional 24.9 pounds of acid spar was required per 1,000 pounds of aluminum in 1942 and 21.3 pounds in 1943 (8 months). Synthetic cryolite has an important secondary use as an insecticide, and it is

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10 See Callaham, J. R., op. cit., and also Finger, G. C. and F. H. Reed, op. cit., for description of the methods and equipment used in the making of aqueous and anhydrous acids.
11 Finger, G. C., op. cit.
12 Callaham, J. R., op. cit.
estimated that 3,000 to 4,000 tons were used for this purpose in 1943.\(^{15}\)

The number of inorganic fluorine compounds is large and their uses so varied that only a listing of the commoner preparations and a brief description of their principal uses can be given here.

**Uses of Inorganic Fluorine Compounds**

1. Elementary fluorine: preparation of special fluorine compounds.

2. Hydrofluoric acid
   a. Aqueous: steel pickling and galvanizing, glass etching and polishing, preparation of inorganic fluorides, enamel stripping, cleaning sand from metal castings, cleaning of copper and brass, lead refining and plating, textile bleaching, antiseptics, etc., chromium plating, removal of efflorescence from stone and brick, removal of silica and iron oxide from graphite, making of filter paper and carbon electrodes, extraction of columbium and tantalum.
   b. Anhydrous: aqueous HF, glass etching, treating polished glass surfaces to reduce reflection, enamel stripping, preparation of organic and inorganic fluorides, organic synthesis, catalyst, reaction medium.

3. Fluorides
   aF: insecticide, wood preservative, preparation of acid fluorides, mold addition to rimmed and capped steels for eliminating skin blow holes, possible preventive of tooth decay, ceramics, substitute for hydrofluoric acid in stainless steel pickling, removal of silica from raw boiler feed water.
   KF: Preparation of acid fluoride, welding flux for silver, antiseptic, preservative, insecticide, syntheses of organic fluoride compounds.
   LiF: Synthetic optical crystals, flux for welding aluminum, ingredient in phosphorescent pigments, minor ingredient in bath of fluorine cells, photography, ceramics.
   CaF\(_2\) (synthetic): optical crystals.
   MgF\(_2\): ceramics, coating on lenses for increased light transmission and definition, antiseptic, insecticide.
   BaF\(_2\): antiseptic, embalming fluids, ceramics.
   CrF\(_3\): textile printing and dyeing.
   AlF\(_3\): manufacture of metallic aluminum, ceramics, insecticide.
   ZnF\(_2\): insecticides, wood preservative, ceramics, synthesis of organic compounds.
   BF\(_3\): catalyst in petroleum, synthetic fiber (VistaneX), and synthetic rubber industries, and in production of propionic and acetic acids.
   SbF\(_3\): catalyst in production of Freon-12, mordant, syntheses of organic compounds.
   AgF: antiseptic (?), laboratory reagent.
   SiF\(_4\): preparation of H\(_3\)SiF\(_4\).
   NH\(_4\)F: antiseptic, antiferment, insecticide.
   CdF\(_2\): amalgams, colors.
   CoF\(_3\): hardening metals, colors, synthesis of fluorocarbons.
   CIF\(_3\): certain types of fluorinations.
   RF\(_3\) (rare earth fluorides): carbon arc electrodes.
   UF\(_6\): gaseous medium for the separation of uranium isotopes by gas diffusion and electromagnetic methods.
   NaSbF\(_4\): mordant in dyes industry.
   Na\(_3\)AlF\(_6\) (synthetic cryolite): manufacture of metallic aluminum insecticides, ceramics.
   BeF\(_2\): glass, production of beryllium metal.
   SF\(_6\): gaseous dielectric for high voltage electrical equipment.
   CuF\(_2\): antiseptic, agricultural insecticide, ceramics.
   PbF\(_2\): antiseptic, laboratory chemical.
   MnF\(_2\): fertilizer, insecticide, ceramics.
   NiF\(_2\): ceramics, galvanizing, catalyst (?).
   SrF\(_2\): antiseptic, ceramics.
   SnF\(_2\): enamel, colors.
   TlF: depilatory, electric light bulb industry.

\(^{15}\) Callaham, J. R., op. cit.
4. Acid fluorides: NaHF₂, KHF₂, NH₄HF₂; laundry sours (antiseptic and fungicide), etching glass, magnesium casting (flux to prevent surface oxidation in melting pots, also added to molding sand to prevent surface oxidation), welding fluxes, antifermentative in alcohol industry, fluorine (from KHF₂), cleaning stone and concrete surfaces.

5. Fluoboric acid and salts.
   HBF₄: production of BF₃, electrolytic oxidation of aluminum to make highly reflecting surfaces for search lights and head lights, electroplating, organic synthesis.
   NaBF₄, KBF₄, NH₄BF₄: electroplating, silver welding flux, antioxidant in molding sand, anealing and heat treating metals.
   NaBeF₄: bath for electrolytic production of beryllium.
   In(BF₄)₂, Sn(BF₄)₂, Pb(BF₄)₂, Ni(BF₄)₂, Cd(BF₄)₂, AgBF₄, Zn(BF₄)₂, Fe(BF₄)₂, Cr(BF₄)₃: electroplating of bearings and instrument parts.

6. Fluosulfonic acid and salts:
   FSO₃H: preparation of BF₃.

7. Fluosilicic acid and salts:
   H₂SiF₆: electroplating, fluosilicate salts, laundry sour, bacteriacide in beer industry, concrete hardener.
   PbSiF₆: lead plating.
   (NH₄)₂SiF₆: laundry sour, anti-oxidant in molding sands, concrete hardener.
   CaSiF₄: insecticide, ceramics.
   BaSiF₆: insecticide, ceramics.
   CuSiF₄: insecticide, wood preservative.
   ZnSiF₄: concrete hardener, wood preservative.
   MgSiF₄: concrete hardener, magnesium foundries.
   Na₂SiF₆: insecticide, laundry sour, ceramics, metal casting.
   Al₃(SiF₆)₃: ceramics.
   Al₃(SiF₆)₃Na₂SiF₆: mothproofing.
   CoSiF₆: metallurgy, colors.
   MnSiF₆: insecticide.
   NiSiF₆: plating.
   K₂SiF₆: antiseptic, manufacture of silicon.

The principal commercial organic fluoride compound is Freon-12 as described earlier. Several other related chlorofluoro derivatives of methane and ethane are also used as refrigerants. Certain chlorofluoroethanes and chlorinated benzotrifluorides also have been found desirable and useful as insulating and cooling dielectrics for electrical apparatus such as switches and transformers. They do not break down into a sludge, are noninflammable, and maintain high viscosity over a wide temperature range.

A fluoro analog of "DDT," used like the latter as an insecticide, was manufactured and used in Germany during the war under the trade name "Fluogesarol." In this country it is called DFDT, an abbreviation of difluorodiphenyltrichloroethane. It is made by condensing fluorobenzene with trichloroacetal in the presence of chlorosulfonic acid. The sodium salt of monofluoro acetic acid is used under the code name "1080" as a rodenticide.

Fluorine-bearing print dyes of clear color, mostly yellow, orange, and red, and of excellent light fastness have been developed. These are coupled products of a Naphthol AS type containing diazotized bases, the latter presumably being derivatives of benzotrifluoride. Certain polymers such as those of tetrafluoroethylene and trifluoro vinyl-chloride have been patented. Tetrafluoroethylene, or "Teflon" is a plastic characterized by high electrical resistance and very high chemical and thermal stability. "Kel-F" is a plastic of similar properties produced from trifluorochloroethylene.

Fluorobenzene is said to be a good solvent for shoe polish. A few fluorine-bearing drugs have either been suggested or actually manufactured for use; three of these are 3-fluorotyrosine, p.p'-difluorobiphenyl, and p-fluorosodium benzoate. Certain organic acids containing fluorine have been suggested as insecticides, fungicides, and disinfectants, but as yet they are of no commercial importance. Color photography has made some use of the diazonium borofluorides.

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Fluorocarbons, compounds of carbon and fluorine alone, have been made experimentally on a relatively large scale. It is said that they may find many industrial uses because of their noninflammability and extreme stability to heat and chemicals. Especially promising fields are those including their use as high temperature lubricants, heat transfer media for high temperature operations, and solvent extractors. Detailed descriptions of the method of preparation and properties of many fluorocarbons as well as of elementary fluorine and many other fluorine compounds have been given in a series of recently published papers.  ^{18}

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CHAPTER 4—FLUORSPAR DEPOSITS

The fluorspar deposits of southern Illinois are of three types, two of them primary and the other of secondary origin. All three intergrade, however, and at several of the outlying properties, whose workings are no longer open to examination, it is now impossible to determine which type of deposit prevailed.

VEIN DEPOSITS

The earliest worked and most widespread fluorspar deposits are fissure veins. This is the type of deposit that has been so productive in the Rosiclare district and elsewhere in both Illinois and Kentucky. The veins follow faults cutting the Mississippian and, to a much lesser extent, the Pennsylvanian rocks of the region. Fluorspar also occurs in Devonian limestone at the old Rose mine, but structural conditions there are not clear. Most of the mineralized faults are of the tension type and have commonly been described as "normal" faults. They extend downward almost vertically or dip very steeply, but several of them are known to turn backward upon themselves so that the terms "hanging wall" and "foot wall" cannot always be applied.

The veins range in thickness from a mere film to a width of more than thirty feet. The only two abundant minerals are calcite and fluorite although several others occur and are locally conspicuous. Calcite is generally much more abundant than fluorite although at some places the veins consist of fluorite from wall to wall. Fluorite may be irregularly distributed through calcite, or vice versa, or it may occur in more or less irregular bands generally roughly parallel to the vein walls. Such bands of fluorite along one or both sides of a vein or along a slickensided center slip are common.

The proportions of calcite and fluorite vary greatly and irregularly. Until recently, vein matter containing much less than 50 percent fluorite was not considered to be minable ore, but the sink-float method now makes lower-grade ores suitable for concentration. Workable ore bodies are quite irregular in shape and exceedingly variable in size. They may terminate gradually or abruptly in either vertical or horizontal directions by passing into uneconomic ore or a pinch where the vein walls draw together. Several of the larger known ore bodies have been more continuous in a vertical than in a horizontal direction and thus may be described as ore shoots. The minimum width of workable veins is determined by the space required for stoping. Veins two feet wide between solid rock walls, even though carrying the highest quality of ore, have rarely been worked profitably.

Most of the fissure vein deposits have been mineralized to the surface at least locally, and were discovered by shallow prospecting. Likewise most of the important ones are located along faults, one or both of whose walls consist of Ste. Genevieve or St. Louis limestone. These relations and the fact that replacement of limestone by fluorite is known to have occurred have caused several previous observers to conclude that the best fluorspar deposits are localized in faults with limestone walls because of the chemical nature of these walls and that replacement was an important determining cause of their development.

Recent investigations have amply confirmed the fact that many of the best vein deposits occur between limestone walls, but they have also indicated that another explanation is more probable in accounting for this relationship.

If replacement of limestone by fluorite were important in the development of the type of deposits under consideration, it is remarkable that only slight evidence of replacement of limestone is to be found in the Rosiclare district, which may be considered the type area of the characteristic vein deposits. Although it is plain, in that district, that replacement of vein calcite by fluorite has been widespread, only minor evidence of replacement of limestone has been discovered in the mines. Moreover, in the old workings of the Blue Diggings
fluorspar deposits of illinois

mine 45 percent of the stope area occurs above the top of the Renault formation where sandstone predominates and limestone is absent in both fault walls. This situation demonstrates conclusively that, at least here, replacement of limestone wall rock had nothing whatever to do with vein development. If this importantly mineralized portion of the Blue Diggings vein is not replacement of wall rock, there is little reason to conclude that veins in other situations, even those confined between limestone walls, owe their existence to major replacement of limestone where evidence of replacement is not conspicuous.

Probably the veins near Rosiclare, and in other similar districts, are true fissure fillings. Also some relation evidently exists between most of the larger ore bodies and limestone of the Ste. Genevieve and St. Louis formations. This relation, however, appears to be with the physical rather than the chemical nature of the rock.

Faulting in the fluorspar region is complex; what are ordinarily considered to be individual faults are rarely simple breaks. Commonly, displacement occurred along a zone of fracturing where interrelated breaks branch and come together both horizontally and vertically in an unpredictable manner and enclose blocks of various sizes and shapes which have been variously moved with respect to each other and to the less broken rock on either side. In hard and strong formations, like the Ste. Genevieve and St. Louis limestones, considerable shattering may have occurred, but actual faulting appears to have been concentrated along planes that are relatively few and relatively cleanly broken. Also in these formations the rock is strong enough to preserve openings between areas where the more or less irregular fault walls are in contact.

Other hard and strong formations, like some of the sandstones, reacted similarly, but shales and other weak rocks, which are common above the Ste. Genevieve limestone, probably were sheared and torn and were squeezed in and adjacent to the fault zones so that the actual breaks are more numerous and more complex. Moreover, friction resulting from the fault displacement and the weight of overlying strata caused the softer shales to be forced into the faults and dragged upward or downward along their planes as gouge to fill openings between walls of harder rock.

Thus open fissures offering suitable locations for the deposition of mineral matter from circulating solutions were most likely to be formed and preserved between walls of strong rock such as occurs in the Ste. Genevieve and St. Louis limestones.

Most economically important fluorspar veins occur along faults of moderate displacement. Thin veins and veinlets are very widely distributed in the fluorspar region but most workable ore bodies of the fissure vein type are restricted to faults of 50 to 500 feet displacement. Apparently irregularities of the walls are generally not sufficient along faults of small displacement to produce openings wide enough or extensive enough to contain workable ore bodies, and faulting of 500 feet or more was accompanied by sufficient shattering and grinding to fill the faults with soft gouge or broken blocks of harder rock.

There are, however, exceptions to these generalities.

Calcite was the first mineral deposited in the veins and at many places it is clear that later fluorspar replaced earlier calcite. At some places the veins consist almost entirely of calcite, and there is a widely current belief that fluorspar mineralization above gives way to calcite mineralization below. It is true that several of the mines end in large calcite runs in their deepest levels but it is also true that equally prominent calcite runs occur in mine workings above large bodies of fluorspar. No sound reason is known why fluorspar mineralization should cease at the comparatively shallow depth reached by these mines (maximum 800 feet), and the possibility of deeper production is worthy of consideration and investigation.

The common association of extensive mineralization with strong fault walls, particularly those formed by the Ste. Genevieve and St. Louis limestones, suggests that
there may be important undiscovered ore bodies at moderate depth along faults where geologic conditions at what is now surface were not favorable for vein formation and only inconspicuous and economically unimportant veins were formed. A large part of the ore in the Daisy vein occurred in such a situation and it is quite possible that other deposits of this type may be found by careful prospecting. Such deposits may be most logically sought in outlying parts of the fluorspar district where common but unimportant mineralization has been observed in strata of Lower or Middle Chester age along faults of moderate displacement.

**BEDDED REPLACEMENT DEPOSITS**

Fluorspar is mined from large bedded replacement deposits in the Cave in Rock district in eastern Hardin County. Although fluorspar was known in the district in early times, large-scale exploitation of the deposits did not begin until the time of World War I. Since then the district has achieved major importance.

The deposits are of the flat-lying replacement type in limestone, chiefly in beds of the Fredonia member of the Ste. Genevieve formation and in the upper part of the Renault formation. They lie along one or both sides of minor fractures and of faults of small displacement, and are characteristically long and narrow. Single deposits have been mined for distances of over 2,000 feet. Widths of 50 to 150 feet and thicknesses of 3 to 15 feet are typical. Deposits which occur along both sides of a more or less central fracture commonly have a lenticular transverse section, being thickest in the center near the fracture and thinning outward toward the margins. Deposits which occur along one side of a fracture, usually a fault with less than 20 feet displacement, are wedge-shaped and thin away from the fault.

The bedded deposits are the result of partial to complete replacement of calcareous material in the host limestone strata. Hot fluorine-bearing solutions from below entered the formations along joints and small faults. In places where further upward or lateral flow along the fractures was restricted, these mineralizing solutions reacted with the calcite in the easily replaceable limestone beds adjacent to the fractures. The fluorine in the solutions combined with the calcium in the calcite to form fluorite (calcium fluoride). Other minerals in the limestone such as clay and quartz were apparently not affected. The process of substitution of fluorite for calcite caused shrinkage, which resulted in cavities and cracking or shattering of parts of the ore beds and collapse of the overlying strata.

The principal ore minerals are fluorite, sphalerite, and galena. The gangue or waste consists of limestone, sandstone, shale, clay, calcite, quartz, and barite. Much of the ore is conspicuously banded, coarse-grained layers alternating with fine-grained layers of a different color in such a manner as to suggest the local term, "coontail" ore. Sphalerite is abundant in some of the deposits, constituting in one mine about 30 percent of the ore. Galena also is sufficiently important as a constituent of the ore in some mines to warrant separation and concentration.

The deposits which were first worked cropped out in a bluff which exposes the principal ore-bearing formations and limits their occurrence on the southwest. From this locality the major replacement deposits lie in a rather well-defined belt which trends about N 50° E. The mineralized strata dip in a general northeast direction, and exploration and subsequent mining have followed the ore to greater and greater depths below the surface. The ore in the farthest mine to the northeast is being taken from a depth of about 600 feet. Drilling still farther to the northeast, and starting on top of a bluff several hundred feet higher than the surface at the mine, has encountered ore more than 1,000 feet below the surface.

**RESIDUAL DEPOSITS**

Near the surface the fluorspar-bearing veins are generally much decomposed, particularly those whose wall rocks consist of limestone. Surface water working downward through the shattered fault zones has
dissolved and removed soluble limestone in the vein walls and calcite in the veins. The unsupported and weakened veins have collapsed, the insoluble fluorspar has been broken into pieces and mixed with residual clay and boulders of resistant or partly weathered wall rock to form the so-called "gravel spar" deposits. As this process results in the concentration of fluorspar from the upper weathered portion of a vein, a vein too narrow to be mined profitably may be overlain by a workable gravel deposit. Likewise a major vein may be marked at shallow depth by a gravel deposit as much as 60 or more feet wide.

Gravel deposits may extend from the base of the surficial alluvial or loessial soil to a depth of 150 feet or more before the vein walls close in and a solid undecomposed vein is encountered, although some veins extend in unaltered condition nearly to the surface. The shallower part of a gravel deposit generally possesses a distinct "overlay" or inclination which may be as much as 45 degrees and probably results partly from the original inclination of the vein and partly from surface creep down a present or past topographic slope.

The bedded replacement deposits are horizontal bodies rather than vertical ones like the veins, and furthermore there has been generally no great amount of fracturing in the rocks above them to provide channelways for groundwater. Hence weathered fluorspar deposits derived from replacement deposits are much less common than those derived from veins. They have been mined at a few places along the outcrops of deposits of the Spar Mountain bluff in the Cave in Rock district and also at several localities in the limestone plain extending southward from that bluff to the Ohio River.

Weathering has the same effect on replacement deposits as it does on veins. The soluble limy wall rock and calcite gangue are partly or wholly removed and the fluorite and other insoluble rocks and minerals such as sandstone, shale, quartz, and galena are concentrated in the residual clay.

MIXED DEPOSITS

Many fluorspar deposits are of mixed types. Weathering of both vein and bedded deposits is greatest at the surface and decreases downward or laterally under cover to unaltered deposits, which, however, may be uneconomic in quantity or quality. Miners generally do not distinguish these differences and commonly all types are indiscriminately termed "veins." Often it is very difficult to determine from a miner's description whether ore was of the fissure vein or replacement type or whether and to what degree it was weathered.

Fluorspar deposits of the vein and replacement types also intergrade. Bastin recognized the occurrence of replacement ore in the outlying districts at the Renfrew prospect and the Hamp mine, but he was unable to determine the relation of this material to possible vein deposits because these workings were not open when he visited them. Recent investigations have disclosed the occurrence of replacement ore, some of it with well-developed banded structure, at a number of places other than the Cave in Rock district, principally in the area west of Hicks dome.

1. Empire District—Banded fluorspar ore from open cuts on Pierce and Sycamore Veins
   Replacement blanket in south wall of Red mine of Empire vein
   Banded fluorspar and sphalerite ore at Oscar Crabb prospect
   Shoots of replacement ore in Slapout mine

2. Sheldon property west of highway just south of Eichorn

3. Seinor property—replacement ore in limestone

4. Stewart Mine District—banded fluorspar ore from dumps of mines at north and south ends of this line of workings

5. Compton Mine—highly siliceous replacement ore observed on dump

At most of these places the possible relation of banded or other types of replacement ore to vein deposits was not observed,
but veins that have been locally worked or prospected occur at all of these places, and undoubtedly the two types of deposits are related. The replacement deposit in the Red mine was worked out at the time this mine was visited, and no specimens of ore from it were seen, but the description furnished by the mine foreman clearly indicated that it was a horizontal offshoot from the vein between unaltered layers of limestone.

Banded ore recovered by open-cut mining on the Douglas property was associated with undoubted vein fluorspar, and in the Slapout mine irregular, nearly horizontal shoots of unbanded ore branched off from the main fractured and mineralized zone.

Much of the ore recovered in the Empire district has been of the weathered type, and many of the veins that occur here are too thin to be mined in their original condition. Another peculiarity of this extensively mineralized area is the very minor displacement of the faults. At one place where the throw of the Empire fault can be accurately estimated, it is no more than 15 feet. Possibly a direct relation exists between the openness of the fissures and the type of fluorspar mineralization that occurred.

The general nature of the faulting in the Rosiclare, Empire, and Cave in Rock districts suggests that, where well-marked faults and presumably open fissures existed, solutions circulated easily, and mineralization was almost exclusively of the fissure-filling type, as at Rosiclare. On the other hand, when faulting was very minor and the fault planes were apparently tight, it is possible that pressure, backing up these solutions, forced them into porous layers of the surrounding rock and that replacement occurred when the chemical character of the rock favored that process. In other regions, such as the Empire district, where structural conditions were intermediate, both processes operated.

It appears to be significant that, in areas of strong faulting and well-marked veins, replacement deposits are insignificant; that, in areas of extensive, bedded replacement deposits, faulting and vein development is insignificant; and that, in areas where both veins and replacement deposits occur, neither forms large or thick ore bodies independently.
CHAPTER 5—EXPLORATION, MINING, AND MILLING METHODS

EXPLORATION METHODS

Prospect Pits
The original discoveries of most of the workable fluorspar deposits in Illinois were in prospect pits. This type of prospecting has been conducted with greater or less intensity for over 100 years, and there are few parts of the district that have not been investigated in this way. Most of the pits were very shallow and were located in a hit or miss way on the basis of various indications of mineralization, any peculiar feature of the outcropping rock, and "witching" or hunches. Almost all were soon abandoned.

Trenches
A less common but more effective method of prospecting is by trenching at right angles to the supposed direction of outcropping mineral deposits. A trench may definitely establish the exact position of a fault, but neither a trench nor a prospect pit can determine the magnitude or value of a possible ore body.

Prospect Shafts
If a fault is located either by pitting or trenching, or if an encouraging amount of mineralization is encountered, it is common practice to sink a shallow shaft, rarely more than 50 feet deep. If mineralization is moderately good, part or all of the cost of sinking may be paid for by ore recovered during this operation. Should an ore body be discovered at such shallow depth, mining may be conducted for a limited time through this shaft before it caves in. It is rarely worthwhile, however, to equip a prospect shaft for actual mining.

Tunnels and Adits
Tunnels and adits are rarely used for prospecting except in a few parts of the Cave in Rock district, where possible mineralized zones of the bedded deposits outcrop on hillsides.

Auger Drilling
Minor prospecting has been done in the past with hand-auger drills to locate gravel spar deposits or to determine the approximate location of faults. Recently a commercial type of gasoline-driven auger drill has been used. It is capable of penetrating 40 to 50 feet of overburden in a very short time, and good samples can be recovered for careful examination. This drill has proved useful in exploring gravel deposits and may be used to trace such material to the parent vein. It can also penetrate weathered vein material for a short distance. This type of drill will probably play an increasingly important role in prospecting new areas.

Core Drilling
Prospecting by diamond drill is now common in the district. Drilling may be started either from the surface or underground from mine or prospect workings. In prospecting a fault for vein deposits, surface holes are drilled at angles commonly varying from 45 to 70 degrees from the vertical. Location and angle of the hole are planned to cut the fault at a predetermined depth. Underground drilling may be done at a much lower angle. Horizontal holes are not uncommon, and some may even be drilled slightly upwards.

It is generally advisable to start surface holes on the hanging-wall side of a fault. Unusual geologic or topographic conditions, however, may make it necessary to start from the foot wall. Then care must be taken that the angle of drilling is not so steep that the hole will parallel the fault and fail to cut it.

Although any beginning angle of a diamond drill hole can be selected, the underground course cannot be closely controlled and holes are rarely straight. In areas of flat-lying or gently dipping strata, drill holes are likely to flatten out gradually, and if the strata are steeply dipping, the holes
tend to extend parallel to the bedding. In deep holes, as at locations where very accurate results are desired, acid bottle surveys should be made at several depths to determine the actual inclination of the hole so that its true course can be plotted. Lateral wandering of the hole is less important and more difficult to determine but can be surveyed by using an instrument consisting of a compass needle floating in solidifying jelly. Because most diamond drill holes cut the veins at angles, the cores do not reveal the actual width of vein material, and this must be calculated from the known or assumed angle at which the drill hole cuts the vein.

The average length of diamond drill holes in this district has been about 350 feet. Holes of more than 500 feet are not common, although a few have exceeded 1,500 feet in length. Prospectors and mining engineers are likely to stop drilling as soon as they think the fault or vein has been cut. Most holes should be continued, however, until they cut a formation boundary on the far side of the fault. In this way important geologic information can be obtained that reveals the throw of the fault, and the chance that a minor break may be mistaken for the main fault can be eliminated.

In prospecting a relatively unexplored fault, the first hole is generally drilled at an angle of 45 degrees at a location from which it is calculated that the fault will be cut at a vertical depth of 150 to 200 feet. After this hole is successfully completed a second may be drilled from the same location at an angle of 60 degrees. Information obtained from these two holes regarding the pitch of the fault and the geology of the walls is generally sufficient to plan further drilling which will test the fault at predetermined depths and at favorable geologic situations.

Vertical diamond drill holes are used in prospecting for bedded fluorspar deposits. Also a few vertical holes have been drilled to obtain geologic information and locate faults in areas where data furnished by outcrops is inadequate.

For the shallow drilling usually done in the Illinois fluorspar district a small skid-mounted, gasoline-driven drill with a capacity of about 750 feet has proved satisfactory and economical. It is general practice to set 3-inch casing a few feet into bedrock and to drill from there with a BX core barrel, making a hole 2 11/32 inches in diameter and recovering a core 15/8 inches in diameter, until a depth is reached where the rock is unweathered and there is little chance of encountering caving ground or losing sludge. AX casing is set here, and drilling is continued with an AX bit making a hole 17/8 inches in diameter and recovering a core 11/8 inches in diameter. Generally the hole is completed with the AX bit. A little experience with local conditions usually makes it possible to do most of the drilling with the AX bit and obtain satisfactory core recovery while running little risk of losing the hole. In broken rock or cavernous limestone it may be necessary to drill to a considerable depth with an NX bit, making a 3-inch hole and recovering a 2 3/8-inch core. In a badly caving hole it may be necessary to reduce from an AX to an EX bit, which drills a 1 15/32-inch hole and recovers a 3/8-inch core. Although it is cheapest to drill an EX hole, most drilling contractors and mining companies prefer to complete their holes with an AX bit.

Usually no attempt is made to recover sludge continuously while diamond drilling, but some operators require the driller to recover small samples for each run, which are discarded if core recovery is satisfactory and there are no indications of ore. In their exploration program the U. S. Bureau of Mines required that all of the sludge be recovered for every run in a four-compartment sludge box measuring 6 by 1 1/2 by 1 inches. At the end of the day the sludge was discarded if there were no indications of ore and the core recovery was satisfactory. Where ore is cut or core recovery is poor the sludge can be analyzed chemically to augment information obtained from the cores themselves.
Caving holes and loss of circulating water often necessitate the cementation of holes. To accomplish the same results, the U. S. Bureau of Mines, in cooperation with the Illinois Geological Survey, experimented with the use of bentonitic drilling mud (Aqua Gel) instead of clear water. Mud of 38 to 42 seconds viscosity was prepared in a 10-barrel capacity slush pit and was circulated in the hole by a 3-horsepower Novo pump. Sludge was removed from the mud by settling in the sludge box and in the pit to prevent unnecessary wear on the pump valves. This experiment successfully prevented caving of shale, and in some instances circulation of the drilling fluid was recovered where otherwise cementing would have been necessary; however, insufficient use of this method was made to justify a detailed report. The use of such mud in drilling increased costs only 2 to 3 cents a foot.

If core recovery is good, well-planned diamond drilling is one of the most satisfactory methods of prospecting. A core, however, obtains only an extremely small cross section of a vein or other mineralized deposit. Drilling may miss good ore bodies or penetrate a very small deposit and thus give rise to inaccurate conclusions. Some good veins have workable ore throughout no more than 20 percent of their extent and thus, when the spacing of drill holes is taken into consideration, one good core in five may be interpreted as favorable. Because core drilling is expensive, under some circumstances it may be advisable to prospect by driving underground workings. If ore is found by them, part or all of the cost may be paid by ore recovered and active mining can be started almost immediately.

Diamond Drill Records

Too much emphasis cannot be placed on the importance of accurate and detailed diamond drill records. The geologist or engineer first examining the cores cannot anticipate all the information that may be valuable in the future or necessary for its application in further prospecting. Many regrets have been expressed after cores have been discarded without detailed logging and the available information has proved inadequate. The following recommendations are made as the result of the experience of the Illinois Geological Survey.

Cores should be carefully arranged in core boxes and marked immediately at the drilling site. A competent geologist or engineer with geological training and experience should examine the cores with a hand lens, describe in detail the characters of the rock, and record the thickness of each individual bed. The driller should also keep his own record of the length of runs and the amount of core recovered so that proper adjustments can be made for thicknesses and depth to compensate for core loss. A typical log as prepared by the Illinois Geological Survey is shown in figure 2.

Before discarding a core, quarter pound samples, in half-inch to one-inch lengths, should be taken at one- or two-foot intervals. These can be broken into chips and stored in 3-by-5-inch rock-sample envelopes each permanently marked with the name or number of the hole and the accurate depth of the sample. About 200 feet of core can be represented in this way in a single carton 3 by 5 by 18 inches. The samples are readily available for further examination and parts of them tested for insoluble residues, heavy minerals, chemical composition, etc., at any time that such additional information may be desired.

It is also recommended that each box of cores be photographed in good light on fine-grained film from which positive transparencies can be made. The latter can be projected onto a screen at natural size and a record of many characters difficult to describe can be preserved for future observation and study.

Complete and accurate records of diamond drill cores make possible the re-examination of data by geologists or engineers, and significant new interpretations may be made many years after the actual drilling of the holes.

Churn Drilling

Churn drilling has economically produced excellent results in the Cave in Rock
district where ore bodies are flat lying. Cutting samples are generally taken at 5-foot intervals in barren rock and at 21/2-foot or smaller intervals in ore-bearing zones. As they are recovered from the hole, samples are arranged in rows on a board or cleared ground and marked by wooden pegs showing the depth of each sample. These are generally examined with a hand lens, and the detailed characters of the rock are described for a permanent record. Samples containing ore are removed for chemical analysis.

Again, the practice of the Illinois Geological Survey is recommended to operators. It is suggested that a small representative portion of each sample be filed in a marked 3-by-5-inch envelope for future study as the examining geologist or engineer cannot be certain that he has recorded all the characters of the rock that may prove to be important for future interpretations of the drilling data.

**Electrical Surveys**

Two principal types of geophysical surveys employing electrical methods have been tried in the Illinois fluorspar district, namely the earth resistivity and earth self potential methods. Investigations begun by M. King Hubbert of the Illinois State Geological Survey in 1931 and continued in more recent years have demonstrated that some faults can be discovered and accurately located by this method. Consequently earth resistivity surveys were undertaken in the Rosiclare district as part of the program of cooperative investigations sponsored jointly by the Illinois Survey and the mining companies of this district. Self potential investigations in limited areas in the Cave in Rock and Empire fluorspar districts were also made by the Illinois Survey.

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1. The text for this section was adapted in part from material prepared by or in cooperation with R. J. Fiersol, Head of the Physics Division of the Survey at the time the electrical surveys were made. Actual field work was conducted by K. O. Emery, M. B. Buhle, and Rex Smith.


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**FIG. 2.—Form of recording geological log of diamond drill core used by Illinois State Geological Survey.**
In addition to the foregoing, privately financed geophysical studies of individual properties have been made from time to time.

**ELECTRICAL EARTH RESISTIVITY SURVEYS**

An electrical earth resistivity survey measures the varying resistance offered by the earth to the passage of an electric current at a series of determined stations. It gives no direct information as to the kind of rock or structure at or near any station, but the differences in the measurements from place to place are meaningful in the light of experience and knowledge of the local stratigraphic section, and predictions can be more or less confidently made.

Field measurement of the resistance offered by the earth to the passage of an electric current is dependent upon a number of factors, the most important of which appear to be the amount and electrical conductivity of the water in the ground. Shales and clays generally contain much water which may be rich in electrolytes, those dissolved chemicals which enable an electrical current to flow, and thus commonly have a relatively low resistivity. Coarse and porous sand and sandstone can hold much water but as it generally contains a smaller amount of electrolytes these rocks ordinarily have higher resistivities than shales. Sandstones cemented by calcite or silica have lower porosity and higher resistivity. In the Rosiclare district shales generally possess resistivities of from 2500 to 7000 ohm-centimeters, saturated sandstones from 6000 to 40,000, and dry sandstones as much as 100,000 ohm-centimeters.

Most pure limestones possess very little primary porosity and unless weathered should be highly resistive. Unweathered thick limestones in the Rosiclare district appear to have about the same resistivities as sandstones and therefore these two kinds of rock generally cannot be distinguished on the basis of resistivity alone. Near the surface, however, nearly all limestones have been attacked by solution and if the solution cavities are abundant and filled with residual clay or water, resistivities are much lower and approximate those of shale.

In the Rosiclare district there are all gradations between the three main types of rock discussed above, and as sandstones or limestones become more argillaceous their resistivities approach those of shale. Also, where sandstone or limestone occurs in thin layers interbedded with shale, the resistivity of the whole is likely to be similar to that of shale alone.

In addition to bedrock, earth resistivity is always influenced by the overburden of unconsolidated soil and residual material, which is present throughout almost all the Rosiclare district to variable thicknesses, and exceeds 50 feet at some places. The resistivity of this material masks to some extent the resistivity of the underlying bedrock, and because it is closest to the surface its influence is greater than its thickness alone would suggest. If the overburden is clay its resistivity is low and similar to that of shale. If, on the other hand, the overburden is sandy its resistivity is likely to be high. Because the overburden in this area is generally rather sandy and easily drained, the shallow resistivity measurements are commonly high and their variations from place to place show much closer relationship to topography than do the resistivity measurements of the underlying bedrock.

Veins in the Rosiclare district, varying in width up to more than 25 feet, are highly resistive where unweathered, but show relatively low resistivity where they consist of gravel fluor spar mixed with residual clay. The depth to which veins have been weathered ranges from a few feet to more than 150 feet. It is improbable, however, that there are many places where the veins themselves exert any noticeable effect upon the resistivity measurements.

Previous resistivity investigations in the Rosiclare district have been directed toward locating faults largely by seeking resistivity anomalies produced by the discontinuity of strata at the fault planes and by the vein material itself. Under favorable conditions this method may yield good results, but in this area the wide range in resistivity of the different kinds of rock, variable thickness of
overburden, and topographic irregularities influencing the position of the water table generally completely mask anomalies resulting from the actual fault planes and vein material.

A more effective method employed in the recent investigations takes advantage of the differences in resistivity of different kinds of rock generally present at the same level on opposite sides of a fault. This method, however, requires an intimate knowledge of the local stratigraphic section and of the resistivity characteristics of the various formations and their parts.

*Surveying procedure.*—The electrical earth resistivity surveys in the Rosiclare district employed the Lee partitioning technique, which requires five electrodes. The instrument is a recent modification of the Gish-Rooney machine which furnishes a 90-volt pulsating current of a maximum of 150 milliamperes to the current electrodes and measures the potential between the potential electrodes. It is so constructed that the resistivity can be read directly on the potentiometer in ohm-centimeters without computation.

A center potential electrode is thrust into the ground at each station. Another potential electrode is located a unit distance to the right of the center electrode and a third potential electrode is located in a straight line to the left also a unit distance from the center electrode. Two current electrodes are located, one to the right, the other to the left and in line with the potential electrodes, each spaced two unit distances from the nearest potential electrode. Current is passed through the two current electrodes and the potential between the center and right and between the left and center potential electrodes is determined. These readings record the apparent earth resistivity to the right and to the left of the station to a depth of two unit distances. By varying the unit distance resistivity can be measured to any required depth.

In actual practice stations were arranged 150 feet apart in a grid network. They were located by means of a Brunton compass and distances were determined by the stretched electric wires. Their relative positions were checked against each other and any available points of known location. The elevation at each station was determined by hand level.

At most stations resistivity measurements were made in four directions along two lines intersecting at right angles. At some stations additional measurements were made along other lines intersecting at intermediate angles. At a few stations the interference of mine workings, buried metal, cinder roads, and waste piles rendered measurements along one of the principal lines unreliable and such measurements were not made.

Along most lines of electrodes, 14 measurements were made, seven to the right and seven to the left; thus 28 resistivity measurements, seven in each principal direction, are recorded for every ordinary station. The spacing of the electrodes at each station varied so that, in succession, double the unit distance is equivalent to 150 first, then 125, 100, 75, 50, 25, and 5 feet. The measurement in each case is a function of the resistivity of the earth to a corresponding depth. Because the measurement is not strictly an average of the resistivities of all strata present it is termed an apparent resistivity.

In spite of the fact that stations were separated by 150 feet, rather than by 100 feet as in earlier surveys, the results of this system are far more detailed and complete because the stations were arranged in a uniform interlocking grid network instead of along more or less widely spaced parallel traverses, and because 28 measurements were ordinarily made at each station instead of one.

*Plotting of measurements.*—For field orientation and general illustrative purposes a map was made showing the locations of stations, cultural features, and generalized topographic contours. The resistivity values measured at a depth of 100 feet are indicated as lines extending from each station in the directions in which the measurements were made and having lengths proportional to their values. Such a map shows clearly
areas of high and low resistivity and the positions of the more prominent resistivity breaks which separate them.

For more thoroughly visualizing, comparing, and interpreting the resistivity measurements two series of cross sections were made extending along the parallel lines of stations in the grid network, the two series crossing each other at right angles. At each station the resistivity measurements to left and right were plotted to scale and depth, and by connecting these points two curves or depth profiles were constructed (see Fig. 3, Sta. B). From these curves, depths to a series of resistivity values selected for contouring were obtained by interpolation and projected horizontally to the sides of an isosceles triangle whose apex is located at the station. This triangle is so constructed that its sides pass through a series of points located 1/2 unit outward from the station and 2 units below. Therefore each point is located midway between the center potential electrode and the position of the outer potential electrode that would be occupied if a resistivity measurement were to be made to that particular depth. After the data obtained at other stations had been similarly plotted, resistivity contours were drawn connecting points of corresponding value at each station. (See fig. 2.)

Interpretation.—Variations of earth resistivity to different depths and from place to place are clearly shown by the contoured cross sections. It must be constantly borne in mind, however, that the successively deeper resistivity measurements at any station are cumulative and the actual resistivity of each deeper zone is more and more masked by the resistivity of the shallower zones. Consequently the profiles constructed from the observed resistivity measurements show less sharp variations than would be the case if it were possible to measure the resistivity of each zone entirely independently of the overlying zones.

Figure 4 shows a series of simple hypothetical contoured resistivity cross sections and corresponding geologic cross sections to illustrate the characteristic patterns resulting from high- and low-resistivity beds variously associated. Beds of sandstone and shale are represented, but limestone and shale beds would produce generally similar patterns.
Fig. 4.—Sample resistivity cross section.
At stations 3 and 4 where high-resistivity sandstone (or limestone) overlies low-resistivity shale, measurements are of course higher near the surface. Comparing the contours between stations 1 and 2, 3 and 4, and 5 and 6 shows that the deeper the sandstone extends, the more the resistivity contours are displaced downward and the higher the resistivity at any given depth. Where shale overlies sandstone, resistivities are low near the surface and increase downward. Comparison of the contours between stations 7 and 8, 9 and 10, and 13 and 14 shows that the thicker the shale, the more the contours are displaced downward and the lower the resistivity at any given depths.

If a bed of either high or low resistivity is both overlain and underlain by material of contrasting resistivity a reversal of the resistivity occurs, as between stations 15 and 16, and 17 and 18, and it may be possible to estimate the depth to the contact between the high- and low-resistivity strata.

Where faults occur and beds of different resistivities are brought into contact, areas of transitional resistivity are present. Such transitional areas are most sharply defined if measurements are made very near a fault, as at station 20.

Other conditions can produce resistivity variations similar to faulting, as shown between stations 22 and 25, 26 and 29, 30 and 34, and 35 and 38, but study of numerous cross sections and a knowledge of the stratigraphic section and probable local geologic relations aid in arriving at correct interpretations.

In actual practice it was found that resistivity surveys produced results of quite variable quality. Some faults were clearly shown but others were not indicated at all. This difference appears to be related to local conditions and does not in any way reflect the magnitude of faulting. Some other results were puzzling and remain unexplained. For example, one resistivity break, evidently related to a known fault, was displaced laterally 100 or more feet from the place where it might normally have been expected. Also resistivity breaks similar to those indicating the presence of faults were found at places where no faulting has occurred.

Such deviations clearly show that resistivity surveys, at least those of the type here described, furnish no sure means of interpreting or predicting local geological conditions. If resistivity surveys are used, however, with a full realization of their limitations they may prove very useful in directing prospecting, and if used in conjunction with shallow vertical drilling, which was not done here, a very good picture of geological conditions could be obtained at comparatively small cost.

**ELECTRICAL EARTH SELF POTENTIAL SURVEYS**

Small differences of electrical potential exist within the earth and may be measured in terms of thousandths of volts with suitable instruments. Local earth potentials arise from a number of natural causes, one of the most important of which is the chemical process of oxidation. As these earth potentials are the result of natural processes and not of the introduction of electricity into the earth by artificial means, as in earth resistivity studies, they are known as "self potentials," and the survey of such electrical conditions as a "self potential" survey.

Differences in local rates of oxidation give rise to local differences of potential. The oxidation of different substances also gives rise to different earth potentials. For example, oxidation of galena (lead sulfide), pyrite (iron sulfide), and iron may produce comparatively strong potentials whereas oxidation of sphalerite (zinc sulfide) produces only a weak potential.

Fluorspar is a stable mineral which does not oxidize and therefore cannot produce

![Fig. 5.—Schematic vertical section showing direction of flow of natural electrical current around oxidizing ore body.](image-url)
any electrical potential effects. Calcite is likewise inert. Other minerals, such as galena and pyrite, that are subject to oxidation, however, may be associated with the fluor spar in ore deposits. A self potential survey intended to locate fluor spar is in reality searching for the associated galena and pyrite, and if results suggest that these minerals are present it may be assumed that fluor spar is probably present also.

In a vertical or steeply inclined ore body oxidizing near the ground surface, current flows downward within the ore body and outward and upward through the surrounding rocks as shown in figure 5. This produces a negative potential at the surface over the ore body that should appear as a "low" when compared with potentials in nearby barren areas. Thus under ideal conditions there should be a long narrow potential "low" or a series of "lows" over an oxidizing galena- or pyrite-bearing fluor spar vein.

If the ore body is flat and has no important associated vein mineralization, as in the case of the replacement ore bodies of the Cave in Rock district, the results to be expected from a self potential survey are much less certain. If such a deposit is oxidizing at a uniform rate throughout it would not produce a surface self potential effect. If it is oxidizing more rapidly along one side than the other, a "low" would occur at the surface over the most rapidly oxidizing portion. If it is being oxidized more rapidly around its outer edges a self potential "low" might surround the deposit like a halo.

Surveying procedure.—Measurements are made with an instrument known as a potentiometer, which is a type of very sensitive voltmeter. Contact with the earth is made with a porous earthenware pot in which a copper electrode is suspended in a solution of copper sulfate. The copper sulfate soaks through the porous walls of the container and into the soil, making a very effective electrical contact between the copper and the soil. These pots are placed in shallow pits 100 feet apart in straight lines also 100 feet apart, so as to form a grid. A single reference pot is placed at a convenient spot within or along one edge of the test area.

In making a set of potential measurements the difference in potential between
one after another of the test pots is compared with that of the reference pot until readings have been obtained for the whole test area. If more detail is then needed other intermediate stations can be used.

Plotting measurements.—The potentiometer readings in millivolts usually are plotted on a map of the test area as in figure 6, and lines of equal potential are drawn so as to make relations more readily apparent. In most instances both positive and negative measurements will be plotted and contoured, although in others, like figure 6, all readings will be of one sign. If a set of readings is taken using a given pot for reference and subsequently another set of measurements is made using a different reference pot, the two sets of readings will differ in absolute values but will both yield the same plotted pattern of "highs" and "lows." In general it is this pattern that is important rather than the actual potential values themselves.

Interpretation of results.—As the oxidation of substances like galena and pyrite in a fluorspar deposit is expected to result in a self potential "low" at the ground surface above the deposit, it is such "lows" that the investigator looks for on self potential maps. Potential drops rapidly at a distance from the source and therefore surface potential above an ore body is normally only a small fraction of the potential at the source. It is possible that some suggestion as to the depth of an oxidizing ore body may be furnished by the pattern of the equipotential contours on the map. If they are closely spaced the body is probably comparatively shallow, whereas a deeper ore body would probably be indicated by more widely spaced contours and also by a less pronounced "low."

Constant attention, however, must be given to local conditions and the possibility of interference from causes other than the oxidation of an ore body. Variations in surface elevation might affect the contours, or if the ore body lies beneath sloping ground the "low" may be shifted down the slope. Interference may arise from the presence of rusting scrap iron. Decaying vegetation can also produce interference but if proper contacts are made between the porous pots and the soil this should not be troublesome. Outcropping sandstone or other rock containing small amounts of oxidizing pyrite might affect a self potential survey. Water moving through porous material ordinarily creates an electric current, and consequently readings near streams or seepages in apparently dry valleys, or over subterranean water courses may be unreliable.

The theory of self potential as applied to the discovery of oxidizing ore bodies is fairly simple, but its application in the fluorspar district is attended by many uncertainties. At present there is lack of information as to the activity of oxidation in the district and little is known as to how small a quantity of galena or pyrite can be detected. Thus the value of self potential surveys is not known and can only be determined after representative field studies have been made and the conclusions checked by more direct methods of prospecting.

MINING METHODS

Most methods of mining employed in the Illinois fluorspar district have been described in detail in other reports. Therefore each of the principal methods is discussed only briefly here.

VEIN DEPOSITS

The method used in underground mining of vein deposits depends upon the strength of ore. In relatively soft weathered ground, which is common to depths of 50 to 200 feet or more, a system of top slicing is generally favored. Raises are driven up from the first level, usually 100 feet below the shaft collar, at 100-foot intervals to the top of

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Needham, A. B., Methods and costs of mining fluorspar from a flat-bedded deposit at Cave in Rock, Ill.: U. S. Bureau of Mines Inf. Circ. 7814, 1949.
the ore body. “Sublevels” are then extended 50 feet in both directions from the top of each raise, and the ore is removed. Usually this is accomplished with pick and shovel as the ore is rarely hard enough to require blasting. Square-set timbers with 4 to 5 foot centers are used to support the back. One or more such cuts may be required depending upon the width of ore. After all ore has been removed the entire floor is poled over and the timbers are drawn out or allowed to fall. The next slice is started from the raise immediately below the poles, and square-set timbers are again used to support the back. This process is repeated as many times as necessary. A portion of each raise is converted into a bin which receives the ore and from which it is drawn off into cars in the haulage way below. Top slicing may be continued from one or more main levels as long as the ore is weathered and soft.

Overhead shrinkage stoping is generally used in hard-rock mining below the weathered zone. The type of roof for the haulage levels depends to some extent upon the width of ore. In a narrow vein the drift is driven along the ore with a height of about 14 feet. As it advances stull timbers are placed above the haulage way at about 5-foot intervals and poled over. Bins are built between alternate sets of stulls at about 10-foot intervals and thus the necessity of shoveling in the stopes is eliminated. The ore is then mined out upward by drilling and shooting down the back. Broken ore accumulates above the stulls and is drawn out through the bins so that miners have room to work between the broken ore and back.

Levels are commonly driven at intervals of 100 feet. Stoping is continued upward from one level to the next. If the overlying drift is to be preserved, an arch of unbroken
vein material of appropriate thickness is left in place. After all the ore has been broken, the stope is nearly full and this ore can be drawn off through the bins into cars as it is required.

In wide veins raises are driven upward from the level at about 25-foot intervals to heights of about 26 feet, depending upon the vein width, and connected by "sub-levels." Stoping is then started above the arch that has been so formed. After all broken ore has been drawn off through the raises the arch may be shot down.

Bedded Deposits

Bedded fluor spar deposits are mined underground by a modified form of the room and pillar method, figure 7. Drifts are driven from the outcrop or shaft along the center of the ore body and rooms are turned off at irregular intervals and continued through the workable deposit. Pillars 10 to 15 feet in diameter are left to support the roof and vertical timbers may be used when the roof is weak, although this is seldom necessary. The working face is simply a long irregular wall which is continuously extended outward from the main drift. The ore is shot down, loaded into cars by hand or with mucking machines, and trammed to the shaft or portal. The larger mines are all highly mechanized.

A different haulage system is used in the Minerva mine. In it the main drifts are driven 30 to 60 feet below the ore body and then connected with it by raises. In the mine workings, broken ore is drawn up ramps by mechanical scrapers and loaded into cars for transport to the raises, or is scraped directly into the raises. Bins constructed in the raises hold the ore until it is drawn off into other cars and trammed to the shaft.

Strip Mining

At a few places draglines and power shovels have been used for strip mining. This method has been fairly successful in shallow weathered deposits of gravel spar. Overburden is removed with bulldozers or power shovels and the weathered vein is then selectively removed with the drag line. This type of mining is limited by the depth of weathering, and the deepest operations have not exceeded 50 feet. Some blasting is locally required to break less weathered portions of the vein. A typical large open cut is shown in figure 8.

Milling Methods

The milling of Illinois fluor spar has been described in numerous technical publications and will not be repeated in any detail.
here. In the Illinois district the only minerals of commercial importance are fluorspar, sphalerite, and galena, but the latter two are rare in some ores and they have been recovered at only a few of the mills. Some mills produce a sulphide concentrate which is shipped away for further treatment. Calcite and quartz are the principal impurities that must be removed in milling. They occur as part of the ore, although quartz in this form is common only in certain deposits, and as fragments of limestone and sandstone which contaminate the ore. A few ore bodies locally contain considerable amounts of barite, which sometimes creates a problem in separation.

Three grades of finished fluorspar are marketed, and a single mill may produce one or more grades from the crude ore. The lowest grade is metallurgical spar, which may be sold in the form of "gravel," artificial pellets, or fine flotation concentrate. Normally the lowest acceptable metallurgical grade contains 60 percent "effective" calcium fluoride. The effective value is determined by subtracting \( \frac{2}{3} \) percentage units of \( \text{SiO}_2 \) for every percentage unit of \( \text{CaF}_2 \) present in the complete analysis. Prior to World War II the lower limits of metallurgical spar were not less than 85 percent \( \text{CaF}_2 \) and not more than 5 percent \( \text{SiO}_2 \). Such a grade would be considered \( 72\frac{1}{2} \) percent "effective" by present standards.

The next grade is commonly termed ceramic spar. It is not standardized, and its composition depends upon the requirements of the buyer. A representative analysis would show about 95 percent \( \text{CaF}_2 \), 2 percent \( \text{SiO}_2 \), and 1\( \frac{1}{2} \) percent \( \text{CaCO}_3 \). The highest grade is termed acid fluorspar and is used in making hydrofluoric acid and other chemical products. It contains not less than 97 percent \( \text{CaF}_2 \) and not more than 1 percent \( \text{SiO}_2 \).

**Log Washing**

Weathered ore from near the surface must be washed to remove residual clay. Some good residual spar requires only cleaning in a simple log washer and hand picking of waste rock to raise it far above the metallurgical grade. Most log-washed ore is produced by small operators and is sold to the larger mills for blending with lower-grade ore.

**Jigging**

Most smaller mills in the district have used jigs as their only means of mechanical concentration. There is sufficient difference in specific gravity of the ore minerals to permit satisfactory preparation of metallurgical, and sometimes higher grade, concentrates.

**List of Specific Gravities**

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluorspar</td>
<td>3.1</td>
</tr>
<tr>
<td>Sphalerite</td>
<td>4.0</td>
</tr>
<tr>
<td>Galena</td>
<td>7.5</td>
</tr>
<tr>
<td>Calcite</td>
<td>2.7</td>
</tr>
<tr>
<td>Quartz</td>
<td>2.7</td>
</tr>
<tr>
<td>Barite</td>
<td>4.5</td>
</tr>
</tbody>
</table>

A typical straight jigging mill is the one formerly operated by the Crystal Fluorspar Co., whose flow sheet is shown in figure 9. Other mills employing very similar methods are or were operated by the Victory Fluorspar Mining Co., Yingling Mining Co., and Fluorspar Products Co. This Hillside Fluor Spar Mines employed a similar technique in conjunction with a small flotation plant. The product of these mills is almost exclusively of metallurgical grade. The Rosiclare Lead & Fluorspar Mining Co., whose flow sheet is shown in figure 10, employs a 4-cell Harz type jig to concentrate minus 14-mesh ore which is too fine to be used in the sink-float plant. They also use a similar jig to separate a sulphide concentrate from their finest sink product of the float-sink plant.

**Sink-Float Separation**

Sink-float plants in the Illinois district are operated by the Rosiclare Lead and Fluorspar Mining Company, the Alcoa Mining Company, the Crystal Fluorspar Company, and formerly by the Alco Lead Corporation. The first plant in the district, that of the Rosiclare Company, was completed in 1944, making this method of mineral separation the most recent to be adopted by the fluorspar operators.
Ore concentrate is separated from waste in a cone containing a suspension or heavy medium consisting of minus 80-mesh ferrosilicon in water. Crude ore, composed of particles 1½ inch by 1 mesh, is introduced into the top of the cone in such a manner as to become completely submerged in the heavy medium. The specific gravity of the medium is maintained between 2.55 and 2.62 at the top and 2.85 and 3.10 at the bottom of the cone. Particles having specific gravities greater than that of the medium near the bottom of the cone, such as fluor spar and the sulfides, sink through the medium and are collected. Particles of lesser specific gravity such as quartz and calcite are buoyed upward and carried away with the overflow from the cone. Ferrosilicon washed from the "sink" and "float" fractions is recovered magnetically and returned to the cone.
Fig. 10.—Flow sheet of mill, Rosiclare Lead and Fluorspar Mining Company.
Fig. 11.—Sink-float plant flowsheet, Rosiclare Lead and Fluorspar Mining Co., Rosiclare, Ill.
The arrangement of sink-float equipment at the Rosiclare Company mill is shown in figure 11. Although operating procedure differs slightly in the various mills the basic scheme is the same. The sink fraction is either the final ore concentrate, a component in the final product, or it is used as the feed in a subsequent milling operation.

**Flotation**

Most acid-grade and ceramic fluorspars shipped from Illinois are concentrates made from mine-run ore by froth flotation. Prior to the development and application of the flotation process, these grades were produced mainly by the careful hand-picking of ores from especially pure deposits or parts of deposits. Flotation is a great boon to the industry in that it not only allows the use of the leaner ores that are being mined now, but also permits separation of the valuable and needed lead and zinc minerals, galena and sphalerite, which occur with fluorspar in some deposits.

Froth flotation is a method of separating and concentrating minerals when dispersed...
as relatively finely divided particles in a liquid by causing certain particles to become attached to air bubbles and rise to the surface while other particles sink. The general steps in the process are (1) grinding in water, (2) dilution to a mixture containing certain proportions of the mineral particles and water, (3) addition of conditioning agents, (4) addition of a substance which coats with a water-repellent film the mineral particles which are to be floated, (5) addition of a substance to aid in the formation of tough, strong air bubbles, and (6) production of air bubbles which rise through the mixture, sweeping the selected particles to the surface where the mineral-bearing froth is collected.

Flotation mills are operated by the Rosiclare Lead and Fluorspar Mining Company, the Ozark-Mahoning Company, and the Alcoa Mining Company in Rosiclare, and by the Minerva Oil Company at its mine north of Cave in Rock. The Ozark-Mahoning concentrating plant is described briefly below, and a schematic flow sheet is shown in figure 12.\(^5\) An article by Duncan\(^6\) will be of interest to those wishing a more detailed description of the process. Flotation schemes similar in general outline but adapted to individual ore characteristics and the type of concentrate desired are used in the other mills.

The Ozark-Mahoning mill treats a variety of materials including ore from the several company mines, ore purchased from other operators, and high-sulfide concentrates from other mills. The plant was designed, therefore, to afford maximum operational flexibility. Its products are lead sulfide concentrate, zinc sulfide concentrate, acid-grade fluor spar concentrate, and pelletized metallurgical-grade fluor spar concentrate. All feed materials are brought to the mill in trucks and stored in receiving hoppers. Coarse ores are crushed in a primary jaw crusher before going to one of four crushed-ore hoppers. A double-deck vibrating screen and secondary cone crusher operating in closed circuit reduce the oversize from the primary crusher. The crushed ore is carefully proportioned from the various hoppers so as to maintain a feed of uniform mineral content to flotation circuits “A” and “B”. These two circuits are practically alike, except that circuit “B” is set up to treat mainly low-sulfide ore and has fewer flotation cells or machines for separating lead and zinc sulfides. Crushed ore passes through one of the two ball mills where it is ground in closed circuit with drag classifiers to such fineness that practically all will pass through a 150-mesh screen. After the proportion of solid material in the resulting pulp (the mixture of water and ground rock) has been increased to 38 percent by means of thickeners, the pulp is pumped first to the set of flotation cells in which the lead sulfide is separated, next to the machines or cells in which the zinc sulfide is removed, and lastly, after rethickening, to the fluor spar cells. As the pulp enters successive sets of cells various chemicals are added to aid in floating the proper mineral particles and to prevent others from floating. In each cell the pulp is violently agitated so that air bubbles are introduced into it from the bottom. The mineral concentrates and air bubbles rise together as a froth and are collected by scrapers at the surface of the cells. From mill feeds containing fluor spar, galena, and sphalerite, respectively, from 20 to 70 percent, up to 50 percent, and up to 25 percent, final concentrates containing 60 to 65 effective units of fluor spar (metallurgical grade), a minimum of 98 percent fluor spar and not over 1 percent silica (acid grade), 67 to 72 percent lead, and 62 to 63 percent zinc are thus prepared.

The lead and zinc sulfide concentrates are dewatered in disc filters and loaded into boxcars for shipment as moist filter cake. The acid-grade fluor spar concentrate is thickened, dewatered in a drum filter, and then dried to a moisture content of 0.25 percent water in an oil-fired rotary kiln. After sampling for chemical analysis, the dried material is stored in a hopper or tanks for delivery into covered hopper cars, paper-


\(^6\) Duncan, W. E., op. cit.
lined boxcars, or to a bagging machine. The metallurgical-grade concentrate is collected on a drum filter and then formed into pellets better adapted for use in open-hearth furnaces than the powdery concentrate would be. The filter cake is batch-mixed with a crude fatty acid binder and a little hydrated lime, and then passed through a briquetting press which forms almond-shaped pellets \( \frac{3}{8} \) of an inch long by \( \frac{3}{8} \) of an inch wide. The pellets are screened, dried in an oil-heated oven, and then either loaded into boxcars or stored in hoppers for later shipment.
CHAPTER 6—GEOLOGY

STRATIGRAPHY

The Illinois fluorspar district is adjacent to the Ohio River in Hardin County, and some mineralization extends into Pope County to the west and into Saline County to the northwest. It occupies an area of about 280 square miles, mostly south of the prominent irregular ridge that extends east and west across the southern part of the state and that is often referred to as the Illinois Ozarks. The ridge is formed by resistant sandstones of the lower Pennsylvanian rising southward out of the Illinois basin. South of this ridge Mississippian rocks come to the surface; this is one of the few places in Illinois where a fairly complete Mississippian succession is available for study in outcrop. In addition Devonian strata are exposed in a small area on Hicks dome.

Rock strata with a total thickness of about 4,000 feet crop out in various parts of the fluorspar region of southern Illinois. In addition 3,000 feet of lower strata have been penetrated in a deep well drilled for oil on the south flank of Hicks dome in sec. 30, T. 11 S., R. 8 E. It is estimated that 5,000 feet of additional sedimentary rocks lie between the horizon of the bottom of the well and the basal granite or other igneous or metamorphic rock. Thus the total thickness of sedimentary deposits in the area is about 12,000 feet. These rocks are divided into a large number of different formations assigned to six geologic systems ranging from the Cambrian to the Pennsylvanian. The stratigraphic section known from outcrops in this district and the average thicknesses of the various formations are as follows:

<table>
<thead>
<tr>
<th>Thickness (Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pennsylvanian system</td>
</tr>
<tr>
<td>Tradewater group</td>
</tr>
<tr>
<td>Stonefort formation</td>
</tr>
<tr>
<td>Macedonia formation</td>
</tr>
<tr>
<td>Delwood formation</td>
</tr>
<tr>
<td>Grindstaff formation</td>
</tr>
<tr>
<td>Chester series</td>
</tr>
<tr>
<td>Caseyville group</td>
</tr>
<tr>
<td>Pounds formation</td>
</tr>
<tr>
<td>Battery Rock formation</td>
</tr>
<tr>
<td>Lusk formation</td>
</tr>
<tr>
<td>Mississippian system</td>
</tr>
<tr>
<td>Glendean group</td>
</tr>
<tr>
<td>Kinkaid formation</td>
</tr>
<tr>
<td>Degonia sandstone</td>
</tr>
<tr>
<td>Clore formation</td>
</tr>
<tr>
<td>Palestine sandstone</td>
</tr>
<tr>
<td>Menard formation</td>
</tr>
<tr>
<td>Waltersburg sandstone</td>
</tr>
<tr>
<td>Vienna formation</td>
</tr>
<tr>
<td>Tar Springs sandstone</td>
</tr>
<tr>
<td>Homberg group</td>
</tr>
<tr>
<td>Glen Dean formation</td>
</tr>
<tr>
<td>Hardinsburg sandstone</td>
</tr>
<tr>
<td>Golconda formation</td>
</tr>
<tr>
<td>Cypress sandstone</td>
</tr>
<tr>
<td>New Design group</td>
</tr>
<tr>
<td>Paint Creek formation</td>
</tr>
<tr>
<td>Bethel sandstone</td>
</tr>
<tr>
<td>Renault formation</td>
</tr>
<tr>
<td>Downeys Bluff limestone</td>
</tr>
<tr>
<td>Shetlerville member</td>
</tr>
<tr>
<td>Iowa series</td>
</tr>
<tr>
<td>Meramec group</td>
</tr>
<tr>
<td>Ste. Genevieve formation</td>
</tr>
<tr>
<td>Levias limestone</td>
</tr>
<tr>
<td>Rosiclare sandstone</td>
</tr>
<tr>
<td>Upper Fredonia limestone</td>
</tr>
<tr>
<td>&quot;Spar Mountain&quot; sandstone</td>
</tr>
<tr>
<td>Lower Fredonia limestone</td>
</tr>
<tr>
<td>St. Louis limestone</td>
</tr>
<tr>
<td>Osage group</td>
</tr>
<tr>
<td>Warsaw limestone</td>
</tr>
<tr>
<td>Osage formation</td>
</tr>
<tr>
<td>Kinderhook group</td>
</tr>
<tr>
<td>Shale</td>
</tr>
<tr>
<td>Upper New Albany shale</td>
</tr>
<tr>
<td>Lower New Albany shale</td>
</tr>
<tr>
<td>Devonian system</td>
</tr>
<tr>
<td>Devonian limestone and chert</td>
</tr>
</tbody>
</table>

Following is a summary of the geologic formations, with their thicknesses and depths, encountered in drilling the Maretta Oil Company and the Northern Ordnance Company—Fricker No. 1 test for oil at a location on the south side of Hicks Dome, 372 feet north of the south line and 181 feet east of the west line of the SE ¼, SE ¼, sec. 30, T. 11 S., R. 8 E., Hardin County:
Recent system

Devonian system

Upper Devonian series
- Chatauquan group
- New Albany shale
- Senecan group
- Alto formation
- Middle Devonian series
- Erian group
- Lingle limestone
- Ulsterian group
- Grand Tower limestone
- Dutch Creek sandy limestone
- Clear Creek limestone

Lower Devonian series
- Oriskanian group
-精神文明
- Helderbergian group
- Bailey limestone

Silurian system

Niagaran series
- Bainbridge group
- Moccasin Springs limestone
- St. Clair limestone

Alexandrian series
- Sexton Creek limestone
- Edgewood limestone

Orndovician system

Cincinnatian series
- Maquoketa shale
- Mohawkian series
- Kimmswick limestone
- 94
- 2110
- 785
- 2895
- Chazyan series
- Joachim dolomite
- Dutchtown formation
- 312
- 3207
- 99
- 3306

An estimate of the thicknesses and depths of sedimentary formations below the bottom of the well is as follows:

<table>
<thead>
<tr>
<th>Formation</th>
<th>Thickness (feet)</th>
<th>Depth (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dutchtown formation (continued)</td>
<td>44</td>
<td>3350</td>
</tr>
<tr>
<td>St. Peter sandstone</td>
<td>100</td>
<td>3450</td>
</tr>
<tr>
<td>Orndovician and Cambrian systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dolomites</td>
<td>3050</td>
<td>6500</td>
</tr>
<tr>
<td>Cambrian system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>St. Croixan series</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dresbach group</td>
<td>1500</td>
<td>8000</td>
</tr>
</tbody>
</table>

FORMATIONS NOT EXPOSED

CAMBRIAN SYSTEM

ST. CROIXAN SERIES

Dresbach group.—Probably the lowest group of sediments underlying Hardin County, not yet reached by the drill, is the Dresbach group, estimated to be 1,500 feet thick though it may be much thicker. It consists of the Mt. Simon sandstone at the base, possibly 700 feet or thicker, and the Eau Claire formation above, possibly 800 feet thick. The Eau Claire consists probably of interbedded and lenticular sandstones, siltstones, shales, dolomites, and limestones. Several deep wells in central Illinois encountered an oolitic limestone in the Eau Claire formation,2 and this may extend below the Hardin County region. In Missouri the Mt. Simon is called the LaMotte sandstone, and the Eau Claire is represented by the Bonneterre dolomite.

ORDOVICIAN AND CAMBRIAN SYSTEMS

Overlying the Dresbach group and extending up to the base of the St. Peter sandstone is a series of dolomite formations estimated to have a thickness of 3,000 or more feet in Hardin County. These formations in northern Illinois are the Franconia and Trempealeau formations of Cambrian age and the Prairie du Chien series of Ordovician age. Altogether they are practically equivalent to the Knox dolomite of Tennessee. In Missouri they consist of formations from the Derby-Doerun up to the top of the Smithville.

ORDOVICIAN SYSTEM

CHAZIAN SERIES

St. Peter sandstone. — The St. Peter formation in the Hardin County region probably consists of a more or less dolomitic and quartzitic fine- to medium-grained sandstone similar to that which was encountered in a well in Webster County, Ky., about 40 miles east, and one in Marshall County, Ky., about 45 miles south of the Fricker well. There are probably some red, purple, and green shales and white chert conglomerates toward the base of the formation, largely derived from the residual material accumulated on the pre-St. Peter erosional surface. The thickness of the St. Peter in Webster County is 75 feet and in Marshall County 100 feet, and it is estimated to be about 100 feet in Hardin County, Ill. Perhaps the top is no more than 50 feet below the bottom of the Fricker well.

Dutchtown formation. — The Dutchtown formation consists of: 1) medium to dark gray dolomitic siltstone grading to silty dolomite and black siliceous shale—these constitute more than 50% of the Dutchtown thus far penetrated; 2) dark gray to black calcareous argillaceous dolomite grading to shale; and 3) minor beds of sandy dolomite to sandstone. Sandstone and sand in the dolomite are not so abundant in the Dutchtown as they are in the lower part of the overlying Joachim formation. The drill penetrated 99 feet of Dutchtown, and it is estimated that probably the entire thickness is near 150 feet. Traces of fluorspar are present in the cuttings from the Dutchtown in the Fricker well.

Joachim dolomite. — The Joachim formation consists mostly of very finely crystalline dolomite, medium to dark gray with some light gray. Some beds are brecciated, showing dark gray fragments in a lighter matrix. In the total thickness of 312 feet, the top 159 feet contains almost no sand, the next 66 feet contains some very fine sand, and the bottom 87 feet contains fine to medium sand and includes beds of white to light gray dolomitic fine- to medium-grained sandstone. The quartz grains of the sandstone are so well cemented in the matrix of dolomite that they commonly break across the grain. The basal 39 feet contains very silty siliceous dolomites similar to those in the Dutchtown and is probably transitional in nature. Traces of fluorspar and veinlets of white calcite occur in the Joachim in the Fricker well.

MOHAWKIAN SERIES

Decorah-Plattin limestones. — The Plattin limestone makes up most of the 785 feet of these formations under Hardin County, the Decorah limestone occupying only an indefinite zone possibly as much as 50 feet thick at the top. The strata consist of partly dolomitic and partly cherty very fine to lithographic limestones in various shades of light to dark brown and brownish gray. There are a few zones of buff, white, and light to medium gray limestones that are usually a little coarser grained than the average rock. Dark grayish brown to black shale partings are occasionally evident in the sample cuttings and there are a few dark argillaceous limestone zones. The basal 159 feet shows more dolomite content than does the limestone above, and some beds of very fine to fine sand are present in the upper third of this portion. A zone of light buff oolitic limestone, estimated to be four feet thick, occurs 23 feet above the bottom of the Plattin formation. Cuttings

2 The advice and assistance of Dr. J. S. Templeton in the interpretation of Dutchtown and lower Joachim sample cuttings is acknowledged.
from the Fricker well throughout the Decora Platin formations contain traces of fluorspar.

**Galena (Kimmswick) limestone.** — The Galena limestone in the Fricker well is the Kimmswick facies; it is white to light gray and light brown, fine- to medium-grained, and semi-crystalline with clear to opaque white calcite. The formation is 94 feet thick. The lowest 22 feet is somewhat cherty and a four-foot cherty zone occurs with its base 51 feet above the bottom of the formation. In the Fricker well traces of fluorite are present, and the top 12 feet contains showings of oil. There may be some nearby variations in the thickness of the formation: in the Pure and Ashland #1 Walker well, in Webster County, about 40 miles to the south, it is only 10 feet thick.

**Cincinnatian Series**

**Maquoketa shale.** — The Maquoketa formation consists mostly of dark brownish gray to black silty and siliceous shale. It is partly calcareous and dolomitic and contains a few thin zones of dark argillaceous limestone in the middle portion. Very fine dark gray argillaceous and calcareous sandstone which grades to siltstone and shale makes up the lowest 21 feet. There are some traces of fluorite in the cuttings. In the Fricker well the formation is 241 feet thick. In the Pure and Ashland #1 Walker well, in Webster County, about 40 miles to the south, it is only 10 feet thick.

**Silurian System**

**Alexandrian Series**

**Edgewood limestone.** — The Edgewood formation consists of cherty dolomitic light to dark grayish brown very fine-grained limestone. The lower half has a more siliceous appearance than the upper half, and argillaceous spots are present throughout the formation. The thickness is 106 feet. In northeastern Illinois, where relations of the Edgewood and underlying Maquoketa have received the most study, the Edgewood is thickest where the Maquoketa is thinnest, filling up the valleys in the Maquoketa produced by pre-Edgewood erosion. As the iron-bearing beds of the top of the Maquoketa are absent at the location of the Fricker well and as the Maquoketa is somewhat thinner than might be expected, it is inferred that perhaps the Edgewood is thicker at this place than is normal for the general region. No trace was found in the Fricker samples of a very fine “pepper-and-salt” speckled sandstone frequently part of the Edgewood of Illinois where the formation is relatively thin.

**Sexton Creek limestone.** — The Sexton Creek formation in Hardin County consists of 14 feet of very fine to fine white dolomitic limestone.

**Niagaran Series**

**Bainbridge group.** — Formerly all limestone of the Niagaran series in southern Illinois was known as the Bainbridge formation. However, Lowenstam has recently designated a lower pink crinoidal purer portion as the St. Clair formation and an upper red, green, purple, and gray argillaceous limestone as the Moccasin Springs formation.

**St. Clair limestone.** — The St. Clair formation in Hardin County consists of light gray to white extra fine grained limestone carrying scattered white and pink coarse crinoid grains. Its thickness is 48 feet at the Fricker location.

**Moccasin Springs limestone.** — The Moccasin Springs formation consists of 125 feet of dolomitic silty and siliceous light to dark gray and pink extra fine grained limestone. Traces of fluorite were noted in the top samples.

**Devonian System**

The top 1,482 feet of strata penetrated by the Fricker well, with the exception of

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the soil, belong to the Devonian system. This system in Illinois lends itself to a grouping into three series, the Lower, Middle, and Upper Devonian series. Each separation between series is distinguished in Illinois by an erosional unconformity on the older series and a more extensive deposition of the younger series.

**LOWER DEVONIAN SERIES**

**Helderbergian Group**

*Bailey limestone.*—The Bailey limestone is very cherty and siliceous, light to dark brownish gray, and very fine-grained. It is somewhat argillaceous throughout but is increasingly so toward the base. Small dark brown sporangites are scattered sparingly in both limestone and chert. A more cherty upper portion has been described from outcrops in Union County and called the Grassy Knob chert, but subsurface studies in Illinois fail to separate this from the rest of the formation, and it is believed that the greater proportion of chert in the outcrops is due only to local leaching of the limestone and concentration of the silica in post-Devonian times. The thickness of the Bailey formation in the Fricker well is 624 feet.

**Oriskanian Group**

*Backbone limestone.*—The backbone limestone is white, very fine- to coarse-grained, and contains white chalk-like to dense chert. The driller reported encountering crevices in the formation in the Fricker well. The thickness of the Backbone there is 42 feet, and it probably thins southward and thickens northward.

**MIDDLE DEVONIAN SERIES**

**Ulsterian Group**

*Clear Creek limestone.*—The Clear Creek formation is 469 feet thick at the location of the Fricker well: the lower 256 feet is classified as dolomitic limestone and the upper 213 feet as calcareous dolomite. Throughout the formation there is white to light gray and brownish gray chalk-like to dense, granular to wax-like chert. The rock apparently is very fine to fine-grained, but the cuttings are too pulverized for good interpretation; it is believed that some beds are medium to coarse-grained like the Backbone, a condition observable in the Clear Creek elsewhere in the Illinois basin. Very fine sand grains that have been recrystallized to short doubly terminated quartz crystals are scattered sparsely throughout the formation.

The Clear Creek was originally, and for a long time, considered to be of Oriskany age and later considered to be of Onondagan age. Its conformable relations with the underlying Backbone, the recurrence of Backbone-type beds in the Clear Creek, and its unconformable relations with the overlying Dutch Creek-Grand Tower beds elsewhere in Illinois suggest that it may be of Oriskany age.

*Dutch Creek formation.*—A very finely sandy limestone 24 feet thick is thought to be equivalent to the Dutch Creek sandstone and sandy limestone of Union County. The limestone in the Fricker well is light to medium brownish gray speckled with dark gray grains, varying in texture from very finely to coarsely granular. It contains some brownish chert and dolomite in the middle portions. The sand here is all very fine, whereas elsewhere in Illinois the Dutch Creek varies to medium and some coarse sand.

*Grand Tower limestone.*—The Grand Tower formation consists of 188 feet of white, light buff, and light brown, more or less cherty limestone of very fine to coarse texture. Some corals were noted. Trace of fluorite occur in the upper part. The lower 44 feet are a little coarser and lighter in color and contain less chert than the beds above, and a few beds are slightly sandy.

The age of these strata is somewhat uncertain. Probably Warthin and Cooper would designate the lower 44 feet as Grand Tower and the upper 144 feet as Hamilton (possibly St. Laurent). On the other hand, by tracing correlations westward from Indiana, it appears that they would be

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called Jeffersonville, of Onondagan age. Inasmuch as the same or a similar problem is not yet completely solved regarding the Devonian strata at Grand Tower, the use of the term Grand Tower to cover all these strata is recommended.

**ERIAN GROUP**

*Lingle limestone.*—The Lingle formation is an argillaceous cherty dolomitic medium to dark brown limestone. The darker the limestone the more argillaceous it is, and dark brown to brownish black calcareous shale partings are common. The chert is generally somewhat translucent, but it has a brownish cloudy appearance. The texture is generally very fine with sparse to numerous coarser grains and fossils that are lighter brown to near white. Flakes of dark brown organic material, in part sporangites, are common. This formation is the Sellersburg (Silver Creek and Beechwood) formation of Indiana. It is 35 feet thick in the Fricker well.

**UPPER DEVONIAN SERIES**

**SENECAN GROUP**

*Alto formation.*—In the Fricker well, 17 feet of thin interbedded brown argillaceous very fine dolomite, brown argillaceous sub-lithographic limestone, and dark brown to brownish black shale, is assigned to the Alto formation. There are some beds of gray to dark brown argillaceous siltstone, and there is a shale and limestone conglomerate at the base. A core test on the Lloyd farm near the center of the SW 1/4 NE 1/4 sec. 30, T. 11 S., R. 8 E., one-half mile northwest of the Fricker well, encountered 14 feet of similar strata, except that the dolomite and limestone beds are very finely sandy. The Alto is more argillaceous than the Lingle, fossils are scarce, and the interbedded shale is similar to the brownish black New Albany shale above. The Alto formation may be traced in the subsurface eastward from Union County, where it is shown in one well to be 70 feet thick. All the strata including the basal conglomerate are characteristic of the formation across the southern part of Illinois. However, it appears very possible that the Alto may be equivalent laterally to the basal portion of the New Albany shale as elsewhere known in the Illinois basin. Traces of fluorite are present in the Alto samples from the Fricker well, and tar and vein calcite in cores from the Lloyd well.

**EXPOSED FORMATIONS**

Descriptions of the following formations are drawn largely from the stratigraphic portion of Bulletin 41 by Stuart Weller and Charles Butts which has long been out of print. Some of the paragraphs are quoted verbatim and others have been recast or altered to accord with present information.

**DEVONIAN SYSTEM**

*Chert and limestone.*—Devonian strata older than the black shale come to the surface only in a restricted area at the center of Hicks dome in secs. 30 and 31, T. 11 S., R. 8 E., and sec. 25, T. 11 S., R. 7 E. Outcrops are few and scarce and are not adequate to subdivide these rocks satisfactorily into formations. Rather coarsely crystalline, medium dark gray limestone outcrops at the mouth of a large ravine at the south end of the dome in the NE 1/4 sec. 31, and a few fragments of similar rock occur on the dumps of the Rose mine. Lithologically this resembles the Grand Tower limestone of Union County, but fossils to substantiate this identification have not been found.

Layers of fractured gray to brownish chert embedded in red clay crop out in a ditch by the roadside in the SW 1/4 sec. 30. It is lithologically identical to part of the Clear Creek chert of Union and Alexander counties, and fossils which confirm this correlation are locally abundant. This formation originally contained much limestone, but near the surface this has been entirely removed by leaching and only insoluble and silicified layers remain.

*New Albany shale.*—This formation, estimated from dips and the width of its outcrop to be about 400 feet thick, comes to the surface in a rudely circular band 1/4 to 1/2 mile wide, enclosing the area of Devonian chert and limestone at the center of Hicks dome. Because it is much less re-
assistant to weathering and erosion than the Devonian chert or the overlying Osage beds, it occupies a lowland drained by headwater tributaries of Goose Creek and Hicks Branch.

The New Albany is a black carbonaceous and bituminous more or less fissile shale. Some layers are very hard, compact, and, when fresh, apparently without bedding. It is very siliceous and is largely composed of very fine quartz grains. Tiny mica flakes are abundant and some pyrite is locally present. Upon weathering this shale loses its deep black color, becomes brownish or grayish, and splits readily into thin platy fragments. Fossils are very rare.

Good exposures of the New Albany shale may be seen on Hicks Branch in the NW 1/4 SE 1/4 and SW 1/4 NE 1/4 sec. 25, T. 11 S., R. 7 E., and by the roadside in the north part of sec. 31, T. 11 S., R. 8 E.

MISSISSIPPIAN SYSTEM

IOWA SERIES

KINDERHOOK GROUP

Overlying the black shale is 10 feet or more of gray to buff argillaceous beds of Kinderhook age. Lenses of somewhat harder material were probably impure limestone before strata near the surface were completely leached. Rather poorly preserved impressions of several small fossils occur in some layers.

In former reports these strata were considered to be the uppermost layers of the black shale formation. Similar beds overlie the black shale in Tennessee, Kentucky, and Indiana, and these strata are probably equivalent to the Rockford limestone and associated beds in Indiana. The best exposure occurs in the bank of Hicks Branch in the NW 1/4 SE 1/4 sec. 25.

Osage group.—Beds of Osage age, which cannot be subdivided into such formations as the Burlington and Keokuk limestone of the Mississippi valley, outcrop in Hardin County only in an oval hilly belt 1/2 to 1 mile wide surrounding the central part of Hicks dome. Because of the width of outcrop and dip of the strata they are judged to reach a thickness of about 550 feet.

As shown in outcrops Osage strata consist almost exclusively of chert in layers up to one foot thick separated by partings or thin layers of siliceous clay. Where freshly exposed they are light gray to almost white, but they weather to various rusty shades. The chert breaks into small angular blocks and varies from compact, brittle, and tough to finely porous. Except for a few scattered fragments of crinoid stems, fossils are very rare. At the base of the Osage there are 1 to 2 feet of silty and glauconitic green to gray shale locally containing phosphatic nodules. These beds may be seen in the outcrop in NE 1/4 SE 1/4 sec. 25 and by the roadside up the hill in the E 1/4 NE 1/4 sec. 36, T. 11 S., R. 7 E.

The Osage chert probably originally consisted of impure siliceous fine-grained limestone but long exposure near the surface has resulted in its being almost completely leached and silicified.

The best exhibition of the Osage beds occurs in an abandoned WPA quarry a short distance up a ravine northeast of the road that follows the valley of Goose Creek in the SW 1/4 NW 1/4 sec. 32, T. 11 S., R. 8 E. Many of the more resistant chert beds are well exposed along Hicks Branch in the SW 1/4 sec. 25, T. 11 S., R. 7 E., and the sharp contact between this formation and the underlying Kinderhook beds may be seen in the bank of this same stream at the east end of this series of outcrops.

MERAMEC GROUP

Warsaw–Salem limestone.—The Warsaw–Salem limestone comes to the surface only in an oval zone generally from 1/4 to 1/2 mile wide concentric to those already described. Its thickness is estimated at about 250 feet.

This formation is best exposed along Hicks Branch just north of the road in the western part of sec. 25, T. 11 S., R. 7 E. Approximately the lower three-fourths is dark to black fine-grained limestone. Locally some secondary chert has been developed near the surface of the outcropping beds. Fossils are fairly numerous but are rather indistinct because they do not
weather or break out readily from the hard limestone. Cross sections of fenestellid bryozoans are abundant at many places.

The uppermost fourth of the formation is much lighter colored and may correspond to the Salem limestone of Indiana. It is mainly thick-bedded and more or less coarsely granular and light gray. Some parts are remarkably pure calcium carbonate. Fossils, especially fragments of crinoids, are locally abundant.

*St. Louis limestone.*—The St. Louis limestone outcrops in an oval zone surrounding the central part of Hicks dome and the area where older formations appear at the surface, along Hogthief Creek for a distance extending about 3 miles northeast of Pankey's store, and along the Ohio River and in the area to the north throughout much of the region between Elizabethtown and Cave in Rock. As shown by diamond drilling near Rosiclare, this formation is at least 500 feet thick, which is considerably more than the previously estimated 350 feet.

The St. Louis is predominantly a dense fine-grained limestone, and some beds are nearly lithographic in texture. Others, however, are more granular, and some are coarsely crystalline. The upper part of the formation is mainly gray to dark bluish-gray, and downward the rock becomes darker colored and a considerable portion of its lower part is nearly black. Most of the beds are hard and tough but those of lithographic texture are brittle and break with a conchoidal or splintery fracture. Chert is common and occurs as lenticular or irregular masses disposed in horizontal zones parallel with the bedding planes. Much of the chert is secondary and has developed near the surface; chert fragments are abundant in residual material produced by the decomposition of this limestone.

The St. Louis limestone is particularly characterized by the colonial coral *Lithostrotionella prolifera,* which often occurs in great abundance in the middle part of the formation and is particularly conspicuously preserved as white calcite in black limestone. These corals are well exhibited in the limestone by the roadside near the center of the south line of the SW ¼ sec. 16, T. 12 S., R. 9 E., and abundant silicified specimens weathered from the rock occur by the roadside near the center of the south line of sec. 36, T. 11 S., R. 8 E. Another coral, *Lithostrotionella castelnaui,* is equally characteristic of the St. Louis but is much less abundant in Hardin County. Other fossils are common in the St. Louis locally but they are difficult to collect from the hard limestone. Fenestellid bryozoans, generally showing in cross section, are abundant in some of the upper layers.

The best outcrops of St. Louis limestone occur in the Ohio River bluffs west of Cave in Rock. The cave was produced by solution in the upper part of this formation.

The St. Louis limestone does not have sharp stratigraphic boundaries. It grades almost imperceptibly into the Warsaw formation below and the Ste. Genevieve limestone above. Any exact boundaries that may be chosen are arbitrary and the boundary with the overlying Ste. Genevieve probably has not been mapped consistently.

*Ste. Genevieve limestone.*—The Ste. Genevieve limestone of Hardin County and neighboring areas is divisible into three persistent members. The largest part of the formation is the Fredonia limestone, the lowest member. This is overlain by the thin calcareous Rosiclare sandstone and the formation is completed at the top by the Levias limestone. At least locally a more or less conspicuous sandy zone, known as the “Spar Mountain” sandstone, occurs within the Fredonia member, and for convenience the limestones below and above are termed lower and upper Fredonia.

The Ste. Genevieve limestone occurs at the surface throughout a considerable area surrounding Hicks dome on all sides except the southeast and also from Rosiclare to 3 miles east of Cave in Rock.

Both parts of the Fredonia member are largely massive limestone whose beds vary considerably in lithologic character. The color ranges from bluish gray to nearly white. On the whole the Fredonia is lighter colored than the St. Louis but the change is gradual, and certain beds similar to the St.
Louis occur at intervals within the Fredonia. The texture of the Fredonia is also variable, and beds which are fine-grained and break with a conchoidal fracture like those of the St. Louis alternate with the more typical granular beds.

Oolites occur in many parts of the Fredonia and are particularly conspicuous in its upper part where some layers are nearly white, richly oolitic, cross-bedded limestone. Much chert occurs in the Fredonia limestone although most of it is confined to strata at and near the surface; obviously, therefore, it is of secondary origin. Chert in rounded or plate-like masses or angular fragments is especially abundant in reddish residual clay derived from the Fredonia. Most limestones in this region weather to reddish clay of this type, but the Fredonia residual clay is locally more brilliantly colored than any other.

Good outcrops of the Fredonia occur along State Highway No. 146 just west of the former railroad spur in the E 1/2 sec. 23, T. 12 S., R. 7 E., in the Ohio River bluffs at Rosiclare, and at the point of rock in front of the Rose Hotel at Elizabethtown. An excellent showing of red chert-bearing residual clay exists along the Cave in Rock road a little more than one mile northeast of Elizabethtown.

The "Spar Mountain" sandstone consists of more or less sandy limestone which has a maximum thickness of about 10 feet. It is not sharply defined and grades into the normal limestone both above and below. This zone is best known in secs. 3 and 4, T. 12 S., R. 9 E., where it consists of very sandy cross-bedded limestone about 60 feet below the Rosiclare sandstone. In the ravines just west of Eichorn, brownish thin-bedded sandstone produced by the leaching of very sandy limestone lies about 50 feet below the Rosiclare. Somewhat similar sandy material has been observed at a few other places, including a diamond drill core from the southern part of the Rosiclare Lead and Fluorspar Mining Company's property near the north extension of the Argo vein. Sandy limestone and sandstone have been observed in a number of cores from the area, occurring about 50 to 65 feet below the Rosiclare. The "Spar Mountain" sandstone appears to be one of several extensive beds of thin sandstone and sandy limestone in the Fredonia formation in the subsurface of south-central Illinois.

The Rosiclare sandstone member of the Ste. Genevieve formation is generally thin but persistent throughout the fluorspar region. Where it is encountered in mine workings, drill cores, and quarries it is highly calcareous and might be described as sandy limestone. Where these beds have been subject to weathering and leaching, however, the lime has been entirely removed, leaving a rather fine-grained and generally porous sandstone that greatly resembles some of the Chester sandstones. Where unweathered the rock is gray to slightly greenish or blueish but where weathered it is rusty brown. Cross-bedding is not uncommon, and unlike most of the Chester sandstones it may contain a few obscure fossil impressions. Locally greenish sandy and slightly micaceous shale occurs at the base of the Rosiclare sandstone. This attains a maximum thickness of about 3 feet and is more generally present where the overlying sandstone is thickest. The contact of the Rosiclare sandstone on the underlying shale is sharp, and at a few places pebbles of limestone suggestive of a basal conglomerate are present, but other evidence of unconformity is not convincing.

Unweathered Rosiclare sandstone is well shown in the old Bean and Masters quarry in the south face of Rich Hill east of Shetlerville. Weathered blocks derived from this member are abundant on the hilltop at Rosiclare. Both weathered and unweathered Rosiclare occur by the side of State Highway No. 1, a third of a mile north of the intersection with State Highway 146. Basal Rosiclare shale rarely occurs in natural exposures but may be seen in some of the open-cut workings at Spar Mountain.

The Levias (formerly known as the Lower Ohara) member of the Ste. Genevieve formation consists of limestone similar to the Fredonia. It is commonly oolitic or
partly oolitic, generally light gray to nearly white although some dense and darker beds are present. It is well exposed in the old Bean and Masters quarry near Shetlerville.

Fossils are fairly abundant in the Ste. Genevieve limestone at many places but they are generally difficult to collect from the hard limestone. Many of the more granular layers contain an abundance of broken crinoid remains that are best recognized on exposed surfaces where they weather out in relief. The most useful fossil for recognition purposes is *Platycrinus penicillus*. The three-ribbed basal portions and the spined-stem segments do not occur in any of the Chester formations, but closely similar specimens may be found in the St. Louis and even lower limestones.

The Fredonia member constitutes the greatest part of the Ste. Genevieve formation. Because of its indeterminate lower boundary the thickness of this member is difficult to determine accurately. It is probably between 180 and 200 feet thick in the Ohio River bluffs northeast of Rosiclare. As recognized in the valley of Hogthief Creek, however, it seems to be somewhat thicker and may reach 250 feet. The Rosiclare sandstone is about 16 feet thick at Rosiclare and varies locally from somewhat less than this to 30 feet or more near Eichorn. The Levias member ranges from about 10 to about 25 feet. This variation results in part at least from the erosional unconformity that separates the Levias from the Renault formation above. The total thickness of the Ste. Genevieve formation probably lies between the limits of 250 and 300 feet.

CHESTER SERIES

*Renault limestone.*—The Renault limestone is the lowest formation of the upper Mississippian or Chester series. It outcrops in a narrow belt on the outer flanks of Hicks dome and in the slopes of hills that rise above the area of St. Louis and Ste. Genevieve limestones east and north of Elizabethtown. Some of the best exposures are in the vicinity of Shetlerville.

The Renault limestone is divided into two parts. The lower or Shetlerville member consists of alternating beds of limestone and shale in about equal proportions. The shales, up to 3 or 4 feet thick, are generally greenish gray, calcareous, and weather readily to clay. Locally they are very fossiliferous. The limestone layers, of about the same thickness, are mostly medium gray, granular, and more or less oolitic. Fossils are abundant in many parts. On the whole the Shetlerville member is quite irregularly developed in lithology from place to place and the limestone and shale beds grade into each other laterally. Locally it is almost entirely limestone but elsewhere shale predominates, and at such places the interbedded limestone consists of thin platy discontinuous layers. Some of the limestone is cross-bedded and finer-grained layers may weather to a buff color. A similar buff color is common in the weathered shales. A little red shale is present in some areas.

At most places the separation of the two members of the Renault is difficult, especially where shale is not abundant in the Shetlerville. At Downeys Bluff just below Rosiclare, however, what appears to be an unconformity separates them, but similar relations have not been observed elsewhere. The Shetlerville member overlies the Levias limestone unconformably and at some places a zone of rounded limestone pebbles marks this boundary. The similarity of limestones above and below, however, generally makes this contact quite obscure, and at many places it can be certainly identified only with the aid of fossils.

The Shetlerville member constitutes one of the most fossiliferous zones in the entire fluorspar region. At places where its shalier beds have been weathered on gentle slopes an abundance of fossils can be easily collected. Most of the specimens are small and the great majority belong to a few common species. Others, however, are excellent guide fossils. Two of the most useful are the coral *Amplexus geniculatus* and the brachiopod *Reticulariina subspinosa*, which occur in no other formation or member in this vicinity. Crinoids belonging to the genus *Talarocrinus* also occur in the over-
lying member of the Renault, and are not
known from any other formation in this
part of Illinois. The blastoid *Metablastus
glaber* and the bryozoan *Cystodictya labiosa*
are locally much more common in the Shet-
lerville than in any other beds. Pentremites
are abundant but in the Renault low, broad
specimens with nearly flat bases make up a
much larger proportion than in any other
formation.

The upper member of the Renault or
Downeys Bluff limestone contains only
small amounts of shale occurring as part-
ing between the limestone layers. The
limestones are commonly gray or bluish gray
in color and are crystalline to more or
less fine-grained. Some beds are conspicu-
ously crinoidal and some are distinctly
cross-bedded. Oolites are present and lo-
cally abundant; they are generally smaller
than those in the Ste. Genevieve. On the
whole the limestone is variable from bed
to bed and from place to place. Some of
it weathers nearly white but other layers
become buff in color. Some chert, probably
secondary, may occur in the upper part.

Most of the fossils of the Downeys Bluff
member are similar to those in the Shet-
lerville except that they may attain some-
what larger sizes. Good exposures of the
Renault formation where fossils may be col-
lected are in the ravine just east of Shet-
lerville and in the Ohio River bluffs to the
west, at Downeys and Fairview bluffs, near Shetlerville, and at
Birds Point south of Golconda.

A few poorly preserved fossils have been
found in the Bethel sandstone, but for the
most part this formation contains no fos-
sils. There are imperfect impressions of
small tree trunks at a few places, particu-
larly near the bottom of the formation.

The Bethel sandstone varies in thickness.
In the fluorspar region it ranges from about
50 feet in the river bluffs below Golconda to
about 100 feet near Shetlerville. It overlies
the Renault formation unconformably. This
contact is generally abrupt and often
marked by a thin zone of pebbles at the
base of the Bethel. It seems to pass grad-
ually into the overlying Paint Creek forma-
tion without any abrupt change in lithology.

*Paint Creek formation.*—This formation
succeeds the Bethel everywhere, but out-
crops of it are generally poor and difficult
to recognize, and at some places it can-
not be separated from the enclosing sand-
stones. In Hardin County it is largely
sandstone. Near Rosiclare the main cen-
tral part is massive fine-grained sandstone
similar to the Bethel and Cypress, under-
lain and overlain by thin irregularly bedded
very fine-grained sandstone layers separated
by partings of dark shale. Material of this
kind is well exposed along Buck Creek in
the W1/4 sec. 34, T. 11 S., R. 7 E. Also
near Rosiclare a thin layer of impure limestone in the upper part of the Paint Creek has been cut in diamond drilling but is nowhere known to outcrop. On the northern flank of Hicks dome the position of the Paint Creek is indicated by gray thinly laminated shale that rarely outcrops but may be found loose in the float in ravines that cut across the outcrop of this formation. In the Minerva shaft 5 miles north of Cave in Rock the Paint Creek is almost entirely sandstone with only a few thin black shale partings.

Because of incomplete outcrops and the difficulty of determining stratigraphic boundaries, the thickness of the Paint Creek can be estimated at few places. Near Rosiclare the formation is shown by diamond drilling to be about 65 feet thick; elsewhere it may be thinner. It was formerly believed to be absent east of Cave in Rock but more likely it has not been recognized because of its dominantly sandy nature.

Cypress sandstone.—The Cypress sandstone is a resistant formation that produces a ridge, along with the Paint Creek and Bethel formations, on the north and west sides of Hicks dome and caps a series of hilltops extending to the Ohio River east of Cave in Rock and southward past Golconda. It also occurs at the surface in smaller areas within the highly faulted zone near Rosiclare and to the northeast.

This formation is a massive sandstone very similar to the Bethel. Some of it, however, especially in the upper part, is more evenly bedded and at some places this bedding gives an outcrop the appearance of regular courses of masonry. It is composed of fine-grained sand, light yellowish brown, buff, or even almost white on freshly broken surfaces; weathered surfaces are commonly much darker brown or reddish brown. Ferruginous streaks and bands are locally present in the sandstone.

Contacts of the Cypress sandstone with underlying and overlying formations are rarely exposed. Diamond drill cores, however, show that an unconformity separates it from the Paint Creek, and that basal conglomerate may be present in the Cypress. Passage from the Cypress to the Golconda, however, is gradual and there is no sharp break between these formations. Very few animal fossils have been found in the Cypress, but imperfect impressions of tree trunks have been seen at several places.

There is an excellent exposure of the Cypress sandstone in the Ohio River bluff just south of Golconda. It may also be seen overlying shale of the Paint Creek in the west side of the large “pull hole” on the Rosiclare vein just north of the railroad at Rosiclare. At this place the other wall of the fault consists of the Fredonia limestone and Rosiclare sandstone.

Golconda formation.—This formation comes to the surface in a narrow band extending north from Golconda, swinging east around Hicks dome and reaching the Ohio river 4 miles east of Cave in Rock. In the western part of this area it outcrops in the hill slope rising on the west side of Big Grand Pierre Creek and on the north side of Pinhook Creek. Isolated outcrops also are found in the complexly faulted area northwest of Elizabethtown and west of Rosiclare.

The Golconda formation is composed of shale and limestone, but outcrops are generally talus-covered and very incomplete and details cannot be observed. Some limestone is present in the lower part of the formation; above is much shale; and limestone is prominent in the upper part. Numerous partings and thin layers of shale occur in the limestone portions, and thin limestone beds are scattered through the shale. A thin rather sandy zone is widely developed in the central part.

The limestone beds of the Golconda are much more generally exposed than the shales. They are variable in character but mostly gray to bluish when fresh, and more or less crystalline. Beds of dense fine-grained texture are somewhat less common. Some of the limestones in the lower part of the formation are a mass of fossil fragments, have rough, weathered surfaces, and may be stained or streaked a rusty brown. Oolitic beds occur but, except locally, they constitute a very inconspicuous portion of
the formation. Chert is very rare or absent in actual outcrops, but fragments of cherty or silicified limestone may be present in the weathered residuum.

The shales of the Golconda are even more variable. Some beds are noncalcareous and grade from gray to bluish or nearly black. Other beds are calcareous and grade into impure limestone. Some of these beds are particularly fossiliferous. Thin layers of reddish shale have been observed at a few places.

The contact of the Golconda formation with the Cypress sandstone is gradational. No sharp line of division can be drawn in the somewhat sandy, shaly beds that separate the more typical parts of these formations. The upper boundary of the Golconda is distinct, however, and at several places massive sandstone of the Hardinsburg rests directly on the upper limestone of the formation. This relation may be seen in the river bluffs above Golconda where some of the best exposures of this formation are to be found. Beds of limestone and shale in the lower part of the formation may be seen in the old cement quarry one and a half miles west of Golconda. The middle shales are well exposed near the northeast corner of sec. 16, T. 12 S., R. 8 E., and limestone in the upper part of the formation outcrops beside the state highway near the top of the hill west of Big Grand Pierre Creek.

The Golconda is one of the thickest of the Chester formations. In Hardin and Pope counties its thickness is estimated at about 145 feet.

Fossils are abundant in the Golconda formation at many places. *Archimeditpora* axes and *Stenosisma explanata* are generally present in the fossiliferous beds and occur also in higher Chester formations but have not been found in any lower formations in this area. The heavy wing plates of *Pterotocrinus capitalis* occur only in the lower part of the Golconda and are unfailing guide fossils, but they have not been found at many places. The Golconda *Pentonmites* include specimens with elongated bases different from older species, but similar ones also occur in higher beds.

**Hardinsburg sandstone.**—The Hardinsburg sandstone is a resistant formation that forms the crests of hills and ridges at most places where it occurs at the surface. Its outcrop extends northward from Golconda and passes around Hicks dome in the ridges west of Big Grand Pierre and north of Pinhook Creek. In the eastern part of Hardin County it reaches the Ohio River bottoms just west of the valley of Honey Creek. This formation is also present at the surface in several fault blocks especially about two miles north of Elizabethtown and in the first ridge west of Rosiclare.

The Hardinsburg is a massive generally irregular cross-bedded sandstone with ripple-marked layers. It is moderately fine-grained, yellowish brown, and weathers to gray or rusty-brown surfaces. The lower part is most massive and often rises in nearly vertical cliffs above a talus-covered slope developed on the Golconda formation. The upper part is less commonly exposed and is apparently more thinly bedded and shaly. Locally, thin gray to nearly black shale members are present.

At its base the Hardinsburg sandstone is differentiated from the Golconda by an abrupt change in lithology, but above, this sandstone grades without a distinct break into the Glen Dean formation. Its thickness varies somewhat from place to place, probably averaging about 90 feet.

The Hardinsburg sandstone may be seen on the state highway near the top of the hill just north of Golconda, by the roadside one mile north of Barnett school near Elizabethtown, and it has been quarried in a small way just south of the road one and three-quarters miles west of Karbers Ridge. Shale, probably in the middle part of this formation, outcrops in a small ravine just north of the main road an equal distance to the east of Elizabethtown.

**Glen Dean formation.**—The general pattern of Glen Dean outcrops closely follows that of underlying formations. Starting north of Golconda it encircles Hicks dome and approaches the Ohio River again just
west of the valley of Honey Creek. Immediately west and north of Hicks dome it generally occurs in the same ridge with the Golconda and Hardinsburg formations.

The Glen Dean formation is generally very poorly exposed, and consequently the details of its lithologic character are not easily determined. Like the Golconda it consists of interbedded limestones and shales. The limestones are quite variable, perhaps even more so than the Golconda. In general they are crystalline and gray to nearly black on freshly broken surfaces. The crystalline nature of these beds results from the presence of abundant fossil fragments, mainly dismembered crinoid plates. Other beds, however, are very fine-grained, hard, and break with splintery fractures. These are usually very dark.

An oolitic layer appears to be widespread in the upper part of the formation. Some limestone beds appear to be very pure calcium carbonate but others are obviously quite siliceous. Some chert is present, generally in flattened masses 1 to 2 inches thick that break into polygonal fragments upon weathering. It is usually dark chocolate brown when fresh but bleaches to yellowish brown and becomes porous after prolonged weathering.

The shale beds of the Glen Dean likewise lack uniformity and vary in color from gray to nearly black. Some weather readily to plastic clay. Others are more or less calcareous and many grade into impure limestone.

Where it is best exposed the upper half of the formation is mostly crystalline limestone with thin shale partings separating individual beds and the lower half consists of interbedded shale and limestone. One of the best series of exposures occurs in and near an old WPA quarry in the NW cor. sec. 15, T. 11 S., R. 9 E. Glen Dean limestone is also well shown in the Ohio River bluff in the western ¾ sec. 10, T. 12 S., R. 10 E., and in a ravine a short distance south of the state highway in the SE ¼ sec. 29, T. 12 S., R. 7 E.

The lower boundary of the Glen Dean is gradational but the upper limit is fairly abrupt with rarely more than a few feet of shale between rather massive limestone and the base of the Tar Springs sandstone. There are few places where the thickness of the Glen Dean can be estimated accurately but it probably ranges between about 50 and 70 feet.

The most useful guide fossil in the Glen Dean limestone is *Prismopora serratula*, which is locally very abundant. This species also occurs in the Golconda and Vienna formations but is uncommon in them.

**Tar Springs sandstone.** — The Tar Springs sandstone comes to the surface in a belt concentric with the other Chester formations from near Golconda to the Ohio River in eastern Hardin County. On the north and west flanks of Hicks dome it forms the top and outward slope of the ridge in whose southern and eastern slopes are the Golconda, Hardinsburg, and Glen Dean formations.

The Tar Springs is so much like the other Chester sandstones of southern Illinois that it is difficult or impossible to identify isolated outcrops. In general Tar Springs is more shaly than the underlying sandstones. The lower part may be massive and cross-bedded but the middle and upper parts consist mostly of thin-bedded and shaly sandstone and gray to dark gray shale. A rather persistent coal bed up to 6 inches thick occurs at or near the top of the formation and coal streaks may be present in other places.

The thickness of the Tar Springs formation averages about 90 feet. Its lower boundary is comparatively abrupt. The Tar Springs probably grades into the overlying Vienna formation; these beds are very rarely exposed.

Unusually massive Tar Springs sandstone crops out in a bluff in the north fork of the "Y" in the road a little more than one mile north of Bassett school. Thin-bedded and shaly middle and upper beds are well exposed in several ravines north of the Karbers Ridge road in the SW ¼ sec. 11, T. 11 S., R. 7 E. A thin coal is exposed here at one place. Coal near the top of the
Tar Springs may also be seen in the ravine north of the gravel road in the NE ¼ sec. 8, T. 12 S., R. 7 E.

Vienna formation. — This formation overlies the Tar Springs sandstone, but nowhere in Hardin County has it been certainly distinguished in outcrops. It has been recognized in diamond drill cores taken at the Lee mine, but mostly the Waltersburg sandstone is too shaly or too poorly exposed to separate the Vienna from the Menard formation.

The Vienna outcrops at several places in eastern Pope County, however. One of the best places to see it is in the eastern branch of the small valley north of the gravel road in the NE ¼ sec. 8, T. 12 S., R. 7 E. Here the lower part contains massive gray, more or less crystalline limestone which is somewhat siliceous and impure, and upon weathering some layers are transformed to very porous chert projecting from the surface of the limestone. The upper portion of the formation appears to be largely shale and is rarely if ever exposed.

The thickness of the Vienna formation averages about 20 feet.

Waltersburg formation. — This formation appears to be poorly developed in Hardin County and is not known to outcrop anywhere. Diamond drilling at the Lee mine indicates that it is mostly dark gray to black shale with some inconspicuous sandy beds in the middle. Its thickness is small but cannot be accurately estimated because the Waltersburg cannot be sharply separated from either the overlying or underlying formations. Possibly the black shale thrown out of a small prospect shaft east of the road near the center SE ¼ sec. 20, T. 12 S., R. 8 E., is from this zone.

The Waltersburg sandstone becomes better developed to the west in Pope County and is locally a conspicuous formation much like the other Chester sandstones. Shaly Waltersburg crops out beside the gravel road near the center NE ¼ sec. 8, T. 12 S., R. 7 E. and to the south where the underlying Vienna may be seen also.

The thickness of the Waltersburg formation averages about 40 feet.

Menard formation. — The Menard formation comes to the surface about 3 miles north of Golconda and extends northward and eastward around Hicks dome and reaches the Ohio River two miles south of Battery Rock. In eastern Hardin County southeast of the Rock Creek graben this formation underlies the hill slope northeast of Honey Creek and continues to State Highway No. 1. It also occurs in some of the fault block northwest of Elizabethtown.

The Menard formation consists of limestone and shale in about equal quantities. Much of the limestone is in beds one foot or more thick separated by shaly partings or layers. It is mostly fine-grained hard rock, of bluish, dark gray, or nearly black color, although a few layers are crystalline or argillaceous. It generally weatheres to a mottled appearance with bands or large irregular splotches of buff separated and surrounded by light gray.

Much of the shale in the Menard formation is fairly light colored and weathers to gray or greenish clay, although some dark gray beds are present.

The contacts of the Menard with the underlying and overlying formations have not been observed in outcrop. Complete gradation probably occurs with the Waltersburg sandstone below, but there may be a sharper break at the base of the Palestine sandstone above.

No outcrops are known where the thickness of the Menard formation can be accurately measured. Subsurface data show that it is about 120 feet thick.

Fossils are abundant at many places in the Menard and some of the limestone beds contain abundant specimens of the large Spirifer increbescens. Specimens of Composita present in this formation are also relatively large and are identified as C. subquadrata. Some of the best collections have been obtained from the lower part of the formation where argillaceous limestone contains Allorisma clavatum and Sulcatopinna missouriensis which are common in no other formation.

Fairly good exposures of the Menard, particularly its limestone beds, occur by the
roadsides west and north of Stone Church in sec. 20, T. 12 S., R. 8 E., and \( \frac{1}{3} \) mile south of Keelin School in sec. 11 of the same township. A small quarry showing both limestone and shale lies on the west side of Rose Creek and north of the state highway in sec. 11, T. 11 S. and R. 7 E.

**Palestine sandstone.**—The Palestine sandstone occurs at the surface from a point about three miles north of Golconda, extends northeast and east around the flanks of Hicks dome and continues to within two miles of Saline River in northeastern Hardin County. This formation is believed to be absent in most of eastern Hardin County where Pennsylvanian beds directly overlie the Menard formation. The Palestine crops out, however, in a few of the fault blocks west of Rosiclare and north of Elizabeth-town.

In general the Palestine is a thin-bedded sandstone and thus differs from most of the lower Chester sandstones. Part of it is quite shaly, but these beds commonly contain considerable sand and therefore are unlike the clay shales associated with some of the other sandstone formations. Ripple-marked layers are common and cross-bedding occurs at many places. Locally some massively bedded layers occur, but even these are composed of fine-grained sand. The Palestine is yellowish brown, similar to the other Chester sandstones, and is generally less deeply colored than much of the Hardinsburg and Tar Springs sandstones.

The Palestine is one of the thinner sandstones of the Chester series. Its upper and lower boundaries have rarely been observed, but its thickness is estimated to be about 60 feet. It overlies the Menard formation possibly with slight unconformity and probably grades into the overlying Clore formation without break.

Because of its generally thin-bedded and shaly nature outcrops of the Palestine sandstone are neither abundant nor extensive, and at many places exposed sandstone that may be Palestine cannot be identified with certainty. Sandstone that is believed to be Palestine outcrops in the ravine crossed by the road near the center of the north line of the NE \( \frac{3}{4} \) sec. 20, T. 12 S., R. 8 E., three miles north of Rosiclare.

**Clore formation.**—The Clore formation has not been mapped separately from the overlying Degonia sandstone and Kinkaid formation in Hardin and eastern Pope counties. It consists mainly of shale and is rarely exposed, but it probably encircles Hicks dome on the west and north and occurs in several of the fault blocks of the Rock Creek graben zone. It seems to be absent in much of the eastern part of Hardin County beyond the Peters Creek fault.

Shale members of the Clore resemble shales in other Chester formations. They are argillaceous or, less commonly, calcareous and generally gray. Limestone layers are thin, variable in lithology, and range from gray to nearly black. Some of the limestones are hard and fine-grained, others are argillaceous or shaly, and comparatively few are crystalline. Siltstone and sandstone occur in the middle part of the formation.

The thickness of the Clore formation is not known from outcrops, but subsurface data show it to be about 100 feet.

No species of fossils is known to be exclusively restricted to the Clore and poor exposures make a thorough study of its fauna impossible. It carries such upper Chester species as *Composita subquadrata* and large specimens of *Spirifer increbescens*. A large productid is common in limestone of the Clore at some places, but this species occurs less abundantly in other formations. The delicate rod-like bryozoan *Batostomella nitidula* is not confined to the Clore, but it is extremely abundant in it at some places.

The only place in Hardin County where the Clore can be seen in relation to most of the other upper Chester formations is along an abandoned and washed-out road extending southward down the hill from the Karbers Ridge road near the line between Townships 8 and 9 east. Here, in a very incomplete section, parts of the Kinkaid, Degonia, Clore, and Palestine formations are exposed, and a short distance to the southeast good outcrops of Menard limestone occur. Neither contact of the Clore
formation is exposed, however, but like the other limestone and shale divisions of the Chester the Clore probably grades into the underlying Palestine but is separated by a slight unconformity from the overlying Degonia sandstone.

**Degonia sandstone.**—The Degonia sandstone has been identified with certainty at few places in Hardin County. It probably occurs on the western and northern flanks of Hicks dome and in the Rock Creek graben, but it appears to be absent in most of the eastern part of the county beyond the Peters Creek fault. Throughout most of the region it is a comparatively inconspicuous formation and probably is thin or consists largely of shaly beds. It is much better developed to the west and in the Lusk Creek fault zone it consists of slabby and cross-bedded sandstone very similar to most of the other Chester sandstone formations. Good outcrops occur near the Eddyville road in the branches of a tributary that joins Lusk Creek from the west.

No good estimates of the thickness of the Degonia sandstone have been made from outcrops in southeastern Illinois, but subsurface data show it to be about 35 feet. In parts of Pope County the Degonia may be 60 or more feet thick and it appears to thin somewhat eastward in Hardin County. It probably overlies the Clore formation with a slight unconformity, but seems to grade upward into the Kinkaid without a sharp break, although these contacts have not been observed.

**Kinkaid formation.**—The Kinkaid occurs at the top of the Chester series except in eastern Hardin County. It is commonly overlain by much talus from the overlying Pennsylvanian, and exposures at most places are not good. Some of the best outcrops occur just northwest of the Lusk Creek fault zone in sections 3 and 10, T. 12 S., R. 6 E. In this vicinity the formation consists of limestone, shale including redbeds, sandstone, and bedded chert.

Shale probably constitutes about half the Kinkaid formation but because of its resistant nature, outcrops are neither large nor abundant. It varies from black to various shades of gray, and a zone in the lower part of the formation contains beds of deep red at many places in southern Illinois, as by the roadside in the SW 1/4 sec. 3 of the township mentioned above. Limestone, however, is much the most conspicuous constituent of the formation. This is generally dark gray, fine-grained to moderately crystalline, and occurs in beds up to about 2 feet in thickness separated by shaly partings. It generally weathers light gray with smoothly rounded surfaces although some impure beds are dark and more or less ferruginous. Limestone is most abundant in the upper part of the formation where it may dominate in a thickness of 40 feet or more of strata. Other beds essentially similar in lithology, however, are irregularly distributed through the remainder of the formation.

Fine-grained, dark, thin-bedded sandstone in one or more beds appears to be persistently present in the lower part of the formation in Pope County. Generally this member varies from 5 to 15 feet in thickness and it also outcrops along the road in the SW 1/4 sec. 3 mentioned above.

Chert in beds up to one foot or more thick also is characteristic of the lower Kinkaid. This material is olive gray where fresh and weathers to a light gray. It is chaledonic and breaks with splintery conchoidal fractures. There are good exposures along the road and in the bed of the nearby ravine in the NE 1/4 sec. 3, T. 12 S., R. 6 E.

Kinkaid limestone has been quarried in the SE 1/4 sec. 8 of the same township, and good exposures also occur south of the Eddyville road just west of Lusk Creek. Kinkaid shale may be seen in ditches by the roadside just north of Keelin school three miles northeast of Elizabethtown.

Transition from the Degonia sandstone into the Kinkaid formation is gradational, but an important major unconformity separates the Kinkaid from overlying Pennsylvanian strata. Erosion cut down to variable depths in the Kinkaid and locally removed it entirely, as in the easternmost part of Hardin County, and left unequal thick-
nesses of the formation from place to place. Where erosion was slight the Kinkaid is one of the thickest of the Chester formations and in parts of Pope County it probably reaches a maximum of about 200 feet. In Hardin County, however, it appears to be much thinner.

**Pennsylvanian System**

**Caseyville Group**

The Caseyville group consists of three formations, in ascending order named Lusk, Battery Rock, and Pounds. These have not been mapped separately in Pope and Hardin counties. Together they outcrop north of the region of Mississippian rocks and they also occupy large areas in the down-faulted blocks of the Rock Creek and Dixon Springs grabens.

The Lusk formation consists principally of sandy shale and shaly sandstone but also includes more or less massive locally developed sandstones, one or more thin coals, and some shale. The sandstone may be either coarse with rounded quartz pebbles like the overlying Battery Rock and Pounds sandstones or fine grained like the better developed sandstones of the Chester series below. Ordinarily this formation occurs beneath steep slopes where it is capped by the thick Battery Rock sandstone and is so covered by talus that outcrops are poor. It is about 100 feet thick in Hardin County and thickens westward to about 200 feet along Lusk Creek northeast of Eddyville.

The Battery Rock formation consists of the coarse-grained, massive, quartz pebble-bearing Battery Rock sandstone 60 or more feet thick and about 100 feet of overlying dominantly shaly beds. The latter include thin sandstones, one or more thin coals (the Battery Rock coal has been mined in a small way in eastern Hardin County), and a thin local fossiliferous limestone known only near Sellers Landing. This formation is bounded both below and above by unconformities.

The Pounds formation is similar in most ways to the Battery Rock. It consists principally of a second massive, coarse-grained, quartz pebble-bearing sandstone about 100 feet thick and is completed above by 40 to 50 feet of shale, partly sandy, which includes the local Reynoldsville coal.

The two prominent sandstones of the Caseyville group outcrop conspicuously at many places and commonly produce cliffs on most of the highest hills and ridges that face south, southeast or, in eastern Hardin County, southwest. The cliffs formed by both sandstones may be seen on the north and west flanks of Hicks dome from either State Highway No. 1 or the Karbers Ridge road within a few miles of Herod.

The Battery Rock and Pounds sandstones are so similar that they cannot be distinguished from one another in areas of incomplete or interrupted outcrops as in the Lusk Creek fault zone or other small fault blocks.

**Tradewater Group**

The Tradewater group is also made up of several formations which have not been separately mapped in the area covered by this report. Those which are present in this region are, from the base upward: Grindstaff, Delwood, Macedonia, and Stonefort. They occur north of the outcrops of the Caseyville group, in the fault blocks of the Dixon Springs graben, and in a small area of northeastern Hardin County near Saline Landing.

As a whole the Tradewater group consists of a variable succession of shales and sandstone with several generally thin coals and at least two thin beds of limestone. The sandstones are much more erratic in their development than are the Battery Rock and Pounds sandstones. Commonly the Tradewater sandstones are less massive and less resistant to weathering and erosion than are those of the Caseyville and consequently they do not produce comparable bluffs and cliffs. Also, quartz pebbles, although locally present, are not nearly so abundant in them.

The shales of the Tradewater possess few characteristics by which they can be recognized. Many of them are finely sandy or silty and some grade laterally into sandstone. Most of the coals are intermittent or
UNEQUAL in their local developments and they are very difficult to identify. The limestones are rarely and poorly exposed in this area.

About 300 feet of strata referable to the lower part of the Tradewater group is present in northeastern Pope County.

IGNEOUS ROCKS

Bodies of intrusive igneous rock and intrusive breccia in the Illinois portion of the fluorspar district have been known since the discovery of the Mix dikes in the bluff of Ohio River two miles north of Golconda, by W. S. Tangier Smith in 1902.6 The occurrences discovered through 1920, including the Orrs Landing, Rosiclare, Mix, and Golconda dikes, the Downey Bluff sill and dike, and the Soward, Sparks Hill, and Grant intrusive breccias, have been described by Bain6 and Currier.7

During recent years a number of other occurrences have been observed. Those in Hardin County include dikes exposed in an adit along the Good Hope vein, in drifts on the 240-foot and 500-foot level of the Argo vein, on the 600- and 700-foot levels of the Blue Diggings vein, on the 300 level crosscut west from the middle shaft on the Blue Diggings vein, and at vertical depths of 970 to 1,150 feet in a deep boring, all noted on the Alcoa Mining Co. property at Rosiclare by A. H. Sutton, company geologist; dikes on the Joiner and Robinson farms, 1.4 miles south-southwest and 1.1 miles southeast of Hicks, respectively, found by R. M. Grogan; a dike near Philadelphia school 2.5 miles east-southeast of Karbers Ridge, discovered by F. E. Tippie; a dike in the Crystal Fluorspar Company mine 3.5 miles northwest of Cave in Rock reported by D. G. Gibson, Jr.; and an exposure of intrusive breccia about four-tenths of a mile north of the Soward farm intrusive and 2 miles northwest of Rosiclare, brought to Grogan’s attention by Omar Austin. In Pope County an occurrence of weathered fragments of granite, discovered by J. M. Weller, one mile southwest of the Empire mine may indicate the presence of a granitic intrusive.8 The location of the various occurrences is given below.9

The dike rocks, including the Downeys Bluff sill, are all dark gray to dark greenish gray in fresh exposure and have many mineralogical and structural features in common. All are more or less porphyritic with

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7 Bain, H. F., op. cit., pp. 27-50. (Petrographic descriptions by Albert Johannsen.)
9 Dikes and Sill:
  - Orrs Landing: SW¼ NE¼ sec. 33, T. 12 S., R. 9 E., Hardin County, dike at water’s edge and in low bluff above Ohio River.
  - Rosiclare: SW¼ SW¼ sec. 33, T. 12 S., R. 9 E., Hardin County, two small dikes in old quarry in bluff of Ohio River.
  - Downeys Bluff: NW¼ SE¼ sec. 5, T. 13 S., R. 8 E., thin anastamosing sill in limestone outcrop near top of bluff facing Ohio River, also dike reported at north end of same bluff.
  - Mix farm: NE¼ NE¼ sec. 18, T. 13 S., R. 7 E., Pope County, boulders from dike, now concealed, in bluff of Ohio River above railroad.
  - Golconda: SW¼ NE¼ sec. 25, T. 13 S., R. 6 E., Pope County, boulders from dike, now concealed, in bluff of Ohio River above railroad.
  - Good Hope: NE¼ NW¼ sec. 5, T. 12 S., R. 8 E., Hardin County, dike up to 12 inches wide cut off by Good Hope fault, exposed in west side of drift approximately 250 feet from entrance at southwest end of collapse pit.
  - Argo 500 level: NE¼ SW¼ sec. 32, T. 12 S., R. 8 E., Hardin County, dike 4½ to 24 inches wide exposed near survey station 508 on 500-foot level of Argo vein, apparently earlier than vein and fault.
  - Argo 240 level: NW¼ SW¼ sec. 32, T. 12 S., R. 8 E., Hardin County, dike about 1 foot wide along Argo vein.
  - Blue Diggings 600 and 700 levels: SE¼ SW¼ sec. 32, T. 12 S., R. 8 E., Hardin County, dike striking N 35° W is exposed for about 100 feet on both 600 and 700 levels of Blue Diggings vein.
  - Blue Diggings 300 level: SW¼ NW¼ sec. 5, T. 13 S., R. 8 E., Hardin County, dike exposed in 300 level crosscut west from Middle shaft on Blue Diggings vein.
  - Deep boring: Aluminum Ore Co. No. 104, collar in NW¼ SW¼ sec. 12, T. 11 S., R. 8 E., Hardin County, dikes cut by diamond drill boring at vertical depths of 970 to 1150 feet in NE¼ SW¼ sec. 32.
  - Joiner farm: SE¼ SE¼ sec. 25, T. 11 S., R. 7 E., Hardin County, main dike exposed for 125 feet in gully trending northeast, also 12- to 18-inch dike 40 feet north of main dike.
  - Robinson farm: SE¼ NE¼, sec. 30, T. 11 S., R. 8 E., Hardin County, weathered mica peridotite exposed in shallow test pit on wooded hillside.
  - Philadelphia school: SW¼ SE¼, sec. 11, T. 11 S., R. 8 E., Hardin County, dike exposed in north bank of creek.
  - Crystal: on SE¼ NE¼, sec. 34, T. 11 S., R. 9 E., Hardin County, exposed in workings near No. 4 shaft of Crystal Fluorspar Company as 6 inch dike in Bethel sandstone vein.

Intrusive breccias:
  - Soward farm: NE¼ SW¼, sec. 31, T. 12 S., R. 8 E., Hardin County, boulders and outcrops in gully on south slope of hillside.
  - North Soward: NE¼ NW¼, sec. 31, T. 12 S., R. 8 E., Hardin County, outcrop 20 feet long and 5 feet high on west slope of low ridge.
  - Sparks Hill: NW¼ NE¼, sec. 19, T. 11 S., R. 8 E., Hardin County, outcrops in east-flowing creek and boulders on hillside to north.
  - Grant: NW¼ SW¼, sec. 6, T. 12 S., R. 8 E., Hardin County, ledge exposed in north-flowing gully.

Granite fragments:
  - Pope County: NE¼ SE¼, sec. 33, T. 11 S., R. 7 E., Pope County, in shallow test pits in hillside on northwest side of Big Grand Pierre Creek, nearly opposite mouth of Buck Creek.
a fine- to medium-grained groundmass, though phenocrysts are uncommon in some exposures. The primary constituents include brown and black mica, pyroxenes, olivine, apatite, magnetite, and titanite. The rocks are extensively altered to carbonate, serpentine, and chlorite. In some instances the only remaining primary mineral is apatite, all the rest of the rock being replaced by carbonate. Although no feldspar or primary quartz has been found in any of the dikes, occasional lath-shaped groups of alteration products may indicate the former presence of feldspars or perhaps some other mineral such as melilite. Many of the dikes contain more or less abundant inclusions of sandstone, shale, limestone, and chert.

Considerable variation is present in the relative abundance of the various primary minerals, which led Johannsen and Currier to divide the dike rocks into two categories: lamprophyres, characterized by absence of olivine and presence of faint indications of possible former feldspar, and mica-peridotite, characterized by the presence of olivine and lack of evidence of former feldspar. After examining the dikes in the field and in thin section, the present writers are more impressed with their similarities than their dissimilarities and are prone to consider them all as being most probably derived from a common magmatic source. This concept is the more likely when the very widespread occurrence of bodies of similar composition in Illinois, Kentucky, Missouri, Arkansas, and Kansas, outside as well as within the fluor spar district, is taken into consideration.

The dikes range upward in thickness from a few inches to a maximum not known because of incomplete exposures. The greatest measured (but incomplete) thickness is that of the larger of the two dikes on the Joiner farm, which is exposed almost continuously for 125 feet in a direction almost at right angles to the strike of the one exposed margin. In at least one occurrence, that at Downeys Bluff, igneous rock was intruded in the form of several thin horizontal sills, and this may be a more common structure in the district than outcrops reveal.

The prevailing strike of the dikes is to the northwest. Where the relation between faults and dikes is fairly clearly displayed as along the Argo and Good Hope veins on the Alcoa Mining Company property at Rosiclare, it appears that the dikes have been cut off and sheared by the faults and thus pre-date them. The Orrs Landing dike, however, follows the course of a fault with 151/2 to 22-inch displacement. It is believed to antedate the faulting, but is itself not faulted. Where dikes and fluor spar veins occur together the fluor spar is clearly of later origin than the dike. Thus it appears that the dikes were intruded along predominantly northwest fractures at a time preceding the faulting which made the openings for the fluor spar veins.

The Soward, North Soward, Sparks Hill, and Grant intrusive breccias are clastic rocks composed of angular to rounded fragments of sedimentary and igneous rocks and minerals in a fine-grained altered matrix. Fragments up to 8 inches in length have been observed (Sparks Hill) but those in the range of 1/8 to 11/2 inches are most abundant. They comprise 5 to 75 percent of the rocks and include limestone, sandstone, shale, chert, quartzite, slate, granite, and large crystal fragments of quartz, dark mica, and hornblende. The matrix also contains much clastic material in the form of angular fragments of quartz, feldspar (plagioclase and possibly orthoclase), pyroxene, apatite, and light and dark micas. Much of the matrix is secondary calcite, presumably at least in part the product of alteration of the original minerals.

On the basis of the abundance of quartz and feldspar in their matrix, Currier considered that these rocks gave evidence of an acidic magma which had been involved in explosive volcanic activity. This conclusion


is not entirely warranted, however, for the quartz, feldspar, and other primary minerals in the matrix are fragmental, just as are the larger rock fragments, and could have been derived by attrition from solid acidic igneous rocks at depth, in the same manner that is postulated for the granite fragments found in the Sparks Hill breccia. In none of the thin sections of breccias examined to date is there any indication of a true igneous matrix of acidic character. On the other hand, the abundant secondary carbonate in the matrix is somewhat suggestive of the alteration of a basic igneous material, as in the basic dikes, although it is possible that some of the calcite may represent comminuted limestone. The breccias apparently are of explosive origin and should therefore be considered akin to the diatremes described from southeastern Missouri\(^{12}\) and possibly the cryptovolcanic structures reported in Kentucky, Tennessee, Indiana, Ohio, and Missouri.\(^{13}\)

The fragments of granite discovered in eastern Pope County were found in shallow hillside test pits in company with other blocks and fragments of sandstone, shale, and silicified limestone. The largest was about 1 foot in diameter, and all were much weathered. The rock is medium grained and has a rude linear flow structure. The principal minerals are quartz, muscovite, biotite, and sericite probably derived from feldspar, of which no fresh material remains. The quartz shows considerable variation in grain size, some being in masses up to 6 cm. in length. Although the character of the rock is compatible with its having been derived from an underlying granite dike or plug, no supporting evidence of such a parent igneous body was found in the field, other than the local occurrence of blocks of highly quartzitic sandstone which might have resulted from contact metamorphism. The alternative possibilities that the granite represents glacial material ice-rafted in Pleistocene time by the Ohio River when it was ponded and swollen with glacial meltwater, that it is outwash derived from a lobe of glacial ice to the north, or that it is a remnant of a hitherto unrecognized ancient glacial drift sheet also gain little support from field relations. With existing data, the origin of the granite must remain an unsolved question.

Both the basic dikes and the fluor spar and its associated minerals are considered to be of magmatic origin, and it has been commonly assumed that there is a direct genetic relation between the two. This relation has not yet been proved, however, probably because there are too many gaps in the geologic record or our understanding of it.

**RECOGNITION OF FORMATIONS IN DIAMOND DRILL CORES**

The characters by which stratigraphic formations are identified in outcrops and in diamond drill cores are somewhat different, and one who is familiar with the outcropping strata may have difficulty in recognizing the same formations in cores, or vice versa. The principal features noticeable in outcrops are the grosser characters of the rocks among which type of bedding, resistance to erosion, and reaction to weathering are particularly important. Also fossils may be sought as an additional aid, often of the greatest significance. None of these is ordinarily observable in diamond drill cores and the minute characters of the rocks such as details of texture and type and relative proportions of constituent materials must be relied upon. The single great advantage of a good set of cores is that all the section is available for observation, whereas in outcrops the less resistant strata are generally hidden beneath overburden and therefore seldom seen.

Diamond drill cores should be carefully studied with a hand lens, and it is generally necessary to break them at frequent intervals in order to observe fresh fracture surfaces.

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12 Rust, G. W., Preliminary notes on explosive volcanism in southeastern Missouri: Jour. Geol., vol. 45, pp. 45-75, 1917.


### Table 3.—Subsurface Characters of Formations Commonly Encountered in Test Borings

<table>
<thead>
<tr>
<th>Formations and members</th>
<th>Units commonly recognizable</th>
</tr>
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<tbody>
<tr>
<td><strong>Name</strong></td>
<td><strong>Thickness, feet</strong></td>
</tr>
<tr>
<td>Menard</td>
<td>90–120</td>
</tr>
<tr>
<td>Waltersburg</td>
<td>25–40</td>
</tr>
<tr>
<td>Vienna</td>
<td>20–40</td>
</tr>
<tr>
<td>Tar Springs</td>
<td>90±</td>
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<td></td>
<td>20±</td>
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<tr>
<td></td>
<td>70±</td>
</tr>
<tr>
<td>Glen Dean</td>
<td>20–70</td>
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<td></td>
<td>15±</td>
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<tr>
<td></td>
<td>15</td>
</tr>
<tr>
<td>Hardinsburg</td>
<td>70–120</td>
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<tr>
<td></td>
<td>25–30</td>
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<td></td>
<td>15</td>
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<td>15</td>
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<td></td>
<td>10–15</td>
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<tr>
<td>Golconda</td>
<td>110–150</td>
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<td></td>
<td>60±</td>
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<td></td>
<td>25±</td>
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<td></td>
<td>55±</td>
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<tr>
<td>Location</td>
<td>Thickness</td>
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<tr>
<td>Cypress</td>
<td>80-120</td>
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<tr>
<td>Paint Creek</td>
<td>0-60</td>
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<tr>
<td>Bethel</td>
<td>60-100</td>
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<tr>
<td>Ste. Genevieve form</td>
<td>0-35</td>
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<tr>
<td>Levias member</td>
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<tr>
<td>Rosiclare member</td>
<td>15-45</td>
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<tr>
<td>Fredonia member</td>
<td>100-220</td>
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</tr>
<tr>
<td>St. Louis</td>
<td>500±</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Warsaw-Salem</td>
<td>250+</td>
</tr>
</tbody>
</table>
In the Illinois fluorspar district no diamond drilling has been done below the Warsaw limestone and consequently the older formations cannot be considered here. Furthermore, the drilling of post-Menard formations has not been common, and where cores of these younger formations have been obtained structural complications resulted in the sections being incomplete, and identifications are often uncertain. Therefore, they will not be discussed. The following descriptions are presented in reverse of the normal stratigraphic order because this is the sequence in which they are revealed by core drilling. A summary of the following data is presented graphically in table 3.

**Menard formation.**—The Menard formation consists of dark brownish very fine-grained to lithographic limestone with much interbedded dark gray calcareous shale. In general the limestone beds are thicker and more abundant in the upper half, whereas the lower half usually contains about equal amounts of limestone and shale. The Menard limestones are very similar to the Kinkaid limestone and in areas where both formations are present they may be mistaken for each other. The Menard is generally about 90 to 120 feet thick.

**Waltersburg formation.**—This formation consists of sandy shale and sandstone that may be difficult to recognize except on very careful examination of cores. It is dominantly dark gray silty to sandy shale with some thin fine-grained sandstone layers, although locally some well-developed sandstone may be present. The upper and lower contacts seem to be gradational and commonly cannot be accurately determined. The thickness of this formation appears to vary between 25 and 40 feet.

**Vienna formation.**—The Vienna formation is generally divisible into three zones. The upper and lower parts consist of black to dark gray smooth shale that is locally calcareous. These beds are most important in the recognition of the formation. The middle part is brownish fine-grained to rather coarsely crystalline limestone which generally includes some chert and may be somewhat sandy. The contacts of the formation are not sharply defined, and it varies in thickness from about 20 to about 40 feet.

**Tar Springs sandstone.**—This formation is dominantly white very fine-grained sandstone with some gray or greenish shaly beds which are commonly most conspicuous in the uppermost 20 feet. Locally sandy shale may constitute nearly half the formation. It averages about 90 feet in thickness.

**Glen Dean formation.**—The Glen Dean is readily divisible into three zones; the upper part consists of limestone, generally light brownish and coarsely crystalline. Fossils are abundant and crinoid stems and bryozoans are commonly recognizable in the cores. However, some fine-grained unfossiliferous layers also occur. This part of the formation varies to a maximum thickness of about 25 feet but it may be much thinner or entirely absent; this variation probably indicates that it is separated from the Tar Springs sandstone by an erosional unconformity.

The middle part of the formation is dark gray calcareous fossiliferous shale about 15 feet thick. The lower part is composed of brownish fine-grained to coarsely crystalline limestone that is somewhat fossiliferous and generally includes some calcareous shale at the base. It is also about 15 feet thick.

**Hardinsburg sandstone.**—The Hardinsburg is mainly white to light gray very fine-grained sandstone with three prominent beds of dark gray sandy shale each about 15 feet thick. The first of these occurs at the top of the formation, the second occurs in the middle, and the last about 10 to 15 feet above the base, which is unconformable upon the Golconda. The formation varies from 70 to about 120 feet in thickness.

**Golconda formation.**—The Golconda formation may be divided into three zones. The uppermost part consists of mostly brownish finely crystalline crinoidal limestone with many thin beds of dark gray calcareous shale. It has an average thickness of about 60 feet.

The middle zone is dark gray to greenish shale that is more or less silty or sandy. At many localities it includes thin beds of fine-grained sandstone. Its limits are grada-
tional into the other zones. It is commonly about 25 feet thick.

The lowest part of the formation is dominantly dark gray calcareous shale with beds of limestone mostly less than ten feet thick which vary from shaly to hard brownish and fine grained. Near Rosiclare the base of the formation is commonly marked by a bed of fine-grained brownish limestone with scattered pink calcite crystals. This zone is about 55 feet thick.

Cypress sandstone.—The upper part of the Cypress is mainly dark gray sandy shale with thin layers of sandstone, and the top is commonly marked by a thin layer of light greenish siltstone. The main part of the formation consists of white to light gray fine-grained sandstone broken by a few shaly beds. At the base a thin conglomerate is commonly present which includes brownish limestone pebbles. The entire formation varies from 80 to 120 feet in thickness.

Paint Creek formation.—This formation is mainly light gray very fine-grained sandstone with irregular dark gray shale partings. The upper half, or less, locally consists of gray to greenish silty shale and at the very top there may be a layer of light gray sandy limestone not more than 5 feet thick. This formation is in places 60 feet thick but locally in the Cave in Rock and Empire districts it has not been separately recognized.

Bethel sandstone.—This is a uniform white fine-grained sandstone, often more or less quartzitic. Shale beds are rare. Its thickness varies from 60 feet in eastern Hardin County to at least 100 feet in northeastern Pope County.

Renault formation.—The Renault formation may be subdivided into five zones originally established on the basis of insoluble residues. The two upper zones constitute the Downeys Bluff and the three lower ones the Shetlerville members.

The uppermost zone consists mainly of light buff, somewhat cherty, partly oolitic, coarsely crystalline limestone. Insoluble residues are mostly silicified fossil fragments, especially crinoid stems. Locally greenish and reddish shale occurs above the limestone. This zone may be as much as 40 feet thick but elsewhere it appears to be absent, probably as the result of pre-Bethel erosion.

The second zone is brownish, somewhat sandy, partly oolitic, finely crystalline limestone. Insoluble residues are very fine sand or coarse silt. It is about 10 feet thick.

The third zone is composed of finely silty calcareous greenish to gray shale with a few buff crinoidal limestone beds up to 10 feet thick. Some shale in the upper part is reddish. The thickness of this zone varies between 20 and 30 feet.

The fourth zone is relatively pure, brownish, partly oolitic to lithographic limestone 10 to 20 feet thick.

The basal zone is mostly argillaceous, coarsely silty, partly finely oolitic limestone with insoluble residues that may exceed 50 percent. It varies from 2 to 14 feet in thickness.

Levias limestone.—This is the uppermost member of the Ste. Genevieve formation. It is white to light gray, partly oolitic, coarsely crystalline limestone. It is particularly characterized by the occurrence of scattered coarse pink calcite crystals. It reaches a maximum thickness of 35 or more feet but may be locally absent as the result of pre-Renault erosion.

Rosiclare sandstone.—As present in diamond drill cores this member is typically light gray to greenish, very calcareous, partly oolitic, very fine-grained sandstone and may be easily mistaken for limestone. Patches of sandy oolitic limestone and layers of fine conglomerate are not uncommon. Locally the basal part consists of greenish to gray sandy shale and siltstone which is best developed in the Cave in Rock district. The base is generally fairly sharp, but this member grades into the overlying limestone. It varies from 15 to 45 feet in thickness.

Fredonia limestone.—This basal member of the Ste. Genevieve formation can be divided into three zones in some areas. The uppermost zone is white to light brownish, more or less oolitic limestone that attains a maximum thickness of about 70 feet.

The middle zone, known as the "Spar Mountain" sandstone, is somewhat similar

to the Rosiclare. It consists of light gray to greenish, slightly glauconitic calcareous sandstone or sandy limestone. Where recognizable it varies from 8 to 15 feet in thickness.

The lowest zone is thick-bedded white to light brownish, more or less oolitic limestone with a few thin locally developed shaly or sandy layers. Its average thickness is about 125 feet but the boundary with the underlying St. Louis limestone is not sharp and it may appear thicker at some places than at others.

St. Louis limestone.—The St. Louis consists of fairly uniform brownish very finely crystalline to lithographic limestone. It contains chert which is partly dolomitic and includes a few thin oolitic beds. Conils up to one inch in diameter are present in many cores. This formation is at least 500 feet thick.

Warsaw limestone.—Two zones are recognized in this formation where it outcrops, but the diamond drill cores have not furnished a complete section. The upper zone is light to medium gray, medium to coarsely crystalline limestone containing many crinoid stems and bryozoans. It seems to be about 60 to 80 feet thick.

The lower zone is dark gray to black, somewhat argillaceous and partly shaly limestone containing chert. It is mostly very finely crystalline, but a few coarsely crystalline layers occur. The total thickness of this member is not accurately known, but about 200 feet has been observed in cores.

STRUCTURE

The fluor spar district of southern Illinois is structurally part of the most complex and disturbed region in the state. It is peculiar in that it lies in the midst of a large area of nearly horizontal or only gently dipping beds.

The most conspicuous structural feature is Hicks dome (plate 4) centering in sec. 30, T. 8 E., R. 11 S., where Devonian chert and limestone rise to the surface. From this center the strata dip in all directions, but they are steepest to the northwest where the beds descend at a rate of nearly 1,000 feet per mile. The prevailing dip of the strata west of Hicks dome is to the northwest, and east of Hicks dome to the northeast, at rates generally varying between 100 and 400 feet per mile. The continuity of strata, however, is broken by two prominent down-faulted zones or grabens and many smaller faults.

The down-dropped grabens extend northeast-southwest and dominate the fault pattern of the area. Each now includes blocks in which various Pennsylvanian formations occur at the surface extending southwestward 15 to 25 miles beyond the main Pennsylvanian boundary. Each is bounded on both sides by faults or zones of faulting, of which the northwestern faults are more sharply defined and greater in displacement. At several places the southeastern boundaries are somewhat indeterminate and consist of a series of step faults, each with downthrow to the northwest.

The Dixon Springs graben extends from the northeast corner of Pope County to the Bay Bottoms at Big Bay (McNoel post office), beyond which it is concealed by the Cretaceous deposits of the Embayment area. Its northwestern boundary, termed the Lusk Creek fault zone in this report, extends southwestward from sec. 25, T. 11 S., R. 6 E., and passes just to the west of Dixon Springs. Part of this area has been carefully studied and consists of a much-shattered zone from 200 feet to a quarter of a mile wide, which has obviously been produced in part by high-angle thrust or compression faulting. North of sec. 25 it splits. One part, which probably carries most of the thrust faulting, extends north and connects with the Shawneetown zone of thrust faulting which curves around the margin of Cave Hill in southeastern Saline County.15 The other part appears to continue northeast as the Herod fault.

The Rock Creek graben extends southwest from the northeast corner of Hardin County, crosses the Ohio River between Rosiclare and Sheterville, traverses the western part of Livingston County, Ky., and reenters Illinois west of Bay City.
beyond which it is concealed beneath Cretaceous strata. This graben changes direction slightly between Elizabethtown and the old Illinois Furnace and in this area is broken into a very complex system of small fault blocks.

The northwestern boundary of the Rock Creek graben is along a series of intersecting and offsetting faults that have been termed the Wallace Branch fault, Illinois Furnace fault, and Hogthief Creek fault. Displacement along part of the Illinois Furnace fault is the greatest occurring anywhere in the fluorspar district and is probably in the neighborhood of 2,000 feet. This and the other faults mentioned above are part of a single complex fault zone comparable in a general way to the Lusk Creek zone except that thrust faulting is not so clearly evident here. This zone has not been studied recently in as much detail as has the Lusk Creek zone, and it is possible that thrust faulting occurred but is now masked by subsequent normal or tensional faulting of much greater magnitude than that which took place along the other zone.

The Rock Creek graben is bounded on the southeast by more closely spaced step faults than is the Dixon Springs graben. The richest, most extensive, and by far the most important fluorspar deposits are associated with these faults.

Other structures in the fluorspar district are minor by comparison with Hicks dome and the Dixon Springs and Rock Creek grabens. The area between the two grabens is cut by several faults, the more continuous of which extend in a northeast-southwest direction. The area in Hardin County east of the Rock Creek graben is comparatively unfaulted.

Except for the thrust faults in the Lusk Creek zone and possible similar thrust faults in the Wallace Branch-Illinois Furnace-Hogthief Creek zone, all the faults in Hardin and Pope counties are of the type that is generally termed “normal.” These have been produced presumably as the result of tension, and in general the hanging wall is downthrown with reference to the foot wall. This relationship is not invariable, however, because the planes of some of the steeper faults dip in one direction at some places and in the opposite direction at others and the terms foot wall and hanging wall cannot be used consistently.

Most of the faults dip steeply and diverge from the horizontal at angles varying from 70 to 90 degrees. Some are more gentle, however, and the most prominent of these, with angles as low as 45 degrees, generally are downthrown in a direction opposite to that of other nearby associated steeper faults.

The surface cover of residual material and soil is heavy throughout most of the fluorspar district, and outcrops of rock are generally inadequate to determine many of the structural details. Most of the principal lines of faulting are evident at the surface, but the faults themselves are rarely seen. The existence of a fault may be shown by the nearby occurrence of outcrops of different formations at similar elevations, by outcrops or residuum of silicified and sheared sandstone, or by outcrops of steeply dipping or disturbed beds. The actual location of the fault, however, can rarely be determined within a distance of 100 to several hundred feet. This is not important in mapping at a scale of one mile to one inch, but it is of great importance if prospecting operations are to be undertaken. Also it is generally impossible to determine from surface observations whether movement was localized along a single fault or distributed among related fractures constituting a fault zone.

Because of the scale of mapping, but also because of inadequacy of outcrops and lack of necessary detailed information, most of the faulting in Hardin and Pope counties is indicated on the map as though it had been accomplished by movements along a comparatively small number of simple and localized faults. Closely spaced diamond drilling, as on the property of the Alcoa Mining Company at Rosiclare, shows conclusively, however, that this is not the actual situation. There and elsewhere drilling and underground exploration have demonstrated that faulting is more abundant and much more complex than the surface features indicate. “Faults” are commonly fault zones characterized by more or less intense shattering of the wall rock and
often include a variably wide series of intimately related individual fault planes which branch and converge both horizontally and vertically in a complex and unpredictable manner. Moreover the more prominent faults or fault zones are connected, and the intervening blocks are cut, by numerous cross faults of varying magnitude, many of which cannot be recognized and located except under the most favorable circumstances.

Many cross faults carry such small displacements that they have no important effect on the general geologic situation and most of them are economically unimportant. Also, in many areas they are probably so closely spaced that it would be impossible to show them on a map at the scale of one mile to one inch. Consequently, on the general map only the prominent, most important, and most probable faults are shown in a somewhat generalized manner. In many parts of the region, however, a more accurate map could not be made even by the most detailed survey of surface indications.

In certain areas where the structure is unusually complex and the rocks are unusually broken, such as northwest of Elizabethtown where the Rock Creek graben changes direction slightly, the fault pattern indicated on the map is believed to represent the simplest interpretation of available data. It is not certain, however, that all stratigraphic identifications in such areas are correct, and likewise it is possible that individual locations where faulting is evident have been connected inaccurately. Probably very detailed restudy, the discovery of additional outcrops, or new evidence furnished by prospecting would necessitate important changes.

In northern Hardin County and northeastern Pope County, particularly on the west, north, and east flanks of Hicks dome, unmapped faults are known to occur. Evidence of this faulting is mostly very local and the course and extent of the faulting has not been determined. Probably most of the unmapped faults are of relatively minor importance.

Dips of strata west, northwest, and north of the center of Hicks dome are as steep as 15 degrees at many places but elsewhere the beds in the fault blocks generally dip very gently. Very local, much steeper dips occur, however, and are common adjacent to the faults where drag along the fault planes has turned them upward in the hanging wall and downward in the foot wall. Disturbance of this sort is much more pronounced adjacent to the stronger faults.

Names have been applied to a few of the economically or geologically more important faults in Hardin and eastern Pope counties. The principal ones are as follows:

Argo fault. — The Argo fault extends east of north in the SW ¼ sec. 32, T. 12 S., R. 8 E. It is nearly vertical and locally overturned with downthrow of about 75 feet to the northwest. Northward its displacement appears to decrease rapidly and southward it joins the Blue Diggings fault. It carries the Argo vein, the most westerly one known to be mineralized in the Rosiclare district.

Big Creek fault. — The Big Creek fault was mapped as extending from Ohio River, along the west side of the main ridge west of Rosiclare, east of north past Stone Church to near the junction of Big and Hogthief creeks. It was described as downthrown to the northwest about 350 feet. Structure in this vicinity is now known to be considerably more complex than was formerly supposed and the Big Creek fault as mapped is probably the generalized representation of several more or less parallel but distinct faults including the Steele and Stone Church faults described below.

Blue Diggings fault. — The Blue Diggings fault is known to extend from near Ohio River north and northeast to the north line of sec. 32, T. 12 S., R. 8 E., beyond which it has not been certainly located. It is downthrown to the southeast from about 75 to 150 feet. This fault throws in a direction opposite to the others in the Rosiclare district and is much more gently inclined, reaching a dip of 45 degrees locally. It carries the Blue Diggings vein, one of the principal mineralized zones of this district.

Daisy fault. — The Daisy fault crosses the northern half of sec. 32, T. 12 S., R.
To the south it splits and joins the Blue Diggings fault and one-fourth mile to the north it appears to join the west branch of the Hillside fault. It is steeply inclined to the northwest and is downthrown in that direction a maximum of about 325 feet. It carries the Daisy vein, one of the principal mineralized zones of the Rosiclare district.

**Dimick fault.** — The Dimick (also West Dimick, Hawkins) extends east of north across the north \( \frac{3}{4} \) of sec. 29, T. 12 S., R. 8 E., and continues into sec. 20. This may be a fault zone rather than a single fault. In its southern part at least, displacement has occurred along two closely spaced parallel faults. The fault planes dip very steeply to the northwest and downthrow is in that direction, about 475 feet in the southern part but increasing to about 650 northward. Fluorspar mineralization occurs at both the Dimick and Hawkins mines.

**Empire fault.** — The Empire fault extends northeast-southwest in the southern part of sec. 27, T. 11 S., R. 7 E. Its plane dips steeply to the southeast but vertical displacement is very slight, probably about 15 feet, with downthrow in the same direction. This fault carries the thin Empire vein.

**Eureka faults.** — The Eureka (East Dimick) zone extends northeast in the eastern part of sec. 29, the northwest corner of sec. 28, and into the southern part of sec. 21, T. 12 S., R. 8 E. It consists of a series of offset and intersecting small faults. Downthrow is to the northwest and appears to decrease gradually northeastward from a maximum of about 100 feet. The fault planes dip very steeply to the northwest and may overturn at some places. Fluorspar mineralization occurs in the Dimick and several Eureka mines.

**Extension or Good Hope fault.** — These are names sometimes used for the southern part of the Rosiclare fault.

**Hamp fault.** — The Hamp fault extends nearly east and west near the line between sections 7 and 18, T. 11 S., R. 8 E. It dips steeply and is downthrown to the south.

**Herod fault.** — The Herod fault cuts the northwest corner of Hardin County and continues southwest across the remainder of T. 7 E. and then goes into the Lusk Creek fault zone. Downthrow is to the southeast and is reported to be about 100 feet near Herod, but increases to the southwest.

**Hillside fault.** — The Hillside fault extends north and south near the center of the NW \( \frac{3}{4} \) sec. 29, T. 12 S., R. 8 E. It appears to split in each direction. To the south it joins the Rosiclare fault and to the north one branch probably joins the Daisy fault. Downthrow, to the west, is about 200 feet. This fault carries the Hillside vein which expanded to the greatest width of fluorspar known anywhere in the Illinois-Kentucky district.

**Hogthief Creek fault.** — This fault extends parallel to Hogthief Creek in central Hardin County and continues to the northeast. Probably a complex fault zone of moderate width, it bounds the Rock Creek graben on the northwest. Displacement is 1,200 or more feet with downthrow to the southeast. Thrust faulting may be involved.

**Illinois Furnace fault.** — This fault cuts the hill which separates Big Creek and Hogthief Creek near their junction and continues to the southwest along the northwest side of the Rock Creek graben, where it becomes part of a complex fault zone with a maximum displacement of about 2,000 feet. Downthrow is to the southeast. Thrust faulting is probably locally important.

**Last Chance fault.** — This is a short split from the Blue Diggings fault which lies in the angle between that structure and the Argo fault near Rosiclare. It is downthrown to the southeast and the displacement is about 5 to 20 feet.

**Lee fault.** — The Lee fault extends northeast-southwest in north central Hardin County. Although mapped as a simple fault it probably consists of several more or less parallel closely spaced faults. Displacement along this zone is as much as 400 feet in places, with downthrow to the southeast. This fault has not been traced far into the limestone area that surrounds the central part of Hicks dome, but possibly it con-
continues across this area to join the Shelby fault northwest of Eichorn.

Lusk Creek fault zone.—The Lusk Creek fault zone begins in sec. 25, T. 11 S., R. 6 E., where the Herod fault joins the south extension of the Shawneetown fault of Gallatin and Saline counties. Thence it extends southwest forming the northwestern boundary of the Dixon Springs graben to the Bay Bottoms. It passes a short distance west of the resort of Dixon Springs.

This zone is exceedingly complex in structure and 200 feet to ¼ mile in width. Where it has been carefully studied northeast of the Eddyville road it is formed by both normal and thrust faults which separate innumerable thin wedges of lower Pennsylvanian and upper Chester formations at the surface. As a whole, downthrow is to the southeast and the fault planes dip in that direction. Also most of the exposed strata in this zone dip to the southeast at angles averaging about 45 degrees. The most western known mineralization in the fluorspar region occurs along this zone.

Pell fault.—The Pell fault extends north from the Wallace Branch fault. Downthrow is to the east and displacement rapidly decreases to the north.

Pierce fault.—The Pierce fault extends north of east in the north part of sec. 34, T. 11 S., R. 7 E. Movement along this fault has not been determined but it is probably very slightly downthrown to the southeast like the Empire fault. The Pierce fault carries a narrow vein that has been successfully worked by surface operations.

Peters Creek faults.—A fault zone consisting of several nearly parallel faults bounds the Rock Creek graben on the southeast. Downthrow is to the north and reaches a maximum of about 1,000 feet. None of these faults are known to be importantly mineralized but they are believed to have been important in connection with the development of the bedded ore deposits of the Cave in Rock district.

Rock Creek fault.—The Rock Creek fault extends northeast-southwest and cuts the northeastern part of the Rock Creek graben. Downthrow is to the northwest with displacement of 500 feet, possibly increasing to 700 feet locally. Possibly this fault is partly the result of thrusting.

Rose Creek fault.—The Rose Creek fault extends north of east in sec. 11, T. 11 S., R. 7 E. Indications of faulting have been observed in both directions for a distance of several miles, but outcrops are inadequate to show their relationship. At the Rose Creek and Knox mines where this fault is mineralized the plane dips steeply to the south and downthrow is in that direction. This fault is similar in many ways to the Hamp fault.

Rosiclare fault.—The Rosiclare fault (known in its southern part as the Good Hope fault) extends from the Ohio River north and northeast to the center of the NE ¼ sec. 29, T. 12 S., R. 8 E. where it joins the Hillside fault. It is almost vertical, and downthrow is to the northwest from 200 to 300 feet. This is the most extensively and continuously mineralized fault in the entire fluorspar region, and production from it has far exceeded that of any other group of faults.

Shawneetown fault.—The Shawneetown fault largely lies outside the region considered in this report. It crosses the Ohio River at Shawneetown, extends west along the north face of the prominent hills in southern Gallatin County, curves southwest around Cave Hill in Saline County and joins the Herod fault in sec. 25, T. 11 S., R. 6 E., to form the Lusk Creek fault zone.

The Shawneetown fault is undoubtedly a complex zone that is dominated by thrust faulting. Displacement is locally as great as 3,400 feet and may be considerably more. Downthrow is to the north and northwest.

Shelby fault.—This is one of the more prominent faults of a system on the southwest flank of Hicks dome known as the Hobbs Creek fault zone. The Shelby fault extends northeast-southwest for an unknown distance and is best displayed near the center S ¼ sec. 9, T. 12 S., R. 7 E. Its plane dips to the southeast at an angle of about 60 degrees and downthrow is in that direction. Cypress sandstone occurs at the surface in the foot wall. The hanging wall is
broken by minor faults and the surface rocks are Tar Springs and Hardinsburg sandstones. Displacement is about 200 feet.

**Shetlerville fault.** — This fault extends in a direction a little west of north just east of the village of Shetlerville. It has been mapped as continuing about three miles in this direction but the last third of its course passes through an area where only sandstone outcrops and consequently it is not well known or accurately located there. Downthrow of 100 or more feet is to the west and in the Ohio River bluff the upper part of the Ste. Genevieve limestone, on the east, is in contact with the Bethel sandstone, on the west.

**Steele fault.** — Diamond drilling on the property of the Alcoa Mining Company near Rosiclare has revealed the presence of many unsuspected faults, mostly of small displacement. One of the more prominent of these is the Steele fault, which roughly parallels, and lies about 600 feet west of, the Blue Diggings fault. It extends northeast-southwest and cuts the northwest corner of sec. 5, T. 13 S., R. 8 E. Its north extension is not known. Downthrow of about 25 to 90 feet is to the west. This fault is not known to be mineralized.

**Stewart fault.** — A fault or a series of related faults extending about 25 degrees east of north crosses the state highway near the center of sec. 14, T. 12 S., R. 7 E. Downthrow is to the west and displacement is locally as great as 100 feet or more. This fault is not clearly revealed by outcrops but several mines have been opened along it. Its north continuation is not known. Southward it probably joins the Shetlerville fault.

**Stone Church fault.** — This fault is not well known. It seems to extend a little west of south from Stone Church, near the junction of the Rosiclare Road with State Highway No. 146. It is probably one of several faults that was shown as the Big Creek fault on the former map of Hardin County but is located some distance east of where that fault was indicated. Downthrow is to the west and the displacement is 80 or more feet.

**Sycamore fault.** — This is a fault probably of very small displacement extending north of east through the center of sec. 34, T. 11 S., R. 7 E., one quarter of a mile south of the Pierce fault which it parallels and otherwise resembles.

**Threemile fault.** — A fault is shown 2½ miles northwest of Rosiclare in the former map of Hardin County as extending northeast-southwest for a distance of about 3½ miles between the Big Creek and Pell faults. There is little possibility that any single fault continues throughout this course, and displacements here which range from comparatively minor ones to others of 1,000 feet or more are probably the result of numerous faults not all of which are closely related. Throughout most of its length this trend or series of faults lies within the southwest continuation of the Rock Creek graben, whose structure is known to be exceedingly complex locally.

**Wallace Branch fault.** — This fault, about three miles northwest of Rosiclare, forms the western boundary of Rock Creek graben and is comparable in every way to the nearby part of the Illinois Furnace fault of which it may be considered the continuation. Undoubtedly it is a narrow complex fault zone in which thrusting is probably important. Downthrow is to the northwest, and displacement is variable but locally exceeds 1,000 feet.

**Wolrab Mill fault.** — This fault as shown on the former geological map of Hardin County is the longest fault in the area and is reported to have been traced nearly to the Pope-Massac County line. It extends northeast-southwest. The location of this fault is not accurately known throughout much of the limestone area on the southeast flank of Hicks dome, and it has not been certainly recognized at the Stewart mine where it is supposed to cross the Stewart fault. Although a zone of faulting doubtless occurs along most of this course as mapped, locally at least, structure is more complicated than formerly supposed.
PALEONTOLOGY

Fossils are abundant, at least in places, in many of the Mississippian formations of the fluorspar region. Altogether several hundred different species have been recognized. All of them are strictly confined to one or more of the formations, and a careful study of the fossils is the best and often the only sure means of stratigraphic identification.

Many fossil species are of little more than scientific interest, mainly because they are rare or difficult to identify. A working knowledge of a few of the commoner species and those forms which are the most reliable guide fossils to certain formations, however, is very useful to anyone interested in the geology of the fluorspar region. The following nontechnical descriptions and the accompanying plates of illustrations are intended to furnish information concerning these commoner and more useful species.

CORALS

The corals are a group of simply organized marine animals which build external calcareous supports upon and within which they live. The supports, or skeletons as they are sometimes called, are commonly cup-shaped internally. They may occur singly in the form of more or less distorted cones or cylinders—fossils of this type are known as horn corals from their shape. Others lived in colonies consisting of branching and diverging cylinders or polygonal tubes. In some colonies the tubes are so closely crowded together that no space remains between them, and their outlines are polygonal. The cups vary considerably in size but are usually about 1/2 inch in diameter. A sharply pointed knob rises in the center of each cup and traces of the radiating plates can usually be seen about the insides of the partitions between them.

_Triplephyllites spinulosus._—Plate 1, fig. 3.

This is the common horn coral of the Chester formations, and very similar specimens occur in the Ste. Genevieve limestone. They are particularly abundant in shaly beds.

These fossils are horn-shaped irregular cones that expand rather uniformly from a pointed lower end to a hollow cup on whose inner sides the radiating plates are well shown. A notch-like depression extends from the center of the cup outward toward the shorter curved side of the cone. They vary in size from about 1/2 to over 1 inch in diameter at the upper end and may attain a length of 2 or more inches. Commonly the sides of the cup are partially broken away.

_Ampexus geniculatus._—Plate 1, fig. 4.

These also are horn corals that grew singly. They are abundant in some of the shaly beds of the Shetlerville member and have been found in no other formations.
These corals are much more slender and expand much less rapidly than the last species. They are generally from $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter and may attain a length of 5 inches or more. The specimens that are collected are generally broken pieces of cylindrical shape and rather uniform diameter. Some of them show that the direction in which the coral grew changed abruptly from time to time. The cups at the upper ends are almost always crushed and broken. The radial plates, which do not reach the center of the cylinder, can often be seen on broken cross sections.

**Blastoids**

These peculiar marine animals, which were related to the starfish, have long been extinct. They were permanently attached to the sea bottom by stems composed of a large number of small, round, button-like plates. The bodies of these animals, at the upper end of the stem, were enclosed in globular or bud-shaped shells formed of closely joined plates. These blastoid "heads" are common fossils at many places and have been mistaken for petrified hickory nuts or similar objects. The attachment of the stem can usually be seen at one end, and at the other are several small holes one of which opened into the internal mouth. Extending downward from these are five "food grooves" composed of numerous generally slightly sunken tiny plates. A large number of small jointed armlets, almost always broken away from the fossils, urged food particles suspended in the sea water upward along the food grooves to the mouth.

Mesoblastus glaber. — Plate 2, figs. 1 and 2.

These tiny blastoids are very abundant in the shaly Shetlerville beds at some places and occur in less abundance in the Ste. Genevieve limestone and Downeys Bluff member of the Renault formation. Very similar fossils have been found at a few places in St. Louis limestone and in the Golconda formation.

Specimens of this species are nearly spherical and vary from $\frac{3}{8}$ to $\frac{1}{4}$ inch in diameter. They are darker colored than most other fossils and where slightly worn are almost black. The food grooves are rather narrow and of almost uniform width. Specimens from the Golconda are nearly twice as large but otherwise quite similar. Those from the St. Louis are smaller and also differ slightly in other respects.

**Pentremites.** — Plate 2, figs. 3–13.

These blastoids are common fossils of several of the Chester formations and also occur in the Ste. Genevieve limestone and much more rarely in the St. Louis. Many different species are recognized but they are difficult to identify because they are so similar and because the group as a whole is so variable in size and shape.

Pentremites are bud-shaped, thickest near the base, and many are somewhat elongated. The food grooves are wide and become narrower downward from the summit. They vary in size from less than $\frac{1}{4}$ inch (these are immature specimens) to a rare large species in the Golconda formation more than 2 inches in height. Most, however, are from $\frac{1}{2}$ to $\frac{3}{4}$ of an inch high.

**Pentremites princetoniensis** (figs. 5 and 6), the common species of the Ste. Genevieve limestone, is close to the average in shape and below the average in size. It also occurs in the Renault.

From this generalized shape, variation proceeds in two directions and most pentremites can be separated either into a low broad group with width about equal to height and an elongated group considerably higher than wide. The latter group includes:

**Pentremites pulchellus** (figs. 3 and 4) is an elongated species with food grooves that extend far down toward the flattened base. It is known from both the Ste. Genevieve and Shetlerville but is more characteristic of the former. Specimens may be found that intergrade almost completely between this species and the last.

**Pentremites okawensis** (fig. 9) is an elongated species very different from the last. Its food grooves are short, not extending more than half way down on the sides, and its basal part slopes steeply to the
PLATE 1

Fig. 1.—*Sulcatopinna missouriensis*. The specimen is broken at both ends. The left end originally extended nearly to a point.

Fig. 2.—*Allorisma clavatum*.

Fig. 3.—*Triplophyllites spinulosus*. Part of the rim is broken away to show the interior of the cup.

Fig. 4.—*Amplexus geniculatus*.

Fig. 5.—*Lithostrotionella prolifera*. Part of a colony seen from above. About half actual size.

Figs. 6, 7.—*Lithostrotionella castelnaui*. A small colony seen from the side and from above. About one-third actual size.
PLATE 2

FIGS. 1, 2.—Mesoblastus glaber. Two specimens seen diagonally from the side and from above. About twice actual size.

FIGS. 3, 4.—Pentremites pulchellus. Two specimens seen from the side and from above.

FIGS. 5, 6.—Pentremites princetonensis.

FIGS. 7, 8.—Pentremites brevis. Two specimens seen from the side and from above.

FIG. 9.—Pentremites okawensis.

FIGS. 10-12.—Pentremites godoni. Three specimens, two seen from the side and one from below.

FIG. 13.—Pentremites pinguis.

FIGS. 14-16.—Reticulariina subspinosa. Three specimens, one seen from the end. About twice actual size.

FIGS. 17, 18.—Reticulariina spinosa.

FIGS. 19-21.—Pugnoides ottumwa.

FIGS. 22-24.—Cleiothyridina sublamellosa. Three specimens, one seen from the side.

FIGS. 25, 26.—Punctospirifer transversa.

FIG. 27.—Stenosisma explanata.

FIGS. 28-31.—Composita trinuclea. 28 and 29, large specimens, the former unusually deeply folded.

FIGS. 32, 33.—Composita subquadrata.

FIGS. 34, 35.—Spirifer increbescens, small variety.

FIGS. 36, 37.—Spirifer increbescens.
PLATE 3

FIG. 1.—Orthotetes kaskaskiensis.

FIGS. 2-4.—Productus (Diaphragmus) chesterensis. Three specimens showing (2) the very convex shell, (3) the flat shell, and (4) a side view.

FIGS. 5, 6.—Talarocrinus. 5, a specimen seen from the side, and 6, another seen from below. Both about twice actual size.

FIGS. 7, 8.—Platycrinus huntsvillae. 7, the base of a broken specimen seen from below, and 8, a stem plate. Both about twice actual size.

FIGS. 9, 10.—Pterotocrinus capitalis. 9, a rare specimen seen from above showing the wing plates in natural position, and 10, a single wing plate seen from the side.

FIG. 11.—Pterotocrinus menardensis. A wing plate seen from the side.

FIGS. 12, 13.—Septopora. Two fragments, about twice actual size.

FIG. 14.—Polydora. A fragment seen from the back, about twice actual size.

FIG. 15.—Fenestella. Two fragments in limestone with other bryozoans. About twice actual size.

FIG. 16.—Lyropora. The supporting structure with both ends broken.

FIG. 17.—Archimediopora. Fragment of supporting axis about twice actual size.

FIGS. 18, 19.—Cystodictya labiosa. Two fragments, about twice actual size.

FIG. 20.—Prismapora. A fragment, about twice actual size.

FIG. 21.—Batostomella nitidula. Fragments in limestone, about twice actual size.
stem. It occurs in the Golconda and Glen Dean formations, particularly the former. Specimens of this general type also are present in other Chester formations, but they are very poorly represented in the Renault and have not been found in the Ste. Genevieve.

The shorter group of pentremites include the following species:

_Pentremites pinguis_ (fig. 13) is about equally wide and tall with a low flat base. The surfaces of the food grooves are nearly flat. It occurs in both the Ste. Genevieve and Renault but is more characteristic of the latter. Specimens intermediate between this species and _princetonensis_ are not uncommon.

_Pentremites godoni_ (figs. 10-12) is very similar to the last and intergrading forms occur. It differs in that the surfaces of the lower parts of the food grooves are noticeably convex and not sunken as much below the bounding edges. This is particularly characteristic of the Downeys Bluff member of the Renault.

Although most of the pentremites of the Ste. Genevieve and Renault can be referred to similar or closely intergrading species, elongated specimens dominate in the former and short specimens are much more abundant in the latter.

_Pentremites brevis_ (figs. 7 and 8) is shaped similarly to the last two species but its food grooves are somewhat V-shaped in cross section and the sides slope inward toward the longitudinal center line. It occurs in the Golconda and Glen Dean formations.

Pentremites are less common in the higher Chester formation and most of them are similar to _P. okawensis_ and _P. brevis_. Several of the species are larger, however, and have heights of 1 inch or more.

**Crinoids**

Most crinoids are stemmed animals similar to blastoids except that there are no exterior food grooves and the "heads" are equipped with long jointed arms (5 or in multiples of 5) which are commonly branched. They have existed in a great variety of different shapes and some are living in the sea today. Fossils are rarely found with the arms still attached and most of the "heads" are broken and the plates of which they are composed scattered through the rocks. The stems are long and commonly built up of small circular plates, but some are oval and a few pentagonal. Crinoids lived in such abundance at some places that limestone may be composed almost entirely of their broken remains.

_Platyrrinus huntsvillae_. — Plate 3, figs. 7 and 8.

This species is a guide fossil of the Ste. Genevieve limestone and has never been found in any of the Chester formations.

Complete heads are very rare, but the basal parts with the stem attachment are found at many places. These are easily recognized by the three radial ridges that extend outward from low spines or small knobs on the circular collar, 1/8 to 1/4 inch in diameter, that surrounds the stem attachment. The stem plates of this species are also characteristic. They are oval, from less than 1/8 to nearly 1/4 inch in long diameter, and bear a number of conspicuous spines on their outer surfaces. Both the bases and stem plates can be best seen on weathered limestone surfaces where these and other fossils stand out in relief. Sometimes the bases can be found in freshly broken rock.

_Talarocrinus_. — Plate 3, figs. 5 and 6.

This little crinoid occurs in the Illinois fluorspar region only in the Renault formation. At many places where the Renault and the Ste. Genevieve consist of similar limestone the contact between them can be determined by noting the occurrence of _Talarocrinus_ and _Platyrrinus huntsvillae_, because they never occur in the same bed and each is an infallible guide to its formation.

Several different species of _Talarocrinus_ have been named but the distinctions between some of them are not conspicuous and can be observed only in exceptionally well preserved specimens. The complete "heads" are generally about 1/2 inch in diameter and
somewhat higher than wide. The basal part consists of 2 plates that look much like a pair of tiny biscuits with the small circular area of stem attachment in the middle. The sides are composed of 5 generally somewhat smaller plates. Projecting from the top is a central knob and commonly 5 other knobs or spines occur around the margin each situated just above an opening where an arm was originally attached. Complete heads are not common but these crinoids can be recognized by their basal plates which are often found separated from the other parts. The only other crinoids with which these basal plates might be confused belong to the genus Pterotocrinus.

**Pterotocrinus capitalis.** — Plate 3, figs. 9 and 10.

Complete heads of this or other species of *Pterotocrinus* are great rarities because after the death of the animals the plates of their skeletons are separated and scattered over the sea bottom. They can be recognized, however, from the "wing" plates of which there were five that originally projected upward and outward from the upper part of each individual between the arms. The wing plates of different species varied considerably in shape and size.

*Pterotocrinus capitalis* is a very characteristic species that occurs only in the lower part of the Golconda formation. At some places the wing plates are very abundant.

The wing plates of this species are commonly about $\frac{3}{4}$ of an inch high and long, $\frac{1}{3}$ to $\frac{1}{2}$ inch thick at the outer end and less than $\frac{1}{4}$ to about $\frac{1}{3}$ of an inch thick at the inner end which is marked by several facets where other plates originally fitted against it. Their surfaces are smooth. Details of shape vary considerably but equally thick and massive wing plates occur in no other formation.

**Pterotocrinus menardensis.** — Plate 3, fig. 11.

This species is particularly characteristic of the Menard formation. Its wing plates are much larger and at the same time thinner than those of the last. Somewhat similar thin wing plates, differing from each other mainly in shape, were possessed by several other species of the Golconda, Glen Dean, Clore, and Kinkaid formations.

*Pterotocrinus* wing plates are small and rare in the Renault and do not occur in any lower formation. One species in the Glen Dean possessed abruptly forked wing plates.

**Bryozoans**

Bryozoans are tiny aquatic animals, mostly marine, that live in colonies much like corals, but their internal organization is quite different. Their external supporting structures are common fossils. These occur in a great variety of forms including several types of branching structures, delicate lace-like expanses, thin encrusting layers on other fossils, massive hemispherical bodies or delicate branching stemlike growths. The surfaces of all of them are pierced by tiny openings within which the almost microscopic animals once lived.

**Cystodictya labiosa.** — Plate 3, figs. 18 and 19.

Fragments of these fossils are common in some of the shaly parts of the Renault formation and have been found in no other in Hardin County.

They consist of thin flattened ribbon-like structures about 1/10 of an inch wide, generally broken into pieces only a fraction of an inch long. They branched in various irregular ways. Both flat surfaces are pierced by closely spaced tiny openings with upraised rims arranged in diagonal rows. A single row usually contains 7 to 10 openings.

**Fenestellid bryozoans.** — Plate 3, fig. 15.

A type of bryozoan very common in most of the Mississippian limestone and limestone-shale formations consists of a lace-like expanse formed by a series of tiny parallel branches joined together by short cross bars. Minute openings in which the animals lived occur on one side.

There are many different kinds of these bryozoans. Not only do the lace-like expanses differ in the number of rows of openings on the branches and presence or absence of openings on the cross bars, but they were attached to different types of thickened supporting structures.
In general three main types of lacelike expanses can be recognized:

*Fenestella.* — Branches with never more than two rows of openings, no openings on cross bars.

*Polypora.* — Openings in more than two rows, no openings on cross bars.

*Septopora.* — Openings in more than two rows, and openings on cross bars also.

Species differ in the size and shape of the lacelike meshwork, the number of rows of openings on the branches and minute features of ornamentation.

*Archimedipora.* — Plate 3, fig. 17.

These bryozoans have been found in Hardin County only in the Golconda and younger Chester limestone-shale formations. At some places they are very abundant.

*Archimedipora* is a name used for screwlike fossils consisting of a central column generally about 1/8 inch or less in diameter bearing a continuous twisted flange. It was the support of a bryozoan colony of the type described above as *Fenestella.* The lace-like expanse originally extended outward from the edge of the flange but is commonly broken off in the fossils. Species differ in the diameter of the central column, the tightness of twisting of the flange, and the type of lacelike expanse attached to it.

*Lyropora.* — Plate 3, fig. 16.

This fossil occurs in the Renault formation but is rare or absent in all others.

This also is the thickened support of a bryozoan colony of the type described above as *Fenestella.* It is U-shaped and resembles a portion of a small irregular jawbone without teeth. The lacelike expanse in which the animals lived was stretched between the two arms of the U but in the fossils has almost always been broken away.

*Prismopora serratula.* — Plate 3, fig. 20.

This fossil is particularly characteristic of the Glen Dean where it is locally very abundant. It is one of the most easily recognized bryozoans because it is so different from any other present in the Mississippian rocks. Specimens may occur very rarely in the Golconda and Vienna formations.

This fossil consists of triangular prisms, occasionally branched. The three flattened faces, 1/4 inch or less across, are slightly concave and pitted with the small openings in which the animals lived. The faces join to form thin scalloped edges.

*Batostomella nitidula.* — Plate 3, fig. 21.

This delicate branching bryozoan is not restricted to any single formation but it is unusually abundant at some places in the Clore.

The branches are cylindrical, 1/25 of an inch or less in diameter, and always occur as broken fragments. The entire surface is marked by tiny pits or openings.

Several other kinds of cylindrical bryozoans occur in the Mississippian rocks, most of them much larger than this species. They can be identified only by the microscopic examination of thin sections.

### BRACHIOPODS

Brachiopods are exclusively marine animals with two hinged shells. They resemble the pelecypods except that the two shells are differently shaped and each is bilaterally symmetrical with equal right- and left-hand parts. The animals which inhabited the shells, however, were very different from the pelecypod.

*Composita trinuclea.* — Plate 2, figs. 28–31.

This is the commonest Mississippian brachiopod of southern Illinois. It occurs in most of the Chester limestone-shale formations, in many places in great abundance. It is likewise common in the Ste. Genevieve limestone and also occurs in the St. Louis and some older formations.

These fossils are ovoid in shape and may be as large as 1 inch long and 3/4 inch wide although many are smaller. One shell has a prominent overhanging beak at the hinged end. At the other end the surface of this shell is folded gently downward to form a depression that corresponds to an upraised fold in the other shell. The surface is smooth except for concentric lines of growth.

This species is quite variable in size, shape, and strength of the folds. Several other species resemble it but they are rarely abundant.
Composita subquadrata. — Plate 2, figs. 32 and 33.

This species is characteristic of the Menard, Clore, and Kinkaid formations where it largely replaces C. trinuclea. It also is very abundant at some places.

These shells are very similar to the last except that they are relatively broader and may be wider than long. They are generally circular to squarish in shape and attain a larger maximum size.

Specimens intermediate between these two species of Composita are not uncommon.

Cleiothyridina sublamellosa. — Plate 2, figs. 22–24.

This is the second most common Chester brachiopod occurring in all of the limestone-shale formations and the Ste. Genevieve as well.

This fossil is rather similar in outline to Composita subquadrata but it is smaller, rarely as much as 3/4 of an inch wide. One shell is much more convex than the other, however, and the beak is not so prominent. Originally a series of closely spaced flat spines continued outward parallel to the curvature of the shell from each of the closely spaced lines of growth. These have usually broken off from the fossils but their bases can be seen easily with a low-power magnifier.

Punctospirifer transversa. — Plate 2, figs. 25 and 26.

This is a common species in all Chester limestone-shale formations.

These shells have a long straight hinge line ending in sharply pointed extremities. Large specimens are 1/2 inch high and nearly 1 inch wide. Both shells are marked by a series of narrow rounded folds radiating outward from the beaks on either side of a stronger, wider central fold. The surface is ornamented with numerous closely spaced growth lines that stand out as little ridges curving upward and downward across the folds and are plainly visible with a hand lens.

Reticulariina spinosa. — Plate 2, figs. 17 and 18.

These fossils are fairly common in most of the Chester limestone-shale formations except the Renault.

This species is similar to the last except that the shells are relatively less broad, the folds are fewer and more sharply crested, and growth lines are much less common. Also the surface is ornamented with the bases of tiny broken hollow spines scattered over the upper parts of the folds and visible under a lens.

The shells of the last species described, this one, and the next are pierced by very tiny crowded pores that may be seen with a magnifier, particularly where the shells are slightly worn.

Reticulariina subspinosa. — Plate 2, figs. 14–16.

This species is fairly common in the Shetlerville where it takes the place of R. spinosa. It is not known from any other formation.

These fossils seldom attain a width of much more than 1/2 of an inch and are about as high as they are wide. They have fewer folds than R. spinosa and are ornamented by similar spine bases.

Spirifer increbescens. — Plate 2, figs. 36 and 37.

This fossil is common at many places in the Menard, Clore, and Kinkaid formations.

These shells are similar in shape to Punctospirifer transversa but are about twice as large and reach a length of 1 inch and a width of 2 inches. The surface is marked by low rounded folds radiating from the beak. Several of these are raised or lowered into a large central fold. Growth lines are not conspicuous, the shell is not pierced by pores, and no spines are present. Ornamentation consists of very fine thread-like markings extending parallel to the folds.

Similar spirifers occur in many other formations and some of the species are quite difficult to differentiate. A type which is common in the lower and middle Chester formations (Plate 2, figs. 34 and 35) is smaller than S. increbescens, about 1 1/2 inches wide, and more delicately marked. No name has been regularly applied to it.
Very similar specimens occur in the Ste. Genevieve limestone.

*Pugnoides ottumwa.*—Plate 2, figs. 19–21.

This species occurs only in the Ste. Genevieve limestone.

The shells measure $\frac{1}{3}$ to $\frac{1}{2}$ inch in length and are about equally wide. Their small pointed beaks give them a somewhat triangular shape. Each shell has from 7 to 10 small sharp folds. The middle 2 to 4 are somewhat smaller than the others and are raised in one shell and lowered in the other to form a large central fold. There are no pores.

Somewhat similar fossils occur sparsely in the Chester formations but they are generally broader and have more numerous and lower small folds which extend all the way to the beak, whereas this part of the shell in *P. ottumwa* is smooth and unfolded. Also, in the Chester species, the large central fold is less distinct and the shells of one species are pierced by numerous small pores that can be seen with a magnifying glass.

*Orthotetes kaskasiensis*.—Plate 3, fig. 1.

This fossil is one of the large brachiopods of the Ste. Genevieve limestone and Chester formations.

It is oval in shape and attains a maximum width of about 2 inches and a length of more than $1\frac{1}{2}$ inches. One shell is broadly convex. The other is flat or gently concave and has a low, wide, triangular flattened area along the hinge line nearly at right angles to the rest of the shell. The surface is marked by numerous fine radiating ribs of somewhat irregular size and a few concentric growth markings.

*Productus (Diaphragmus) chesterensis.*—Plate 3, figs. 2–4.

This species is abundant at many places in the Chester formations and is less common in the Ste. Genevieve limestone.

Specimens may reach a width of about 1 inch and an approximately equal length but are generally somewhat smaller. The two shells are unequal in size and shape. One, starting from an incurved beak, rapidly increases in width and in mature specimens curves through a complete semicircle. The other is flat or gently concave and is sunk within the larger shell. In many specimens the smaller shell cannot be seen. The larger shell is marked by irregular low rounded ribs which radiate from the beak and may be slightly swollen here and there where they bore spines, almost always broken from the fossils. The smaller shell has less distinct radiating markings and a few concentric lines of growth.

Larger fossils of similar appearance also occur in the Mississippian rocks and at a few places are abundant in some of the upper Chester limestone-shale formations but they are commonly crushed. Some have coarser and others have finer surface markings.

*Stenoscisma explanata.*—Plate 2, fig. 27.

This little fossil can usually be found by careful searching in the Golconda and all higher Chester limestone-shale formations, but it never occurs below the Cypress sandstone.

This species resembles *Pugnoides ottumwa* but rarely reaches a size of $\frac{1}{3}$ inch. The shape is somewhat triangular, and length, width, and thickness are about equal. Most of the shell surface is smooth, but toward the edge away from the beak are several comparatively broad, low, rounded folds. Two of these in one shell are raised into the main central fold, and in the other shell one occurs at the bottom of the corresponding fold.

**PELECYPODS**

Pelecypods, or clams, possess two unsymmetrical shells that are usually similar to each other. One shell occurs on the right and the other on the left side of the animal's body, whereas each of the two dissimilar shells of a brachiopod possesses equal right and left halves. Pelecypods live both in marine and fresh water. Most of them crawl sluggishly over the bottom and some burrow in mud.

*Allorisma clavatum.*—Plate 1, fig. 2.

This species is abundant at some places in the Menard limestone and has been found in the other upper Chester limestone-shale formations, but it does not occur in lower beds.
The shells are elongated ovals about twice as long as wide with beaks close to one end. Size varies up to a maximum of 2 inches or more in length. Ornamentation consists of a series of low rounded concentric markings parallel to the outer shell margin.

_Sulcatopinna missouriensis._ — Plate 1, fig. 1.

The occurrence of this species is similar to that of the last.

These shells are very elongated triangles and are moderately convex. Length is about 3 times height, and large specimens reach a size of about 6 inches. The surface is ornamented with low rounded markings of irregular size that radiate from the small end parallel to the sides and are crossed by less conspicuous irregularly spaced growth lines.

Complete specimens are quite rare but this species can be recognized from fragments of lenticular cross section with sharp, slightly diverging edges and characteristic surface markings.

**GEOLOGIC MAP**

The geologic map of the fluorspar district which accompanies this report (pl. 4) is largely based on previous geological work. It is somewhat larger than the one published with the older report on Hardin County in order that it may include almost all localities of fluorspar mineralization known in the region.

Approximately the northern half of this map is the work of Charles Butts, and the southern half, the work of Stuart Weller. In both areas, but particularly in the northern one, inaccuracies are suspected. Some alterations and corrections have been made but time was not available for a complete remapping of this region.

Patterns are used to show the areas where the various geologic formations, as shown in the columnar section, occur at the surface. For purposes of simplification these formations are shown in several groups rather than individually. This grouping does not conform to the standard classification recognized by most stratigraphers, but is designed primarily for practical use in this particular district. In most areas where structural complications and faulting are not important, individual formations can be identified by noting the nature of the outcropping rock and its position, whether near the top, middle, or bottom of the indicated group. Where adjacent similar limestones are mapped together, for example the St. Louis and Fredonia or the Levis and Renault, discrimination is difficult and can only be made by a specially qualified geologist. In structurally complex areas identification of individual formations, particularly sandstones, is very difficult, and even the most experienced geologist may be mistaken.
CHAPTER 7—MINING DISTRICTS

ROSICLARE

Location
The Rosiclare fluorspar district is located in southwestern Hardin County, Illinois. It extends from Ohio River west of the town of Rosiclare, east of north for nearly four miles to Big Creek and occupies principally the eastern half of sec. 29 and the central part of sec. 32, T. 12 S., R. 8 E., and the western half of sec. 5, T. 13 S., R. 8 E. (pl. 5).

Importance
The Rosiclare district has long been a principal source of domestic fluorspar, and its past production bulks large in the total for the Illinois-Kentucky region.

This district has been controlled by three companies, (1) Rosiclare Lead and Fluorspar Mining Co., the overall outstanding producer, (2) Alcoa Mining Co., successor to the Aluminum Ore Co., present owner of the old Franklin Fluorspar Company's properties, and since 1943 the most important producer, and (3) Hillside Fluorspar Mines, which ceased operation here in 1948. Each of these companies owns or controls properties in other parts of southern Illinois and western Kentucky, but the major part of their production has come and (except the Hillside Company) is now coming from five veins near Rosiclare: (1) Hillside, (2) Rosiclare—sometimes termed Good Hope and Extension to the south, (3) Daisy, (4) Blue Diggings, and (5) Argo. Figure 13 shows the surface plant of the Rosiclare Lead and Fluorspar Mining Co.

Geologic Map
The accompanying geologic map (pl. 5) is based upon all available information including outcrops, mine data, and drill records. Outcrops are rare in most parts of the Rosiclare district and consequently geologic details are uncertain at many places. Faults are shown as solid lines only where they are accurately known from mine workings or drilling. Probable or possible faults elsewhere are shown as dashed lines. As new information is obtained, it will undoubtedly be necessary to make important and extensive corrections in the map. Advance in knowledge of the geology in the Rosiclare district over a period of nearly 30 years may be seen by comparing this map with the corresponding portion of the geologic map of Hardin County published in 1920 (Plate 1 of Bull. 41, Ill. Geol. Survey). This advance has resulted almost entirely from additional mining and prospecting operations.

Veins
The fluorspar-bearing veins of the Rosiclare district occur along faults. The principal gangue mineral is calcite; other minerals that commonly occur in small amounts are quartz, sphalerite, galena, pyrite, chalcopyrite, and barite. The proportions of these minerals present in the veins vary greatly and unpredictably from place to place. Sphalerite and galena locally are present in sufficient quantity to be separated as valuable by-products. Figure 14 shows the appearance of a typical vein of fluorspar.

Deposition of vein minerals along the faults apparently occurred from ascending solutions as fissure fillings. At places where open fissures were not present, the veins pinch out although the faults continue.

Calcite was the first mineral deposited in the veins, and at most places it is clear that calcite formed simple fissure fillings entirely unrelated to the chemical nature of the enclosing walls. Fluorite, introduced later, replaced calcite in the already existing veins and also crystallized in openings still present in them. Although Bastin described specimens collected from the dump of the Hillside mine which exhibited evidence of fluorite replacing limestone, this process was unimportant in the Rosiclare district, and those parts of the mines recently available for study commonly show the veins to be bounded by sharp, uniform, and often slick-

ensided walls. Also fragments of rock enclosed within the veins are mostly angular and sharply bounded. It is quite clear that fluorite, although it replaced calcite of the earlier veins extensively, did not replace the limestone walls to an important extent in this district.

**Faults**

Faults in the Rosiclare district are generally steeply inclined and at most places are of the "normal" type (hanging wall downward relative to foot wall) but locally the fault planes are overturned and the relations of the walls are reversed. Slickensides show that the movement along some of the faults was lateral as well as vertical, and it is probable that in general the lateral movement was important. So far as is known, all of the faults in the Rosiclare district were formed at essentially the same time and previous to the mineralization.

Some movement and readjustment, however, occurred along the faults after mineralization, because slickensided surfaces are present within the veins at many places and locally the vein matter is sheared so extensively that it appears to be composed of a series of horizontal or gently inclined layers two to four inches thick.

The major faults of the district roughly parallel one another and generally extend in a direction about 20 to 30 degrees east of north, although the Hillside fault is directed north and south and the fault or series of faults upon which the Eureka mines are located trend nearly northeast. In the southern part of the district, however, there is a general change in direction, and the faults curve to the south as they approach Ohio River.

Most of the faults are not simple fractures but consist of sheared zones of variable width, particularly where weak beds of the
Chester series are involved in the faulting. Subordinate slickensided slips are common on either side of the main fault planes, and "horses" or large displaced blocks occur along the faults at many places. The importance of side slips and subsidiary fractures is difficult to determine in the course of routine mining operations. Many of them are mineralized to some extent. Some important ore bodies have been missed because drifts were driven along the wrong leads; they were discovered later more or less by accident. Others as yet undiscovered probably exist close to old workings. Although the major faults are roughly parallel, they are quite irregular in detail, and underground workings show that they follow undulatory courses and locally change direction sharply for short distances. At some places they join each other at acute angles and thus produce an anastomosing pattern for the district as a whole. Such junctions are likely to be highly fractured and if displacement along the faults involved is not too great, mineralization may be unusually important. On the other hand, if a fault of moderate displacement splits into several small faults near its junction with another, only slight mineralization ordinarily may be expected. Cross faults of relatively minor displacement are common although they are often unrecognized in the mines. Mineralization along them is generally slight.

Most of the faults in the Rosiclare district are downthrown to the west and possess planes inclined westward at angles varying from 70 to 80 degrees, although they are locally vertical and at some places overturned. The principal exception is the Blue Diggings fault which is downthrown to the east and whose plane dips eastward.
rarely more steeply than 65 degrees and locally flattens to about 45 degrees. Southward on the property of the Alcoa Mining Co. this fault splits at several places, its displacement is divided along two or more distinct fault planes and it becomes nearly vertical.

Displacement along the faults of the Rosiclare district varies from infinitely slight to 650 feet or more. The smaller faults are, of course, exceedingly difficult to recognize and trace, and many of them may never be discovered. The general locations of the larger faults, however, are fairly well known although the details of their relationships outside of the mined or drilled areas have not been accurately determined. Amount of displacement, however, is of little importance in connection with mineralization except that the smaller faults (25 feet or less) have not been well mineralized, and abundant shaly gangue along the larger faults may have interfered locally with the passage of mineral-bearing solutions.

**Stratigraphy**

The following succession of formations outcrops at the surface or has been penetrated in the mine workings of the Rosiclare district:

- **Upper Mississippian (Chester series)**
  - Vienna-Menard limestone and shale
  - Tar Springs sandstone and shale
  - Glen Dean limestone and shale
  - Hardinsburg sandstone
  - Golconda shale and limestone
  - Cypress sandstone
  - Paint Creek shaly sandstone
  - Bethel sandstone
  - Renault limestone and shale

- **Lower Mississippian (Iowa series)**
  - Ste. Genevieve formation
  - Levis limestone
  - Rosiclare sandstone
  - Fredonia limestone
  - St. Louis limestone

Outcrops in the district are in general poor, and the following brief descriptions are based mainly on the study of diamond drill cores.

- **Vienna-Menard.** — The Vienna and Menard limestone and shale formations are normally separated by the Waltersburg sandstone, but in the Rosiclare district they cannot be satisfactorily distinguished because the Waltersburg is poorly developed and is not known to crop out. Here these formations are probably 100 or more feet thick. Black carbonaceous shale is conspicuous in the lower part. Above this probably occurs some interbedded limestone and shale which is succeeded above by sandy shale that represents the Waltersburg. The main upper part, corresponding to the Menard, is largely composed of greenish to gray more or less calcareous shale with interbedded limestone layers up to 3 feet thick. The limestone is generally dark gray and fine grained but weathers characteristically to light gray mottled with large splotches of light rusty brown.

**Tar Springs.** — The Tar Springs sandstone is probably between 100 and 150 feet in thickness. Much of its upper part is thinbedded and shaly although some fairly massive fine-grained sandstone may be present. Near the top is a persistent thin coal bed up to 6 inches thick with medium gray underclay that shows numerous root markings. The middle part of the formation is predominantly shaly, and as much as 40 feet of dark gray to black sandy and somewhat micaceous shale may be present with interbedded thin sandstone lenses. Much carbonaceous material is contained in these beds, including more or less well preserved plant fossils and possibly one or more discontinuous thin coal seams. The lower part of the formation is mainly fine-grained light gray massive sandstone.

- **Glen Dean.** — The Glen Dean formation is probably about 60 feet thick and consists of interbedded limestone and shale. The limestone appears to be most abundant and to occur in thicker beds in the upper part of the formation. It varies from medium to dark gray in color and from coarsely to very finely crystalline in texture. Some oolites may be present. Shale occurs as partings between limestone layers and as beds several feet thick, particularly in the lower part of the formation. The shale is generally dark gray and varies from argillaceous and even-bedded to siliceous or cal-

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**FLUORSPAR DEPOSITS OF ILLINOIS**
careous and is indistinctly bedded with thin impure limestone layers.

**Hardinsburg.** — The Hardinsburg sandstone is probably 100 feet or less in thickness. It is mostly fine grained and light colored. The upper beds are more or less shaly and some dark gray sandy shale may be present in the midst of the formation. The lower part is generally the most massive, and near the base the layers are unusually even bedded.

**Golconda.** — The Golconda formation varies from 125 to about 180 feet in thickness, is thinnest to the north, and consists of about one-third limestone and two-thirds shale. Limestone becomes more abundant upward and the most prominent bed, about 10 feet thick, occurs near the top. The shale members are thicker below, and the lower 25 feet contains little if any limestone. Lithology of both shales and limestones is very similar to that of the Glen Dean. Some maroon shale may be present near the middle of the formation and black shale may occur a little higher.

**Cypress.** — The Golconda grades downward through transitional sandy shale to the Cypress sandstone which is about 80 feet thick. This sandstone is mainly fine-grained, light gray with darker gray streaks and some dark shaly partings, particularly in the upper part. A thin conglomerate containing dark shale pebbles may be present at the base.

**Paint Creek.** — The Paint Creek formation attains a maximum thickness of about 65 feet and appears to thin somewhat in the southern part of the Rosiclare district. Where fully developed a few feet of dark sandy calcareous shale and 1 to 3 feet of dark gray shaly limestone are present at the top. The main part of the formation consists of about 40 feet of very fine-grained gray to dark gray even-bedded sandstone with some dark shaly partings. Between this and the above-mentioned limestone is about 15 feet of interbedded dark gray sandy shale and thin light gray, very fine-grained sandstone in uneven crinkly and minutely cross-bedded layers. At the base is 5 to 10 feet of similar interbedded shale and sand in thin even layers.

**Bethel.** — The Bethel is commonly about 85 feet thick but thickens a little in the southern part of the Rosiclare district. It consists of fine-grained sandstone, medium dark to light gray in color and commonly more or less speckled. Some shale partings are present, particularly near the top. A thin conglomerate with shale and limestone pebbles may occur at the base.

**Renault.** — The Renault varies from about 60 to 80 feet in thickness and consists principally of limestone, most of which is gray crystalline to finely granular with some dark gray beds and other beds that are more or less shaly. Oolites may be present. Shale occurs in two or three beds about 5 feet thick in the lower half and also as thinner partings between limestone layers. The shale is characteristically greenish gray and may be noncalcareous or more commonly calcareous with thin impure limestone lenses. Some reddish shale is locally present.

**Levias.** — The Levias limestone is 30 to 40 feet thick and is mainly limestone, dark to light gray, fine to coarsely crystalline, and somewhat oolitic. Pink calcite crystals occur in variable abundance in the lower part and dark gray calcareous shale up to 2 feet thick may be present in the upper part.

**Rosiclare.** — The Rosiclare is calcareous fine-grained sandstone, 15 to 20 feet thick. It is greenish to light gray in color and grades downward into a variable but thin greenish sandy shale. Some oolites may be present in the sandstone just above the shaly basal bed.

**Fredonia.** — The thickness of the Fredonia is estimated at about 200 feet. It is almost entirely limestone, light to dark gray in color and coarse to very fine-grained in texture. Oolites are fairly abundant. Richly oolitic layers in the upper part are unusually light colored but may be somewhat stained with black asphalitic bituminous matter. Some calcareous gray shale in thin beds may or may not be present. A thin finely sandy zone about 95 feet below the top is perhaps the local representation of the Spar Mountain sandstone member.
**St. Louis.** — The St. Louis limestone is believed to be at least 500 feet thick. It cannot be separated sharply from the Ste. Genevieve in drill cores because these formations grade imperceptibly into each other. In general, however, the St. Louis includes a larger proportion of dense dark-colored beds, and some of the limestone in the lower part is nearly black. Oolites are much less common than in the Ste. Genevieve. Some chert is present in the St. Louis and a few argillaceous or shaly beds occur in the middle and lower parts.

**IMPORTANT MINING PROPERTIES**

The properties in the Rosiclare district that were studied and reported on during the period 1942–1945 are as follows:

**Rosiclare mine and vicinity.** — The Rosiclare mine of the Rosiclare Lead and Fluorspar Mining Co. is historically the most important in the district. It is located on the Rosiclare fault and vein which have been known for more than 10½ years. This mine resulted from the consolidation of several separate shallow workings in the early years and has been continuously productive from the eighties to the present except for an interval between 1924 and 1940 when it was flooded. Not only was the Rosiclare vein more continuously and consistently mineralized than any other known in the entire Illinois-Kentucky fluorspar region, but in the Rosiclare mine mineralization continues importantly to a greater depth (absolute elevation) than is known elsewhere, and the base of the deposit has not yet been reached at the lowest mine level 720 feet below the surface.

**Blue Diggings mine and vicinity.** — The Blue Diggings mine, located on the fault and vein of the same name, was one of the early important producers in the Rosiclare district. In about 1924, however, it was considered to be largely worked out and operations ceased. Subsequently this property was acquired by the Aluminum Ore Co. and an extensive program of diamond drilling disclosed the presence of additional important ore bodies, mainly south of the deposits that had been worked previously. The old mine was thereupon reopened and the new ore bodies were developed rapidly, in time to be of outstanding importance in satisfying the greatly increased demands for fluorspar occasioned by World War II. The company name was changed to Alcoa Mining Co. in 1948.

The Blue Diggings mine is of particular interest geologically because it is located upon a fault whose inclination and throw is opposite to that characteristic of the other faults near Rosiclare. Also, in part, it is much less nearly vertical. The geological conditions along and adjacent to the Blue Diggings fault are exceptionally well known because of extensive diamond drilling and underground geologic study that has been continuous since operations here were renewed.

**Good Hope-Extension mine.** — Also located on the property of the Alcoa Mining Co. are the southern workings of the Rosiclare vein. Here the Good Hope and Extension mines were active until 1924 when by mishance they became flooded and they have never been reopened. Although considerable ore is known to remain in this part of the vein, little or no new information is available and consequently this part of the Rosiclare district was not studied or reported upon as fully as other properties at Rosiclare.

**Daisy mine and vicinity.** — The Daisy mine worked deposits along the Daisy and Blue Diggings veins which dip toward each other and probably meet a short distance below the deepest mine level at 800 feet. Ore here was discovered as the result of lateral diamond drilling from the Rosiclare mine. Important mineralization on the Blue Diggings fault and much of that on the Daisy fault do not extend closer than 250 feet to the surface. Geological conditions in this mine suggest that other similar faults may also have commercial ore bodies at shallow depth which do not continue to the surface, so they cannot be discovered by surface observations or prospecting.

In 1941 the main deposits in this mine were worked out, and subsequent production has come from subordinate workings on the north part of the Daisy fault.
A program of diamond drill exploration below the lowest working level at the Daisy mine was conducted by the U. S. Bureau of Mines in 1945-46. Borings which encountered the Blue Diggings vein at depths of 1,010 to 1,260 feet below the surface showed it to be from 5 to 45 feet wide but without fluorspar. Apparently the Daisy vein joins or is cut off by the Blue Diggings vein below the mine workings.

**Hillside mine and vicinity.** — Mineralization on the Hillside fault was discovered by diamond drilling from the Daisy mine. Important production began in 1922 and continued until about 1937 when the deeper stopes above the 550- and 650-foot levels were worked out. Smaller subsequent production was obtained mainly from splits at the south end of the vein and by the removal of arches above the 250-foot level. This mine encountered a 34-foot vein, the widest vein of fluorspar mined anywhere in the entire Illinois-Kentucky fluorspar region.

Deep diamond drilling by the U. S. Bureau of Mines in the Daisy mine included several borings that cut the Hillside vein from 790 to 1,360 feet below the surface and below the existing workings. The vein was found to be 5 to 18 feet wide and barren of fluorspar except for a trace in one boring.

**Dimick mine and vicinity.** — This mine is more interesting for geologic than for economic reasons. Production has been small but it is located on or near a structural focus where four faults, two from the south (Daisy and Hillside) and two from the north (East Dimick or Eureka and West Dimick or Hawkins) converge.

**Eureka mines and vicinity.** — The Eureka mines are a series of small workings located on several relatively minor intersecting faults which continue the East Dimick fault to the south. Displacement appears to become progressively less to the northeast, and production has been small. The Hawkins fault to the west, which is an extension of the West Dimick fault, has a greater displacement than any other in the Rosiclare district. A small amount of ore has been obtained from a single shallow shaft.

**CAVE IN ROCK**

**Definition**

The Cave in Rock fluorspar mining district lies north and west of the town of that name on Ohio River in the eastern part of Hardin County. The principal mines and known but undeveloped deposits occupy an area which includes part or all of secs. 23 to 27 and 33 to 36, T. 11 S., R. 9 E., and secs. 2 to 4, T. 12 S., R. 9 E., and which centers about 3½ miles northwest of Cave in Rock. There are a number of smaller mines and deposits outside the principal belt outlined above which are of the same general character and therefore should be included in the district. In the large sense, therefore, the Cave in Rock district may be considered to be bound on the south by Ohio River, on the northwest by the Peters Creek fault zone, and to extend westward so far as to include the deposits on Lead Hill and the Tower Rock tract and eastward to include the Minerva mine and the Winn, Underwood, and Frayer properties.

Access to the district is by roads only, the nearest rail connection being at Rosiclare. Illinois State Highways Nos. 1 and 146 pass through the district.

**Importance**

The Cave in Rock district is an important source of fluorspar, having produced an estimated 813,400 tons or 22 percent of the total 3,676,113 tons shipped from Illinois mines in the years 1880 through 1947. All but a few thousand tons were produced in the years following 1916, although the presence of fluorspar deposits was known for many years prior to that time. As a result of finding new deposits through extensive prospecting and development of new mines, the district has risen in recent years to the status of a major producer, as indicated by the fact that in the period 1940 through 1947 it yielded an estimated 548,100 tons or 44 percent of all
fluorspar shipped from Illinois. Fluorspar mining operations are or have been conducted by eight companies within the past several years. Four of these, namely the Ozark-Mahoning Co. (formerly Mahoning Mining Co.), Minerva Oil Co., Crystal Fluorspar Co., and Victory Fluorspar Mining Co., are the major producers; the other four, Austin, Grischy, Inland Steel Co. (formerly Hillside Fluor Spar Mines), and Fluorspar Products Co., mine or formerly mined on a smaller scale. A ninth company, the Alco Lead Corporation, formerly operated a lead mine and mill in the district but was not a fluorspar producer. The principal fluorspar mines are the West Green, W. L. Davis-Deardorff, W. L. Davis No. 2, East Green, A. L. Davis (all operated by the Ozark-Mahoning Co.), Minerva, Crystal, and Victory.

The district is also important for zinc and lead and for fluorspar crystals of specimen quality. The W. L. Davis-Deardorff mine was the first in which zinc and lead minerals constituted an important part of the ore, but zinc is also of importance in the Minerva mine and to a lesser extent in the West Green mine. The ore in the partially developed East Green mine carries zinc, and it is fairly certain that the district will continue to produce zinc for some years. Except in the Davis-Deardorff mine and the Patrick mine of the Alco Lead Corp., lead minerals are usually of minor value as compared with fluorspar and zinc. Many beautiful fluorspar crystals have been found here, particularly in the Victory, Crystal, W. L. Davis-Deardorff, and West Green mines. Although of relative insignificant value as compared with the value of all fluorspar produced, these specimens are of great interest to collectors and museums and rank with the finest in the world.

The district has undeveloped and partially developed reserves of fluorspar apparently capable of supporting large-scale production for many years. There is also a possibility that new deposits will be discovered northeastward along the strike of the present major productive area or in stratigraphic positions either above or below those exploited at present. Either eventuality, if realized, would be an example of history repeating itself, for all of the deposits discovered since 1939 have been along the general strike of the older deposits which were located through showings in outcrop, and several are at stratigraphic levels above and below the one principal level known in the early days.

By its example this district has stimulated an interest in exploration for similar replacement fluorspar deposits elsewhere in the Illinois-Kentucky field. The first discovered deposits in the Cave in Rock district cropped out or occurred nearby at shallow depth. The success of later drilling in locating new deposits and the knowledge of the character and geology of the deposits gained through the development of the mines have led many to consider the possibility that similar deposits may lie hidden at depth in unprospected areas elsewhere in the field.

**Topography**

The southern part of the district is a gently rolling limestone plain dotted with numerous sinkholes and having an elevation ranging from 400 to 460 feet above sea level. The plain has a strong system of underground drainage (as evidenced by the large number of sinks) and practically no surface streams except in the southernmost part close to Ohio River. Bounding the plain on the north and northwest is a prominent 200- to 250-foot bluff, one of the most prominent topographic features of the district. The bluff exposes one of the principal ore horizons and thus led directly to the finding of fluorspar in outcrop and facilitated early exploration at that favorable horizon.

The bluff is capped by resistant Bethel sandstone, the lowest sandstone member of the Chester series of alternating sandstone and limestone-shale formations. The topography northeast of the Bethel bluff consists of a series of linear southeast-northwest valleys and dissected ridges reflecting the regional southeast-northwest strike in that
area and the presence of alternating resistant sandstone formations (ridges) and less resistant limestone-shale strata (valleys). The ridges are asymmetrical with steep slopes on the southwest and gentler back slopes on the northeast approximating the angle of regional dip. The series of linear ridges and valleys is terminated on the northeast by a final 200-foot bluff capped by massive basal sandstone of the Pennsylvanian system at an elevation of 600 to 660 feet, and on the northwest by the trace of Peters Creek fault system, beyond which downfaulted lower Pennsylvanian sandstone strata also form a bluff at some places. Erosion in the area of ridges and valleys has now cut deep enough to expose any of the principal ore horizons, and all of the deposits therein have been discovered by prospect drilling.

Three topographic features of the district, namely Lead Hill, Spar Mountain, and the "Sink" merit special mention. Lead Hill, scene of some of the earlier mining in the district, is a narrow elongate hill whose crest has an elevation of 650 feet and which is capped by the Renault formation. It is an erosional outlier of the bluff which is elsewhere capped by Bethel sandstone. Spar Mountain is a lobate southward extension of the Bethel bluff and was also the locale of early mining operations. The Crystal mine and the group of Austin deposits are disposed around its lower slopes, and the Victory mine shafts and mill are located near the southern rim of its crest. The "Sink" is the local term for a large basin-like sinkhole occupying approximately 800 acres close to the north edge of the limestone plain south of the Crystal mine. Periodically its underground outlet becomes clogged and the basin fills with surface runoff water, which remains for a period sometimes as long as two or three years, terminated by a swift outflow when the subsurface outlet once again is opened by natural processes.

One further point with regard to topography warrants discussion, namely its questionable relation to underlying ore deposits. Minor topographic features such as alignments of the courses of gullies, lines of small sinkholes, wet-weather springs or seeps, and marked reentrants in bluff lines have been used in the district as guides to prospecting under the assumption that such features might be indicative of favorable structures such as faults and zones of strong fracturing of the type associated with the known deposits. This type of geological reasoning is good, but accumulated experience suggests that there is usually no more than a coincidental accordance of those minor topographic features and the courses of linear fluor spar deposits.

**Stratigraphy**

The geological formations exposed within the Cave in Rock district are of sedimentary origin, consisting of sandstones, limestones, and shales of the Mississippian system, sandstones of the Caseyville group of the Pennsylvanian system, unconsolidated Pleistocene alluvium and loess, and Recent soils. Igneous rock of the type known elsewhere in Pope and Hardin counties has been found at only one place in the district, the workings of the Crystal mine adjacent to No. 4 shaft.

The lowest formation exposed is the St. Louis limestone. Southeast of Peters Creek fault zone, owing to the interaction of topography and structure, the various formations crop out in successive belts from oldest on the south bordering Ohio River to youngest on the northeast in the vicinity of the Minerva mine. In the downfaulted block northwest of Peters Creek fault zone only upper Chester and Pennsylvanian rocks are exposed. The formations present, with brief notes as to salient lithologic characteristics and thicknesses typical of the district, are as follows:

**Geologic Formations**

**Pennsylvanian system**
- **Pottsville series**
  - **Caseyville group**
    - Sandstone and conglomerate, fine to coarse grained, white to light gray and buff. Thickness dependent on topography.

**Mississippian system**
- **Chester series**
  - **Kinkaid, Deagonia, Clore, and Palestine formations**
    - Not known in outcrop, but one or more may be present locally. These formations appear to have been removed by pre-Pennsylvanian erosion in northeast portion of the area.
Menard limestone
Fine grained, light to dark limestone, some cherty, with beds of shale. Thickness probably 100 to 125 feet.

Waltersburg sandstone
Not definitely recognized in outcrop. Mostly gray siltstone and sandy shale at top, grading through light gray quartzitic sandstone to dark gray shale at bottom. Thickness 40 to 60 feet.

Vienna limestone
Not definitely recognized in outcrop. Limestone, white and oolitic to dark grayish brown and fine to very fine grained, argillaceous and slightly cherty, with a dark gray shale at top in some places. Thickness 10-20 feet.

Tar Springs sandstone
Very fine grained, light gray to yellow-brown sandstone with silty shale streaks. Thickness probably 100 to 120 feet.

Glen Dean limestone
Gray calcareous shale at top grading down into limestone with shale streaks. Upper 20 to 30 feet of limestone is light colored, coarsely crystalline, and fossiliferous; lower part mostly fine grained and shaly. Thickness 60 to 70 feet.

Hardinsburg sandstone
Fine to very fine grained, light gray to white sandstone with abundant shale. Thickness 80 to 120 feet.

Golconda formation
Succession of limestone and shale beds, more limestone at top and more shale toward the bottom. Persistent bed of red and green shale 6 to 10 feet thick occurs 45 to 65 feet below the top. Thickness 125 to 155 feet.

Cypress, Paint Creek, and Bethel formations
Cypress is fine to very fine grained light gray sandstone with locally abundant shale and siltstone. Paint Creek is thin, with variable lithology, mostly interlaminated thin layers of sandstone and shale. Bethel is fine to coarse grained, light gray sandstone with minor shale and siltstone. Group thickness 200 to 240 feet.

Renault formation
Consists of upper limestone ("Downeys Bluff"), middle shale, and lower limestone (together termed "Shetlerville"). Limestone strata are mostly dark gray, some oolitic, dolomitic, shaly and sandy; basal beds characteristically sandy or silty. Shale commonly green and gray, locally red. Thickness 45 to 80 feet.

Iowa series
Meramec group
Ste. Genevieve formation
Levias limestone member
Dominantly light-gray oolitic limestone beds, some with pinkish calcite crystals. Thickness to 35 feet.
Rosiclare sandstone member
Mostly very fine-grained, grayish-green calcareous sandstone, commonly with green shale at bottom. Thickness 25 to 45 feet.
Fredonia limestone member
Light colored oolitic or partly oolitic beds at top grading down into light buff to dark brown and dark gray mostly fine grained beds below. Strata near base are usually cherty. Thin local shale strata, usually green or gray-green are common. A bed ranging from very fine grained and often crossbedded greenish sandstone to buff or brown very sandy limestone to a thin shale is locally present 40 to 65 feet below the top of the member. This bed is known in the district as the "sub-Rosiclare" or "Spar Mountain" sandstone. Thickness of Fredonia probably about 175 feet.
St. Louis formation
Dominantly fine to very fine grained dark gray cherty limestone, including some dolomitic strata. Thickness not known from drilling or outcrop, but variously estimated to be 350 to more than 500 feet.

Characteristics of the Deposits

AREAL AND STRATIGRAPHIC DISTRIBUTION

The larger deposits occupy a rectangular area 4,000 to 5,000 feet wide and 5 miles long trending N. 50° E. in a direction generally parallel to Peters Creek fault zone and at a distance of 1,800 to 4,600 feet southeast of the latter (fig. 15). This area, which may be referred to as the principal mineralized belt, contains the Minerva, Crystal, and Victory mines, and the Ozark-Mahoning, Austin, Grischy, and Fluorspar Products groups of mines. The deposits which lie outside the principal mineralized belt are the Winn, Underwood, Frayer, Hill, Tower Rock, and those in the vicinity of the Patrick lead mine, all south of the principal belt, and the Martin and Eureka prospects along the trace of Peters Creek fault north of the principal mineralized belt.

The deposits of the Cave in Rock district are of the bedded-replacement type in limestones of Mississippian age, and like many deposits of that type the world over, they occur predominantly at certain favored stratigraphic positions. Within the principal mineralized belt there are four of these favored positions within a vertical distance of approximately 190 feet, namely (1) the Spar Mountain sandy bed, (2) various higher strata in the Fredonia limestone and especially the uppermost 15 feet, (3) the upper part of the Levias limestone and basal portion of the Renault limestone, and (4) the uppermost part of the Renault limestone. The principal deposits are at positions (1), (2), and (4). The few de-
posits south of the principal mineralized belt occur at positions lower in the Fredonia limestone or in the upper part of the St. Louis limestone.

A few years ago only the top of the Fredonia limestone was considered to be of any importance, but subsequent drilling has disclosed very important deposits at both higher and lower levels. There remains the question, therefore, of whether additional deposits remain to be discovered at still higher and lower stratigraphic positions. The Fredonia limestone below the "Spar Mountain" sandy bed has been but little tested with the drill and the St. Louis limestone essentially not at all, even though small bedding-replacement deposits are known to occur in those lower rocks. The Chester strata above the Renault formation have been penetrated frequently by borings, but so far only traces or minor shows of mineralization have been found in the higher beds, mostly in the Bethel and Cypress sandstones. In view of the past history of the district, however, it is quite possible that future prospecting will discover minable replacement deposits in beds other than those now most productive in the district.

In addition to the replacement deposits discussed above, a few deposits of residual ore have been found and mined. These were formed by erosion and weathering of outcropping replacement deposits along the foot of the prominent bluff capped by the Bethel sandstone described above. The fluor spar occurs as fragments that range from sand size to large boulders mixed with masses

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**Fig. 15.—Mineralized trends in Cave in Rock district.** (From Economic Geology, vol. 44, p. 607, 1949.)
of limestone and insoluble caprock in reddish and yellowish residual clay. Although none of the several deposits has been a large producer, the fluorspar has been of high purity owing to the natural leaching of the accompanying limestone, and has been easily recovered by simple crushing and log washing.

**FORM AND STRUCTURAL RELATIONS**

The ore deposits of the Cave in Rock district are typically elongate and lie essentially parallel to the bedding of the enclosing limestone. Single ore bodies have been mined for distances approaching 2,000 feet along the strike and 480 feet normal to it, although lengths of 200 to 1,500 feet and widths of 50 to 200 feet are more common. For the most part the ore occurs in individual beds a few inches to several feet in thickness. Usually there are several such beds 1 to 3 feet thick, in places separated by poorly or nonmineralized beds or shaly partings that range from a fraction of an inch to several feet in thickness. The aggregate thickness of ore in the major deposits commonly ranges from 4 to 15 feet, although in restricted areas thicknesses up to 30 feet have been found. The deposits wedge out at their margins as the number of individual ore beds decreases. Generally the lower beds disappear first, the uppermost last. The boundaries of the deposits as indicated by the extent of the mine workings are those at which ore becomes too thin to mine profitably, and mine maps show them to be generally irregular.

The deposits follow the course of groups of joint-like fractures and minor pre-mineral faults trending N. 45 to 60° E. and N. 30 to 85° W., which from their close association with the deposits are considered to have been the channelways through which mineralizing solutions gained access to the replaced beds. Many small deposits, such as a

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Test borings

- Trace or less than two feet of mineralized rock
- More than two feet of mineralized rock
- Mine shaft
- Dip of roof
- Fault and direction of dip
- Prominent fracture
- Property line

Mine workings shown as of August 23, 1944

Fig. 17.—Map of A. L. Davis mine, Ozark-Mahoning Company, Hardin County, Ill.
number of those on the Fluorspar Products Co. property (figure 16), consist of interconnecting ore bodies along a number of individual intersecting fractures, whereas larger deposits commonly include several main parallel fractures with occasional side branches that follow intersecting joints. Although such individual joints usually have no great length, a narrow zone comprising a number of such joints, but acting as one, may persist for hundreds of feet. These fractures are commonly filled with small veins of massive fluorspar a fraction of an inch to several inches wide. They extend through the deposits from bottom to top and sometimes into the floor and roof as well, forming the miner's "floor veins" and "roof veins."

The faults are all of small displacement, commonly a few inches to 10 feet, with a recorded maximum of 20 feet, and are prominent principally in the more recently developed deposits. In general the faults have greater lateral persistence than the joints; for example fault II in the Davis-Deardorff mine has been followed for 1,300 feet and may persist several hundred feet farther. The faults characteristically have maximum displacement at some central point and progressively smaller displacement toward either end. Especially in the faults with small displacement, there is a noticeable tendency for the movement to have been distributed along several parallel breaks in a zone up to 10 feet wide, although in some instances all of the movement was confined to one major break. It is not definitely known that any of the faults visible underground extend to the surface a few hundred feet above, and it may be that they die out rapidly vertically. Faults with only a foot or so of displacement have been observed to die out within a vertical distance of 30 to 40 feet.

Minor post-mineral faulting has taken place in the Victory and Davis-Deardorff ore bodies. The amount of movement, evidenced by brecciated and slickensided fluorspar, in all instances appears to have been slight. In general, however, the pre-mineral faults and joints all appear to have been formed at about the same time. Based primarily on their association with one or the other type of fracturing, the principal replacement deposits fall naturally into two categories, those disposed more or less symmetrically on either side of a centrally located zone of joint-like fracturing or minor faults, and those lying on one side, usually the upthrow or footwall side, of a minor fault. The first of these is exemplified by the more southerly of the northeast-trending ore bodies in the Crystal mine (plate 6), and the second by the A. L. Davis ore body, figure 17. Schematic cross sections of the two types are shown in figure 18. In deposits of the central-fracture type the ore is thickest close to the center line and thins toward both margins, whereas in the fault-bounded type it is thickest next to the fault. In some deposits of this kind, principally those in which the displacement is 5 feet or less, a small amount of ore is also present on the other side of the fault, as shown in the diagram. A crescentic cross section is characteristic of the central-fracture type of deposits which have the shaly and relatively incompetent Rosiclare sandstone for a caprock, but so far as limited mine exposures permit observation, it is not so marked in those which are capped by the more competent Bethel sandstone. Mine exposures indicate a slight dip of the roof from the margin toward the fault in deposits bounded on one side by a fault. The inward dip of the roof in central-fracture deposits gives them the appearance of lying in the troughs of synclines, and exploratory drilling has demonstrated that synclinal depressions above the mineralized areas are of general occurrence.

In addition to the two main types of deposits there is a third general group which might be termed "hybrid" deposits because they are a cross between typical fissure vein deposits and typical flat-lying replacement deposits. A number of such deposits have been mined in the Cave in Rock district but outside the principal mineralized belt, such as those on the Hill and the Underwood properties, and also elsewhere in the county as in the Crabb and Red mines in the Empire district and on the Sheldon property.
near Eichorn. The features characterizing all are a narrow vertical or near-vertical vein of fluorspar with one or more small replacement ore bodies extending laterally on one or both sides of the vein at the intersection with beds favorable for replacement.

Structural features within the principal mineralized belt are shown in plate 7, by means of contours that represent the contact of the Bethel and Renault formations, which is the top of the uppermost principal ore horizon. The Bethel-Renault contact was chosen for contouring because it is readily identifiable and because more borings penetrated it than any prominent lower stratigraphic marker.

Peters Creek fault system, which bounds the area on the northwest, is one of the major fault zones of the fluorspar district. Its downthrow is to the northwest and amounts to at least 550 feet and probably exceeds 1,000 feet locally. The movement apparently was confined to one principal fault plane in the northeast portion of the district but was distributed across several branch faults in the southwest portion. Prospecting thus far has revealed no commercial ore deposits along Peters Creek fault, although it is reported that a few tons of fluorspar with some lead and zinc were mined during exploratory work at the Martin and Eureka prospects.

Southeast of Peters Creek fault the strata have a general north to north-northeast regional dip of approximately 2 3/4 degrees which is interrupted by a number of northeast- and northwest-trending structures, most of which appear to be small but narrow and steep elongate synclines. Some of the structures interpreted as synclines may actually be narrow fault-bounded grabens like the shallow graben southeast of the W. L. Davis No. 1 shaft at the Davis-Deardorff
mine, which is shown in underground workings to be bounded by faults. There is generally a complete absence of complementary and similarly well-marked anticlines.

The best defined anticline in the area is that which trends northwestward through the north half of the NE 1/4 sec. 34 from the W. L. Davis No. 2 mine, and which might be considered to extend southwest with somewhat less expression into the area adjacent to the A. L. Davis mine in the NW 1/4 sec. 35. It is asymmetrical, having a steeply dipping southwest flank and a gentle dip coincident with the regional dip on the northeast flank. The sharp fold on the southwest flank may actually become a fault in the area west-northwest of the W. L. Davis No. 2 mine, and it is possible that the fault which borders the A. L. Davis mine is a related feature with the same strike but offset a short distance to the northeast. This anticline appears to pre-date the Davis-Deardorff graben which, with its synclinal extension to the northeast, seems to cut across the anticline and the several synclines which indent its northeast flank, and hence may represent a period of mild folding that preceded the general fracturing and faulting most in evidence.

Besides the two structures just discussed, the other major northwest-trending structures are the syncline in the vicinity of the West Green mine and the sharp fold in the northeast part of the Crystal mine. In both these places the structure is shown as one of folding for it is not certain that the faults present in the top of the Fredonia limestone, as drawn on the individual mine
maps, persist as high as the Bethel-Renault contact on which the structure contours are drawn.

Study of the map shows that there is a strikingly close relation between the synclines and the areas of mineralized ground. Almost every boring which encountered more than a minor amount of mineralized rock, and most of those which did encounter only a minor amount, is within or close to one of the synclines. For example, the syncline which trends northeast through the East Green mine in the NE 1/4 sec. 35 and the SW 1/4 sec. 25 is reproduced in figure 19 with the area of main mineralization shown by a cross-hatched pattern. The structure as mapped is 5,400 feet long, has a width of 300 to 700 feet, and a depth of 10 to 40 feet. The area of strongest mineralization coincides closely with the course of the syncline.

Cross sections through the foregoing and other similar synclines where numerous test borings make accurate representation possible disclose the fact that the synclinal structures are unusual in being confined to certain strata including the replaced beds and those for some distance above them. The common relations demonstrated in greater or less degree of perfection in practically every section that may be drawn are portrayed in figure 20, which is a cross sec-
tion through the East Green syncline at the place indicated in figure 19. The contact between the Bethel and Renault formations dips inward in synclinal fashion from the barren area on either side toward the central area of mineralization. The inward dip is mirrored by formational contacts down to the top of the Fredonia limestone and upward for some distance into the Bethel sandstone, but still lower and higher in the section the strata continue their uniform slight dip from one side to the other with no reflection of the synclinal structure between. Such structures are believed to have resulted from a net loss in rock volume during the mineralizing process, and this is discussed more fully in the section on the origin of the ore deposits.

Records of drilling demonstrate that the association of synclines, thinned strata, and mineralized ground is a general feature of the district. The results of a statistical
study of variations in the interval from the base of the Bethel sandstone to the top of the Fredonia limestone in barren and mineralized areas are shown in the three histograms on the left side of figure 21. Each bar in the histograms records the number of borings in which the reference interval between the base of the Bethel sandstone and the top of the Fredonia limestone is a specified thickness.

In the topmost histogram, which illustrates 383 borings in barren ground, the median thickness is 115 feet, as indicated by the black bar. In 46 percent of the borings the thickness was less, and in 45 percent of the borings the thickness was greater, than the median thickness. For 121 borings in which the Renault and/or the Levias limestones were strongly mineralized but the Fredonia was barren, the middle histogram shows that 86 percent of the intervals had lesser and 11 percent greater thicknesses than the median thickness in barren ground.

For 219 borings in areas where the Fredonia was mineralized and the Renault and Levias were not, the bottom histogram shows that 41 percent of the intervals are less and 53 percent are greater than the median barren thickness. Possible explanations for each situation are shown in the diagrams to the right of each histogram. Shown at the top is the original state in which the thickness of the reference interval is 115 feet. In the middle diagram mineralization in the top of the Renault and at the Renault-Levias contact has resulted in thinning of adjacent limestone beds and consequent sagging, and therefore the reference interval is less than it was originally. The bottom diagram illustrates how the reference interval is increased where the Fredonia has been mineralized and thinned but the Renault and Levias have not been affected.
Closely related to the broad large-scale synclines described above are smaller structures indicative of marked collapse-brecciation present in parts of some replacement deposits. In magnitude these range from the minor shale-sandstone breccia common in the upper foot or so of many deposits to linear zones as much as 25 feet wide, 10 feet or more deep, and several hundred feet long, in which large and small fragments of caprock and of more or less replaced limestone form a coarse breccia in which the interspaces may be open, partially filled, or completely filled with fluor spar and calcite.

The minor breccia at the tops of deposits appears to be caused by volume shrinkage attending the formation of the ore below, and the subsequent spalling of the caprock into the opening thus produced, followed by more or less complete cementation by fluor spar and calcite. The linear zones appear to mark the courses of channelways in which the mineralizing solutions circulated most actively and removed much limestone by direct solution. The overlying and adjacent strata then collapsed into the resulting opening, perhaps progressively as the limestone was removed, in such a way that the fragments incline downward and inward toward the center of the structure, figure 22.

Convincing evidence that the mineralizing solutions dissolved beds or parts of beds of limestone without compensating deposition of fluor spar is frequently observed along margins of deposits.

MINERALOGY

Fluorspar (commercial name for fluo­rite), sphalerite, and galena are the valuable minerals of the deposits. The common accessory minerals include calcite, quartz, barite, chalcopyrite, pyrite, marcasite, wisterite, strontianite, smithsonite, cerussite, and malachite. Traces of pyromorphite have been found in the mill concentrate from the Patrick lead mine. Petroleum and bitumen are of widespread occurrence.

Fluorspar occurs in coarse- and fine-grained layers in banded replacement ore, as disseminated grains in partly replaced rock, as cubic crystals of large and small size in crystal-lined cavities, as massive bodies of various shapes within the ore bodies, and as veins in the ore and the adjacent strata above and below the ore. Some is colorless, white, or gray, but much is tinted various shades of purple, yellow, or rose, with blue and green varieties much less common. Zonation of color parallel to the cube faces is conspicuous in many crystals, the commonest arrangement being a purple or blue exterior around clear or yellow cores. Multiple thin bands of color are common in crystals. Often the thickness of the colored zone is different on the several cube faces, a condition apparently resulting from greater rates of crystal growth in some directions than others, probably the directions from which the feeding solutions came. Although the surfaces of some crystals are glassy smooth, those of most crystals are more or less irregular in detail, due to the fact that the surfaces grew, at least in the final stages, by coalescence of many adjacent small cubes. Individual crystals of considerable size are occasionally found and highly prized by collectors. One such crystal in a group from the Crystal mine measures 12½ inches on an edge.

Sphalerite, although practically lacking in many deposits, is sufficiently abundant in others, such as the Davis-Deardorff and Minerva mines, to warrant separate discussion. It occurs principally as a replacement of limestone in the fine-grained layers of banded ore. Crystals larger than one-quarter of an inch in diameter are uncommon. The mineral is dark brown to black, suggesting a fairly high iron content. Cadmium and gallium occur in sphalerite from the Davis-Deardorff, West Green, and Minerva mines, and probably in others as well. Assays reported to the Ozark-Mahoning Company, operators of the first two mines, showed 0.33 percent cadmium as the arithmetic average of 13 carloads of sphalerite concentrates shipped at the rate of 3 cars a month. Individual samples contained 0.28 to 0.40 percent cadmium. The amount of

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gallium present is not known, but it is reported to be great enough to cause some trouble in the electrolytic refining of the zinc metal from the sphalerite concentrates. It is said that sphalerite concentrates from the Minerva mine commonly contain from 0.8 to 1.0 percent cadmium.

Galena is more widespread in its occurrence than sphalerite, but like the latter it is abundant enough to pay for its systematic recovery in only a few deposits. It is believed that the first deposits worked in the district were exploited for their yield of lead. The mineral occurs for the most part as well-crystallized masses from one-fourth to 3 inches in diameter in coarse-grained layers of banded ore and in crystal-lined cavities. It contains some silver, the general amount of which is indicated by an assay obtained by the Ozark-Mahoning Company on 2+ carloads of galena concentrates principally from the Davis-Deardorff mine, showing the presence of 7.38 ounces of silver per ton.

Calcite, other than in unreplaced remnants of limestone, is not abundant except locally. It occurs principally as crystals in vugs near the top and along the lateral margins of ore bodies. It is common also filling the center seam of the coarsely crystalline layers of banded ore. The crystals are often large, cleavage faces 6 inches or more across being relatively common.

Quartz varies greatly in abundance in different deposits. It occurs in two principal forms: as tiny doubly terminated crystals in the fine-grained layers of banded or disseminated ore and in the limestone adjacent to the ore in some deposits, and as small to large crystals encrusting other minerals in cavities. Quartz is very abundant in some deposits and practically absent from others. Some of the banded ore from the Shipp and Covert mine on Lead Hill and from the Cave in Rock mine consists of alternating bands of fluorspar and quartz, some of the latter being coarsely crystalline in some specimens and fine-grained in others. Because of its abundance in certain deposits and its close association with the ore, there is little room for doubt that quartz was introduced during the mineralizing process, but it is also possible that some of it was recrystallized from sand grains and silt particles originally present in the limestone.

Barite, like quartz, is sporadic in its occurrence, being exceedingly abundant in some deposits or parts of deposits and essentially lacking in others. It occurs principally as fine-grained aggregates replacing limestone, calcite, and fluorite, to a lesser extent as bunches of small bladed crystals in cavities, and rarely in stalactitic forms pendant from the roofs of cavities or crusting floors of cavities. At several places it has completely replaced the coarsely crystalline fluorspar in banded ore, leaving the fine-grained layers relatively untouched. In general the barite seems to have replaced massive or coarsely crystalline fluorspar preferentially over fine-grained fluorspar. Barite appears to have formed late in the period of mineral deposition, and to have been deposited principally along the top, bottom, and margins of the deposits.

Bastin and Currier considered barite a late secondary mineral. It seems more likely, however, that most of it is a late primary mineral, and only a very minor part, represented by the stalactitic and encrusting forms, is of secondary origin and formed as the result of groundwater deposition as erosion brought deposits near the surface. Some of the finest specimens of banded barite-fluorite ore yet discovered came from the Minerva mine at a depth of over 600 feet.

Chalcopyrite occurs as small crystals included in cubes of fluorspar and also encrusting the surface of fluorspar. It is present in every deposit but abundant in none. The crystals included in fluorspar have a nail-like form comprising an irregular Shank gradually increasing in size from the point toward the head, and a four-sided pyramidal head. The "nails" are usually oriented at right angles to the cube faces of the fluorspar crystals with their points toward and their heads away from the center. It is common for the heads of a number of the "nails" to lie in a common plane which represents an earlier cube face at one stage in the growth of the fluorspar crystal.
Pyrite occurs as small crystals, usually pyritohedrons encrusting fluorite and calcite, and also locally disseminated in ore, particularly in shaly partings.

Marcasite is present, though apparently not as commonly as pyrite. Small masses of crystals were observed on fluorite in a few places, and it has been reported as inclusions within fluorite crystals. Several specimens collected as marcasite proved, on the basis of X-ray diffraction patterns and positive chemical tests for copper, to be chalcopyrite.

Witherite has been found in the Minerva and West Green mines, and strontianite in the Minerva mine.\(^7\) The witherite occurs in grayish pseudo-hexagonal twinned mosaic crystals as much as 3 inches long and 1 1/2 inches wide in cavities in the ore. In some places it appears to be an alteration product of barite. The strontianite occurs as slightly pinkish bladed grains and brownish aggregates, both with radial structure. No well-formed crystals of strontianite were found.

Smithsonite, cerussite and anglesite, and malachite are found in small quantities in the oxidized portions of near-surface deposits. They result from groundwater alteration of sphalerite, galena, and chalcopyrite, respectively.

Pyromorphite occurs as tiny yellowish to bluish-green crystals along with galena, cerussite, and anglesite in oxidized ore in the Patrick open-pit lead mine.\(^8\) Although difficult to find in mine exposures, it shows up conspicuously on concentrating tables in the mill as a broad fringe of green material at the upper margin of the lead concentrate. The mineral is of secondary origin.

Petroleum forms small globular inclusions in fluor spar crystals and also fills cavities and open seams in the deposits. The oil within the inclusions is green by reflected light and orange by transmitted light, is strongly fluorescent, and gives rise to the petroleum odor characteristic of many freshly broken crystals. Gas bubbles out of the oil when inclusions are first opened.

"Live" oil oozes from joints in the Levias limestone in the sub-level haulageways in the Minerva mine and is sometimes encountered in prospect drilling. In places the Cypress sandstone contains considerable thicknesses of "dead" oil saturation. Occasionally small amounts of gas are encountered in the strata, particularly in the Rosiclare sandstone; in one churn drill boring the temporary gas pressure was sufficient to blow the water from the hole. Probably the oil trapped as inclusions within the fluor spar existed within the rocks at the time of mineralization and in some degree has persisted to the present time in the host rocks.

The mineral assemblage listed above is much the same as that present in the vein deposits of the Rosiclare district. The order of deposition of the primary minerals is also about the same, but apparently less primary calcite was available for later replacement by fluor spar. The general sequence of mineral deposition in the sulfide-rich Davis-Deardorff deposit is shown in figure 23. In the Minerva mine it is reported that calcite, barite, strontianite, and witherite, in that order, followed fluorite and sphalerite deposition and preceded late fluorite and quartz.\(^9\) Some variation from one deposit to another is to be expected.

A suggestion of mineral zoning is apparent in figure 15, with sphalerite (Zn) being relatively more abundant in the

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\(^9\) Grawe and Nackowski, op. cit., p. 331.
northeast three-fifths of the district and galena (Pb) and quartz (Qz) relatively more abundant in the southwest two-fifths. Quartz and galena are closely associated and appear to be more abundant in deposits formed at the level of the Spar Mountain sandy bed. Currier\textsuperscript{10} suggested that the abundant quartz might have been derived by dissolution and reprecipitation of clastic quartz in the siliceous beds. This might be the best explanation for the association of quartz with deposits at the Spar Mountain level, except that in those deposits where quartz is most abundant, the Spar Mountain sandy bed is either absent or only a few inches thick. Furthermore, quartz is not abundant in the upper parts of deposits which have sandstone roofs and which commonly contain fragments of sandstone and shale that are in direct contact with fluor spar. The solution of this particular problem will have to await the gathering and correlation of more data.

The group of minerals present in the deposits is indicative of deposition at moderate temperatures. Lindgren\textsuperscript{11} placed the fluor spar deposits of Illinois in the mesothermal class, which implies a temperature of 175°C to 300°C. Bastin\textsuperscript{12} considered that the replacement deposits were formed at moderate temperatures. Studies of the formation temperature of fluorite crystals from the Cave in Rock district have been made in the

\textsuperscript{10} Currier, L. W., op. cit., pp. 58-39.


\textsuperscript{12} Bastin, E. S., op. cit., p. 68.
Illinois State Geological Survey laboratories by heating specimens and recording temperatures at which vapor bubbles within primary fluid inclusions in the crystals disappeared. This work indicated that depositional temperatures were in the range of 83° to 167°C, and that commonly the growth temperature increased slightly for some distance outward from the center and then dropped off toward the exterior of crystals. Non-primary inclusions in the same crystals were formed at temperatures of 112° to 172°C, which suggests a considerable total range of temperature at various times in the history of the deposits.

TEXTURE

A prominent textural feature of some deposits is the pronounced layering of the ore, which consists of bands of coarsely crystalline, prevailing light-colored, and practically pure fluor spar alternating with finer-grained and darker layers containing fluor spar, other minerals, and un replaced limestone in varying proportions. The layering gives exposed surfaces of the ore a conspicuously banded appearance, because of which the ore has been termed "coontail ore" or "banded ore" (figure 24). The layers range from a fraction of an inch to several inches thick, most being one-half to one inch thick. Some layers are continuous for many feet, whereas others terminate abruptly or split into two parts within short distances. In most places the layering is prevailingly parallel to the major bedding planes, or it curves and is inclined much like the ordinary cross-bedding in sediments. In some exposures, however, the banding is contorted, bent, or broken in a manner difficult to associate with any possible original sedimentary structures.

The fluor spar in the coarse layers consists of a pair of crusts whose crystal-studded surfaces face inward toward a center seam. In some places the crystals have grown so that they interlock and the crusts meet along an irregular, approximately centrally located plane; elsewhere they project into an open center seam or cavity. This comblike structure is common in vein deposits and is believed to indicate that the crystals grew into an open space.

The fine-grained darker layers have no comb structure. They contain fluor spar, sphalerite in some deposits, and various impurities such as grains of calcite, ferriferous calcite or dolomite, and quartz. Of these impurities, the calcite and the round-grained quartz represent unreplaced remnants of the original limestone, whereas the quartz which is in tiny needle-like crystals is believed to have been introduced by the mineralizing solutions. The status of the ferriferous calcite or dolomite as either a primary or introduced mineral has not been established.

In some of the banded ore from Lead Hill and from the Cave in Rock mine the coarse layers consist of comb quartz or comb quartz on fluor spar, and the fine-grained bands consist of fine-grained quartz representing completely silicified limestone. In other deposits the fluor spar in the coarse layers is more or less completely replaced by fine-grained barite.

Most or all of the ore in some deposits has an imperfectly banded texture in which layering, indicated by variations in color, grain size, and purity, is clearly evident but not so consistent and regular as in "banded" ore (figure 25). In general, imperfectly banded ore contains less fluor spar than banded ore, but this, like the textural distinction between the two, is largely a matter of degree. It is common to find beds of imperfectly banded ore interlayered with beds of banded ore.

Occasional ore beds, which appear essentially non-laminated, contain more or less abundant fluor spar, and sometimes sphalerite, in disseminated form. These occur within sets of imperfectly banded beds, but are most commonly found at the outer margins of deposits and generally represent weak or incipient mineralization of limestone which might ultimately have been converted to imperfectly banded ore. Much of the "disseminated" ore and some of the imperfectly banded ore is softer than the original limestone, sufficiently so that in many places it may be cut with a knife. Together these two textural types make up
Fig. 25.—Imperfectly banded fluorspar ore exposed in pillar in Addison deposit of Victory mine, Cave in Rock district. Scale indicated by Brunton compass and shovel handle.
the material referred to by the miners as low-grade ore.

Massive fluor spar, commonly called "acid spar" in the district, is common in the form of horizontal veins and lenticular masses primarily at the tops and margins of deposits, and as irregular masses having the general shape of vertical veins of varying width. Mostly it appears to have been deposited in cavities rather than as a direct replacement of limestone. Closely related features are the vugs or cavities lined with crystals of fluor spar, calcite, and other minerals which are abundant in practically every deposit. These range from a few inches to many feet in long dimension, and are commonest at the top and margins of deposits. In the imperfectly banded and disseminated types of ore, massive fluor spar commonly fills spreading and complexly branching networks of veinlets a fraction of an inch to 6 inches in width. The veinlets follow bedding or lamination planes for short distances, then angle upward or downward in irregular fashion.

Structures relict from limestone which are still recognizable in the deposits definitely indicate a replacement origin for the ore, as has been generally recognized by previous investigators.13 Those structures on which there has been general agreement include fossils, stylolites, oolites, outlines of original calcite and quartz crystals, and evidences of the original large-scale stratification preserved by shale and clay partings. Conclusions regarding the origin of the prominent layering have been divided, however. Schwerin, Currier, and the present writers believe that the layering reflects the lamination, cross-bedding, and general variations in lithology characteristic of the replaced limestone beds. Bastin, on the other hand, considered the banded structure to be the result of rhythmic precipitation of fluor spar during replacement of the limestone in a manner unrelated to the lamination or cross-bedding of the rock. What led Bastin to this view were the local departures of the banding from strict parallelism with bedding planes of the enclosing rocks, particularly the local development of V- or W-shaped banded structures centering about spar-filled fractures in the ore.

Evidence favoring the first hypothesis seems quite convincing. Banded ore appears to have formed only from beds and groups of beds in which the original limestone, as evidenced by that left unreplaced, was markedly laminated, cross-bedded, and commonly oolitic. Imperfectly banded ore, on the other hand, was derived from limestone less perfectly laminated, not so conspicuously oolitic, generally finer grained, and apparently containing somewhat greater amounts of clayey and siliceous impurities. The Fredonia limestone, to which deposits of banded ore are practically confined, varies notably in lithologic character from bed to bed and also within short distances laterally, making it relatively impossible to correlate beds on the basis of lithology for more than a few hundred yards. This rapid lateral variation is reflected in the ore of different deposits and parts of deposits in the same stratigraphic position. It is demonstrated by the almost exclusively banded nature of the ore in the main Carlos ore body of the Victory mine and the contrastingly high proportion of imperfectly banded ore in the adjoining Addison ore body in the same mine, both of which occupy the topmost beds of the Fredonia limestone, as well as by the vertical interlayering of banded and imperfectly banded ore beds in many deposits.

In the banded ore examined in the Victory mine and in some other deposits the layers appear to be grouped in pairs, each pair consisting of a coarse layer in gradational and irregular contact with the fine-grained layer above it and set off from the

next higher and lower pairs by sharper and more even contacts. Much the same relations are found in many sedimentary rocks, wherein each depositional lamina is more or less sharply set off from the ones above and below and exhibits a variation in particle size from coarser at the bottom to finer at the top. Some beds in the Fredonia limestone are thus laminated, but the gradation in particle size is less evident in the limestone than in the banded ore. The coarse fluor spar layers are believed to have formed in the coarser-grained basal portion of lam inae present in the original limestone; in a few instances where such texturally laminated limestone has undergone incipient mineralization, stringers of coarse, pure fluor spar have formed in the coarser-grained bands. This point cannot, however, be considered definitely established.

In deposits consisting largely of banded ore, it is commonly observed that the layering is much more regular in those portions which are some distance away from the linear fracture zones that served as conduits for the mineralizing solutions. Along the fractures the layering is often contorted and also much massive fluor spar is present, both at the top and within the body of the ore. These relations are especially noticeable in the narrower ore bodies that have especially thick mineralized zones in their central parts. It is believed that the contorted banding, including the V- and W-shaped structures along vertical fractures observed by Bastin, resulted from the collapse, settling, and minor brecciation that accompanied excessive volume loss along the main “feeding” fractures during mineralization.14 Banded ore appears to have been formed laterally where there was no strong flow of mineralizing solutions, in sort of “backwater” situations.

The possible mechanics and chemistry of the process by which the banded ore was formed have been discussed at length by Currier.15 Starting from the primary ob-

of yards of bedded deposits than elsewhere, which suggests that the iron-bearing carbonate in the brown layers may itself be, at least in large part, a product of the mineralizing and replacing process rather than an important original impurity in the limestone. In both weathered mine dumps and fresh underground exposures, the brown color due to the oxidation of the ferrous iron in ferriferous carbonates is most apparent in those rocks that show some trace of fluorspar mineralization, and is commonly not detectable or only faintly visible in the barren limestone fragments.

The effect of texture, particularly the effect of particle size and possibly permeability, may have been relatively more important than purity in the formation of banded ore. The laminated beds of the Fredonia limestone which were transformed to banded ore are composed dominantly of oolites and fossil fragments. The laminations were caused by the natural sorting of coarse oolites and fragments into certain layers or parts of layers, and the finer oolites and fragments into others. Though not checked by experiments, it is believed probable that the coarser layers have greater permeability than the finer layers.

Although it seems obvious that the crystals comprising the coarse fluorspar layers grew into open spaces, no such spaces have been observed at the ends of coarse layers. It may be that the ore solutions continued to deposit fluorspar after they ceased to dissolve limestone, and thus filled with fluorspar the openings already made. The formation of the coarse fluorspar layers involved cavity filling and cannot be considered replacement in the strict volume-for-volume sense of the word, although the fine-grained layers apparently were formed in such a way. Replacement proceeded more slowly than the formation of the coarse fluorspar layers, for the fine-grained layers of ore still contain some unreplaced carbonates, and, as Bastin observed, those in the lower parts of ore bodies contain more unreplaced carbonate than those in the upper parts, which is not a characteristic of the coarse fluorspar layers.

ORIGIN

The fluorine present in the fluorspar deposits is considered to have come from some hidden igneous source in depth, the exact nature of which is a matter for conjecture. Evidence of igneous activity in the general fluorspar field consists of basic dikes, breccias of the explosive type, and a possible small granite mass. The relation of fluorspar to these igneous bodies is apparent only in the few places where basic dikes are cut by small veinlets as at Orr's Landing, or by vein-bearing faults as at Rosiclare, in every instance of which the fluorspar was formed later than the igneous body.

Whether or not the initial emanation at depth was gaseous or liquid is not known, but the fact that the fluorspar was deposited in its present sites from liquid solutions is well established by the presence of liquid inclusions in fluorspar crystals, representing small bits of the liquid in which the crystals grew. Furthermore, the measured temperature of formation of the fluorspar, in the range of 83°C to 167°C, is well below the critical temperature of pure water, and is such that a pressure of less than 10 atmospheres would be sufficient to keep the liquid from boiling, whereas the pressure on the bedded deposits at the time of their formation was probably in the range of 160 to 235 atmospheres, corresponding to depths of approximately 3,000 feet.

The chemistry of the ore-forming solutions is a subject about which very little is known. It is apparent from the list of minerals formed that they carried fluorine, zinc, lead, copper, iron, sulfur, silicon, and probably barium. Hundreds and possibly thousands of feet of easily acid-soluble limestone had to be traversed before the sites of deposition were reached and fluorine acids are among the most corrosive known to chemists; therefore it is assumed that the solutions were not far from neutral in reaction. It is likely that their character changed from time to time, either because of change in the character of incoming solution or because of changes in temperature, for it is known that they had the ability
both to dissolve limestone actively and to deposit calcite, and that minerals were deposited in a fairly definite sequence. Beyond these simple facts and assumptions there is little to be said.

Major normal faulting along Peters Creek fault zone and presumably concomitant minor fracturing in the wide and otherwise structurally undisturbed area to the southeast provided the structural setting for ore deposition in the Cave in Rock district. The linear near-parallelism of the principal mineralized belt with the course of Peters Creek fault, itself locally mineralized to slight degree, and the lack of other major structural breaks in the district, implies that Peters Creek fault was the avenue by which the fluoriferous solutions rose from depth. It is postulated that they spread outward and upward along intersecting minor fractures in the area to the southeast, probably because free rise along the main fault was impeded by a relatively tight filling of gouge where shaly Chester formations were included in the movement along the fault. Probably certain of these minor fractures, by virtue of their relative openness and inter-connections, carried the bulk of the mineralizing solutions. The form of the deposits suggests that the solutions rose into sites of deposition along relatively limited sectors of the fractures, then spread laterally as far as openness of the fractures and supply of solution permitted. The spreading of solutions from main fractures or fractured zones out along cross fractures for varying distances is illustrated by the outlines of many deposits, and the lining up of narrow ore bodies in adjacent mines, such as the Lead mine and the nearby Victory mine.

The lateral spreading of the solutions probably took place when further vertical ascent was prevented or greatly impeded by upward constriction or termination of the vertical fractures, and it is assumed that deposits were usually formed in the highest limestone beds readily available to the solutions. Although it is not uncommon to find mineralization for 200 to 300 feet vertically in the vicinity of deposits, and in fact to find mineralization at several levels one above another, experience has shown that significant ore formation took place predominantly at only one stratigraphic horizon in each mineralized zone. At many places the caprocks over deposits are sandstone, such as the Rosiclare and Bethel, but at other places they are limestones as in bodies at the "sub-Rosiclare" level and near the Levias-Renault contact. Deposits appear to have formed without regard to the presence of a capping of shale, contrary to former opinion based on observation limited to deposits beneath locally thick shale at the base of the Rosiclare sandstone. Factors contributing to the selection of certain of the accessible limestone strata may have included greater purity, greater porosity or permeability, or abundant joints and fractures.

The deposits were formed primarily by replacement but partly by filling of cavities. The formation of banded ore involved both of these processes, as already discussed. One feature of the mineralizing process not much emphasized by earlier investigators, but clearly revealed during the more recent work, is the large effect of net loss in volume undergone by the strata affected by the solutions. "Hidden" synclines developed along the course of deposits. Incompetent caprock sagged inward and downward over ore bodies. Collapse breccias and structures found beneath undisturbed roofs in many deposits, the lamination of banded ore contorted at some places in a manner explainable only on the basis of slumping, and numerous crystal-lined cavities and open spaces at the tops of ore bodies also indicate volume shrinkage. The loss in volume is considered partly due to the substitution of fluor spar (a denser mineral) for calcite, in proportions approaching molecular equivalency, and partly to the complete removal of certain beds or parts of beds by direct solution by the mineralizing fluids.

Long after the deposits were formed, erosion removed enough of the estimated 2,000 to 3,000 feet of original cover so that some of the deposits became exposed at the surface.
Important Mining Properties

The fluorspar mines in the Cave in Rock district, discussed briefly in the following paragraphs, were studied during the years 1942 to 1945; they are the most important mines in the district (pl. 4).

Ozark-Mahoning mines and vicinity.—The Ozark-Mahoning Company operates the W. L. Davis-Deardorff, W. L. Davis No. 2, A. L. Davis, West Green, and East Green mines and is currently developing a sixth, the North Green mine. Prospecting and mining operations began in 1937 and 1938, respectively. The ore bodies occur at the “sub-Rosiclare” level and in the top of the Fredonia and Renault limestones. All were discovered by drilling and are mined through shafts. Ore is treated in the company’s differential flotation plant in Rosiclare, where acid and metallurgical grades of fluorspar, as well as sphalerite and galena concentrates, are produced. The W. L. Davis-Deardorff mine is one of the largest and richest in the district. For a number of years the crude ore taken from it assayed approximately 50 to 60 percent fluorspar, 12 to 14 percent zinc, and 3 to 5 percent lead. The West Green mine is also one of the larger mines of the district. The ore from it contains less zinc than the Davis-Deardorff, and practically no lead.

Minerva mine and vicinity.—This mine, one of the largest producers of fluorspar and zinc in the Illinois-Kentucky field, was opened in 1943 following four years of exploration and development work. The three ore bodies in the mine occur in the topmost beds of the Renault formation, and they are the most northeasterly of those being worked in the district. The hoisting shaft is 645 feet deep, the deepest in the Cave in Rock district. Crude ore is treated in a flotation plant located at the mine. In 1945 the feed to the mill averaged 35 percent CaF₂ and 4.2 percent zinc. Galena is almost completely lacking in the ore. Ceramic-grade fluorspar averaging 93 percent CaF₂ and less than 1½ percent SiO₂, metallurgical-grade fluorspar averaging 85 to 88 percent CaF₂, and sphalerite concentrate averaging 63 percent zinc are produced. The company is the largest producer of ceramic fluorspar in the field.

Victory mine and vicinity.—The Victory mine comprises two groups of workings, one reached by the 160-foot Carlos shaft, the other by the 170-foot Addison shaft. The two workings are isolated in the sense that apparently nowhere is ore continuous between them, but the several ore bodies within each group are mostly connected by ore. The ore occurs principally in the topmost beds of the Fredonia limestone. Banded “coontail” ore is prominent in the main Carlos body. Much of this ore was sufficiently pure to be shipped as metallurgical-grade spar without concentration. The company operates a jig mill on the property for the production of metallurgical-grade concentrate only. The ore contains only local slight amounts of sphalerite and galena. Mining operations began in 1928. An underground diamond drilling campaign was conducted by the U. S. Bureau of Mines in 1943 and 1944. Twenty-one borings were made to test for deposits below the existing workings. Except for mineralization close below the mine floor no new deposits were found.

Crystal mine and vicinity.—An exploratory adit driven into the hillside in 1929, following a lean showing of ore at the top of the Fredonia limestone, soon encountered a portion of one of the company’s principal ore bodies and thus became the first step in the development of the present ramified workings of the Crystal mine. The mine contains a number of individual ore bodies, many of which are connected by ore, and all but one of which are in the upper portion of Fredonia limestone. One deposit is in the top beds of the Renault limestone. In 1946 a total of seven shafts gave access to the workings. Sphalerite and galena usually occur in insignificant amounts, and until recently there was no provision for separating these minerals from the fluorspar. For many years the company mill employed a simple jig mill for producing metallurgical fluorspar con-

centrate, but in 1949 a heavy media separation plant was added to the mill circuit. The Crystal mine is one of the major producers in the district.

**Austin mines and vicinity.**—These are also known locally as the "Benzon mines," and the property as the "Benzon property," in reference to the Benzon Fluorspar Company which owned and operated them during the period 1925 to 1939. The group includes the West Morrison-Oxford open pit, the Lead (or Lead Adit) mine, the Cleveland mine (including the 32-Cut and Keeling mines) and the Green-Defender mine. Being located on Spar Mountain along the outcrop of the Fredonia limestone and Rosiclare sandstone where ore bodies had been exposed by erosion, this area attracted the attention of miners and prospectors early in the history of the district. The earliest important mining began about 1900 and was concerned chiefly with recovering lead. The chief producing years for these mines were those from 1920 through 1937 under the management of the Spar Mountain Mining Company and the Benzon Company. Since then much of each year's production has come from removal of mine pillars and other scavenging operations. The principal ore bodies are found in the topmost 10 feet of the Fredonia limestone, with lesser ones in beds extending 50 to 60 feet lower in the limestone. The deposits are entered through adits leading directly into the hillside. Much of the ore is of the banded variety and of high purity. Galena and sphalerite are essentially lacking except in restricted areas. The ore mined from the West Morrison-Oxford open pit was clayey and deeply weathered, but most of that from other deposits was solid and unweathered.

**Grischy mines and vicinity.**—Included here are a number of small fluorspar deposits on two 40-acre tracts, known locally as the "Cave in Rock" and "Lead Hill" tracts, on which mining has been done for many years. Most of the deposits occur in the top beds of the Fredonia limestone, with others at lower levels in the Fredonia and some in the Levis and basal Renault limestones. The deposits are worked through adits and shallow shafts. The ore exhibits the usual textural and mineralogical features characteristic of the replacement deposits. One interesting feature is the abundance of quartz and galena in three of the stratigraphically lowest deposits. Sphalerite and smithsonite occur in small amounts.

**Fluorspar Products mines and vicinity.**—This group of mines is located on the south end and west side of the ridge known as Lead Hill. Access to the deposits is given by a considerable number of adits, and the various workings literally honeycomb the narrow ridge, some extending from one side of it to the other. Owing to the extensive robbing of pillars and aging of timber supports there has been much roof subsidence and many of these openings are no longer accessible. Deposits are present at three principal levels in the upper 54 feet of the Fredonia limestone. They are characteristically long and narrow and exhibit the usual textural types of ore. Deposits at the lowest level are more siliceous than the others and contained a higher proportion of galena, from which it is probable the name of the hill was derived. It is known that some mining was done here prior to 1917, and because the deposits cropped out and were easily accessible, it is likely that this was the scene of some of the earliest mining in the district.

**Wall property.**—A number of small and shallow deposits of weathered ore have been worked from time to time on the Wall property, which consists of 170 acres partially surrounding the north end of the "Sink." Much of the ore was in the form of lumps and boulders dispersed in a clayey matrix and was easily concentrated to salable condition by treatment in log washers.

**Winn, Underwood, and Frayser properties.**—A northeast-trending linear series of shallow mine and prospect workings extends for about 1,200 feet across these three properties near Cave in Rock village. Small, narrow replacement ore bodies and their weathered residual equivalents have

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17 This and the succeeding properties lie outside the principal mineralized belt of the Cave in Rock district.
been mined at three levels within a vertical zone of about 30 feet in the basal part of the Fredonia limestone. Galena and sphalerite are not conspicuous in the ore. Production is reported to have been small.

**Hill mine.** — In this mine replacement deposits have been worked at two shallow levels arranged vertically along one or more narrow northeast-trending fissures. Mineralization has been followed for a distance of about 700 feet. The wall rock is the Fredonia limestone. The ore produced was principally of the clayey residual type, and much of it was strongly baritic. Lead and zinc minerals were essentially absent. The amount of ore mined was comparatively small.

**Tower Rock mine and vicinity.** — At this place a series of shafts and test pits extending for 950 feet in a northeasterly direction marks the course of a zone of mineralization in the St. Louis limestone, apparently along a fault of minor displacement. The ore produced is thought to have occurred in the form of narrow veins and small replacement bodies, adjacent to which the wallrock was strongly silicified. Most of the workings are shallow, the deepest shaft reported to be only 120 to 130 feet deep. Some of the ore mined was of the weathered type in a clayey matrix, some in the solid form. Traces of galena were noted in the waste rock, but no sphalerite was observed.

Other mining properties in the Cave in Rock district which were studied and reported upon include the Patrick mine and vicinity, and the Terns property, the locations of which are given in the accompanying tabulation of mines and prospects. Under the recent management of the Alco Lead Corporation, the Patrick mine was a producer of lead minerals in which fluor spar was only an accessory mineral. The ore consists principally of primary galena and the secondary lead mineral, cerussite, with minor amounts of anglesite, pyromorphite, and the zinc carbonate, smithsonite. It occurs as particles and masses from sand size to 2 feet across, embedded in the clayey, cherty, silicified residue that resulted from deep weathering of the surrounding St. Louis limestone. The ore appears to have consisted originally of galena in the form of narrow veins and replacement bodies. Originally worked by means of shallow shafts and short drifts, the deposit was mined by the Alco company as an open pit with a power shovel and dragline. The ore was concentrated by means of heavy-media equipment and shaking tables in a mill on the property. For a while the Alco company attempted to concentrate the fine sizes of cerussite by means of a flotation method involving sulfidizing, but the scheme did not prove economically feasible. 18

The Terns property has been the scene of intermittent unsuccessful prospecting for a number of years. Through the period covered by the report on the Terns property, exploratory work included a number of shallow shafts and test pits and a few diamond drill holes. Since then it has been reported that a small ore body has been discovered and some mining work done.

**OUTLYING AREAS**

Fluorspar mineralization in Illinois outside the Rosiclare and Cave in Rock districts is widespread and extends from Hardin County into Pope County to the west and Saline County to the north. The deposits are mostly fissure veins associated with faults, or are of the residual “gravel spar” type resulting from the weathering of veins. Here and there replacement ore, some of it of the “coontail” banded variety, has been encountered, and some of the deposits contain both fissure vein and replacement types of ore. Galena and sphalerite are abundant in some deposits and rare or lacking in others, and the same is true of barite. The distribution of these accessory minerals does not appear to follow any regular pattern of regional mineral zonation. Mineralization occurs in rocks of ages ranging from Devonian (Rose mine) to uppermost Chester and Pennsylvanian (Rock Candy Mountain mine and others along the Lusk Creek fault zone).

As compared to the Rosiclare and Cave in Rock districts, the operations in outlying areas have been of relatively lesser importance. Several properties have, however, been commercially successful, and a few have produced considerable quantities of excellent ore. The fact that the great majority of prospects have been unsuccessful is typical of every mining region. For the most part, this prospecting has been very superficial and there is no reason to conclude that the potentialities of the outlying districts have been exhaustively tested. In fact, the possibility still exists for the discovery of important ore deposits that are not apparent at the surface, or in places where only minor indications of mineralization are present at the surface. This may be especially true in localities where the surface rocks are the Cypress and Bethel sandstones and where traces of mineralization or small veins have been found along small faults or fractures at or near the surface. Experience indicates that in such places mineable deposits sometimes occur in the limestones below, particularly in those parts of the faults where the upper part of the Fredonia limestone forms one or both walls.

Between 1942 and 1945 the following mines, properties, or areas were examined in greater or lesser detail and reported upon. Locations of the various mines are shown on plate 4.

Empire district. — This district includes several mines that produced in the past from shallow underground workings, including the Empire, Red, Pierce, Douglas, Slapout, and Hicks Creek mines. During World War II some of the deposits were successfully worked by surface trenching with power machinery. More recently underground mining has been started on the Pierce and Empire veins in ore bodies mostly discovered since the end of the war, and a considerable amount of diamond drill prospecting has been done by the government and by private companies. Banded replacement ore was mined from several deposits. Galena and sphalerite are not major components of the ores of the district, but are locally abundant enough to be sorted by hand for separate sale.

Stewart mine and vicinity. — The Stewart and several other mines, including the Mackey group, the Williams group, the Jefferson, and the Baker, are located along a minor northeast-trending fault or group of related faults in this area. Although the deepest workings extend about 300 feet below the surface, most of the ore was found above 200 feet. The veins are narrow but yield fluor spar of high purity. Galena and sphalerite are abundant in parts of the Jefferson mine but are not common in the others.

Hamp property and vicinity. — This property is crossed by a complicated series of small faults trending approximately east-west, roughly parallel to the strike of north-dipping formations on the north flank of Hicks dome. Some of the faults throw to the south, in a direction opposite to the direction of regional dip. A mineralized vein and its offshoots have been successfully worked at various times in the Hamp and several other small mines. Some banded replacement ore is reported from the property. Galena and sphalerite are present in local small amounts.

Lee mine and vicinity. — The Lee mine is the most important of a number of mining and prospecting operations on the northeast-trending Lee fault system along which mineralization has been found for nearly 1 1/2 miles. The Lee mine was closed in 1938 and has not been worked since then. Exploratory diamond drilling below the old workings was done in 1944 and 1945 by the U. S. Bureau of Mines. At the Lee mine the fault has a large displacement amounting to 450 feet down to the south. Ore occurred generally to depths of about 100 feet, and at a stratigraphic position higher than is generally common in the district. Only minor amounts of galena and sphalerite were present.


**Rock Candy Mountain property.** — This property is crossed by the Lusk Creek fault zone. Locally this zone consists of a very complex system of faults produced by the junction of the southwestward continuation of the Shawneetown zone of thrust faulting and the Herod normal fault. As a result the rocks are broken into many narrow slivers which are variously displaced with respect to each other. The Rock Candy mine is one of the few which has produced fluorspar from a vein walled by Pennsylvanian sandstone. The ore from this mine is high in silica and low in galena and sphalerite.

**Lusk Creek fault zone between Lost 40 and Rock Candy properties.** — No fluorspar is known to occur here, but this area is similar to and lies between two mineralized properties.

**Lost 40 property.** — This property is crossed by the complicated Lusk Creek fault zone, along which prospecting and small scale mining has been carried on for many years. The most important of these efforts, the Lost 40 mine, was opened in 1940 and worked to a depth of over 100 feet following a vein between walls consisting principally of quartzitic sandstone and clay. Some of the ore was of relatively high purity, whereas the remainder was more or less siliceous. Galena is locally abundant in surface exposures on the property, but sphalerite is present only in traces.

**Ora Scott property.** — This property, also cut by the Lusk Creek fault zone, has produced a small tonnage of ore from a few shallow shafts and drifts. The mineralization is in the form of small veins in shattercd limestone and quartzitic sandstone. Much of the ore contains silica. Galena and sphalerite are practically lacking.

**Gilbert property.** — This property, upon which no mineralization has been noted, extends along the Lusk Creek fault zone for over one mile.

**Clay Diggings and vicinity.** — Several shallow shafts have been sunk in the Lusk Creek fault zone following narrow veins carrying fluorspar, galena, and sphalerite. Production is believed to have been small. A quarry in Kinkaid limestone on the property was worked by the CCC in the 1930's. Fragments of bluish to white halloysite clay on the waste dumps are said to have come from a deposit found at shallow depth along one of the faults. This clay is reported to have been mined in the 1860's, probably for use in making ceramic articles such as pottery or stoneware.21

**Lake Glendale area.** — This area is located on the southwest extension of the Lusk Creek fault zone. Minor showings of fluorspar and barite are exposed in several test pits, but no mining has been done here. A small amount of diamond drill exploration has been done by private interests. Although no thorough geological restudy was made of this area, preliminary examination of outcrops and interpretations of diamond drilling suggest that lower Chester and Ste. Genevieve strata crop out in this area, but their distribution is not well enough known for them to be shown on the geologic map of the district.

**Compton mine and vicinity.** — This is the southernmost property worked for fluorspar in Illinois and has produced small amounts of ore intermittently since about 1900. There are three shafts on the property, and their workings are said to interconnect. Part of the ore was mined from the vein along a fault trending northeast and dipping southeast and part from small fissure veins and replacement bodies in the sandstone on the southeast side of the fault. Galena accompanied the fluorspar in the sandstone, but sphalerite was present only in minor amounts. There has been a small amount of diamond drilling in the vicinity of the mine.

**Berry mine and vicinity.** — This is a complexly faulted area within the Rock Creek graben where the prevailing trend of the Rosiclare faults (N 20° E) changes to the Peters Creek trend (N 60° E). Evidence of mineralization occurs at several places and several prospect shafts have been dug but very little ore has been produced.

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Shelby and Seinor properties. — Shafts and test pits at numerous places on these tracts have exposed near-surface showings of vein and replacement fluorspar locally accompanied by sphalerite, but no sustained production of ore has resulted. The mineralization occurs along parts of a complex system of faults known as the Hobbs Creek fault zone. Considerable diamond drilling has been done both by private interests and by the U. S. Bureau of Mines.

Dubois property. — A mineralized fault with a displacement of about 850 feet down to the southeast crosses this property in a northeasterly direction. A series of shallow shafts and open pit workings have encountered showings and locally mineable concentrations of fluorspar for somewhat over 1,000 feet along the fault. The ore produced has generally been siliceous and lacking in galena and sphalerite. The U. S. Bureau of Mines drilled four diamond drill holes on the property in 1944.

In addition to the foregoing, numerous prospects and small mines are distributed throughout the fluorspar district. Although these were not completely studied, available data regarding them has been collected and is summarized in table 4. Except where indicated, these data are presented as of the date they were compiled, November 1, 1942. Whenever possible the data were obtained by personal observation, otherwise they were obtained from operators, owners, or former miners of properties. The list of mines and prospects is arranged according to township, range, and section. The locations were ascertained by means of actual visits to the various properties. Principal mines in the Rosiclare and Cave in Rock districts have been omitted.


<table>
<thead>
<tr>
<th>NAME; Latest Operator Recorded</th>
<th>LOCATION</th>
<th>CHARACTER OF DEPOSIT</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>LOCATION</strong></td>
<td><strong>CHARACTER OF DEPOSIT</strong></td>
<td><strong>REMARKS</strong></td>
</tr>
<tr>
<td></td>
<td>Sec. ¼ ¼ ¼ County</td>
<td>Vein in rock</td>
<td>Weathered gravel spar</td>
</tr>
<tr>
<td>King; A.B.C. Mining Co.</td>
<td>T. 10 S., R. 7 E.</td>
<td>21 — NW SW Saline</td>
<td>x</td>
</tr>
<tr>
<td>Gibbons; Cantrell &amp; Gibbons</td>
<td>T. 11 S., R. 6 E.</td>
<td>32 NE NE SE</td>
<td></td>
</tr>
<tr>
<td>DeSautels</td>
<td>25 SE NE SW Pope</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tripod</td>
<td>25 NE SE SW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Williams</td>
<td>25 SW SE SW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rock Candy Mountain; Inland Steel Co.</td>
<td>25 NW SE SW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T. 11 S., R. 7 E.</td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td>-----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td><strong>Tanner; Sronce and Cantrell</strong></td>
<td>11 SW SE NE Hardin x</td>
<td>N55°W; 80°SW</td>
<td>70'</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N55°E; 80°SE</td>
<td>155' and 300'</td>
</tr>
<tr>
<td><strong>Rose Creek; Yingling Mining Co.</strong></td>
<td>11 SW NE SW a x</td>
<td>N50°E; SE 4'</td>
<td>265'</td>
</tr>
<tr>
<td><strong>Knox; Knox Spar Corp.</strong></td>
<td>11 NE SW SW a x</td>
<td>N40°W; 85°SW 3'</td>
<td>150'</td>
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<tr>
<td><strong>Nick Hamp; Yingling Mining Co.</strong></td>
<td>12 SE SE SE a x</td>
<td>N32°E; 80°W 2'</td>
<td>90'</td>
</tr>
<tr>
<td><strong>J. Hamp; J. Hamp</strong></td>
<td>12 NE SW SW a x</td>
<td>N32°E; 80°W 20'</td>
<td>B</td>
</tr>
<tr>
<td><strong>J. R. Hamp; J. N. Ledbetter</strong></td>
<td>13 SE SW NE a x</td>
<td>N34°E 20'</td>
<td>O</td>
</tr>
<tr>
<td><strong>Williams; Beecher Williams</strong></td>
<td>22 SW SE SE Pope x</td>
<td>N34°E 20'</td>
<td>O</td>
</tr>
<tr>
<td><strong>Rainey; Knight, Knight and Clark</strong></td>
<td>22 SE SW SE a x</td>
<td>N34°E 20'</td>
<td>O</td>
</tr>
<tr>
<td><strong>Fowler; Spiller and Willis</strong></td>
<td>23 S1/2 NW SW Hardin x</td>
<td>N34°E 20'</td>
<td>O</td>
</tr>
<tr>
<td><strong>Carnett; Geo. Carnett</strong></td>
<td>26 NW SE NE a x</td>
<td>N34°E 20'</td>
<td>O</td>
</tr>
<tr>
<td><strong>Hicks</strong></td>
<td>26 NE NW SE a x</td>
<td>N34°E 20'</td>
<td>O</td>
</tr>
</tbody>
</table>

**Symbols are:** A = Abundant; B = Moderate; C = Minor; O = None.

b Indicates data including information more recent than 1942.

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Prospect shaft exposed veinlets of spar. Near Herod.


Probably same fault as Rose Creek mine. Ore is siliceous. Commercial production. Near Herod.


Reported minor production. Near Karber's Ridge.


Also known as the Hutchinson mine. Several prospect pits in vicinity. Near Eichorn.

Two open cuts made with drag line. Gravel spar deposit had maximum width of 15', limestone below contained only veinlets of fluor-spar. Numerous other traces of fluor-spar exposed in test pits in W1/2 SW SW sec. 23. Near Eichorn.

Test pit exposed trace of gravel spar. Near Eichorn.

Old prospect pits. No fluor-spar visible on dump. Near Eichorn.
<table>
<thead>
<tr>
<th>NAME; Latest Operator Recorded</th>
<th>LOCATION</th>
<th>CHARACTER OF DEPOSIT</th>
<th>REMARKS</th>
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<tbody>
<tr>
<td>Farrell; Ralph Farrell</td>
<td>Sec. ¼ ¼ ¼ County</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Baldwin; J. C. Conrad</td>
<td>26 S½ NE NW Hardin</td>
<td>x</td>
<td>N32°E; 85°SE 5' 40' C O</td>
</tr>
<tr>
<td>Charles Crabb; Knight, Knight &amp; Clark</td>
<td>27 NE SW NE</td>
<td>x</td>
<td>N20°E -55' C O</td>
</tr>
<tr>
<td>Acup; Acup &amp; Sons</td>
<td>27 SE NW NE</td>
<td>x</td>
<td>N30°E 50' C O</td>
</tr>
<tr>
<td>Conrad; Conrad &amp; Baldwin</td>
<td>27 SE NW NE</td>
<td>x</td>
<td>N-S; 85°W 9'-16' A C</td>
</tr>
<tr>
<td>aOscar Crabb; Karber &amp; Adams</td>
<td>27 SW NE SE</td>
<td>x x</td>
<td>N55°E; 70°SE 23/4' 19'-180' C O</td>
</tr>
<tr>
<td>bEmpire; G. B. Mining Co.</td>
<td>27 SW SE</td>
<td>x x</td>
<td></td>
</tr>
</tbody>
</table>

FLUORSPAR DEPOSITS OF ILLINOIS

TABLE 4.—(CONTINUED)
<table>
<thead>
<tr>
<th>Company</th>
<th>Section</th>
<th>Township</th>
<th>Range</th>
<th>Meridian</th>
<th>NAD83 Zone</th>
<th>Depth</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oscar Crabb; Oscar Crabb</td>
<td>27</td>
<td>NE NW SE</td>
<td>Pope</td>
<td>x</td>
<td>N20°E; SE</td>
<td>15°</td>
<td>50'</td>
</tr>
<tr>
<td>Davenport; Oscar Crabb and Son</td>
<td>27</td>
<td>SW NW SE</td>
<td>a</td>
<td>x</td>
<td>NE; 10°</td>
<td>55'</td>
<td>C</td>
</tr>
<tr>
<td>Chas. Crabb</td>
<td>27</td>
<td>NE NE SW</td>
<td>a</td>
<td>x</td>
<td>N50°E; 80°SE</td>
<td>100'</td>
<td>B</td>
</tr>
<tr>
<td>Red; H.C.B. Mining Co.</td>
<td>27</td>
<td>SE SE SW</td>
<td>a</td>
<td>x</td>
<td>N55°E; 80°SE</td>
<td>4½'</td>
<td>120'</td>
</tr>
<tr>
<td>O'Rear; O'Rear</td>
<td>27</td>
<td>SE NE NW</td>
<td>a</td>
<td>x</td>
<td>N60°E; SE</td>
<td>3°</td>
<td>70'</td>
</tr>
<tr>
<td>Todd; J. M. Todd</td>
<td>27</td>
<td>SW NE NW</td>
<td>a</td>
<td>x</td>
<td>N20°E; 1½'</td>
<td>20'-60'</td>
<td>A</td>
</tr>
<tr>
<td>Big Joe; Pierce</td>
<td>27</td>
<td>NW SE NW</td>
<td>a</td>
<td>x</td>
<td>N20°E; 6°</td>
<td></td>
<td>B</td>
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<tr>
<td>Douglas; Yingling Mining Co.</td>
<td>34</td>
<td>Center</td>
<td>a</td>
<td>x</td>
<td>N65°E; SE</td>
<td>2½'-3'</td>
<td>35'-200'</td>
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<tr>
<td>Pierce; Karber &amp; Adams</td>
<td>34</td>
<td>SW NW NE</td>
<td>a</td>
<td>x</td>
<td>N70°-80°E; 85°SE</td>
<td>35'-200'</td>
<td>C</td>
</tr>
<tr>
<td>McKee; Southern Fluorspar Co.</td>
<td>34</td>
<td>SE NE SW</td>
<td>a</td>
<td>x</td>
<td>N70°E; 6'</td>
<td>70'</td>
<td>O</td>
</tr>
<tr>
<td>Hicks Creek; Hicks Creek Mining Co.</td>
<td>34</td>
<td>SE NE NW</td>
<td>a</td>
<td>x</td>
<td>N70°E; 6'</td>
<td>70'</td>
<td>O</td>
</tr>
<tr>
<td>Gullett; A.B.C. Mining Co.</td>
<td>34</td>
<td>NW NE NW</td>
<td>a</td>
<td>x</td>
<td>N70°E; 6'</td>
<td>85'</td>
<td>O</td>
</tr>
</tbody>
</table>

Most of ore came from bedded deposit of fluorspar and sphalerite at depth of 35'. Near Eichorn.

Prospect shaft. Near Eichorn.

Prospect shaft. Near Eichorn.

On SW extension of Empire vein. Commercial production for a number of years. Also known as Roberts, Knight, and Redd mine. Near Eichorn.

Prospect shaft. Near Eichorn.


Old prospect workings. Near Eichorn.


No mineralization reported. Near Eichorn.


Shaft being deepened after diamond drilling showed ore at deeper level. Near Eichorn.

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<table>
<thead>
<tr>
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<th>CHARACTER OF DEPOSIT</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sec. 1/4 1/4 1/4 County</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vein in rock</td>
<td>Weathered gravel spar replacement</td>
</tr>
<tr>
<td>Slapout; Karber &amp; Adams</td>
<td>T. 11 S., R. 7 E.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Turner; Geo. Turner</td>
<td>34 SE SE NW Pope</td>
<td>34 NW SW NW &quot;</td>
<td>x</td>
</tr>
<tr>
<td>Williams; Beecher Williams</td>
<td>T. 11 S., R. 8 E.</td>
<td>7 S1/2 SW SE Hardin</td>
<td>x</td>
</tr>
<tr>
<td>Carnett; Geo. Carnett</td>
<td>7 SW SW SE &quot;</td>
<td>x</td>
<td>E-W; 70°S</td>
</tr>
<tr>
<td>Weidman; C. Weidman</td>
<td>7 SW NE SW &quot;</td>
<td>x</td>
<td>E-W; 70°S</td>
</tr>
<tr>
<td>Gintert; Beecher Williams</td>
<td>8 SE SW SE &quot;</td>
<td>x</td>
<td>N45°W; NE</td>
</tr>
<tr>
<td>Gintert; Beecher Williams</td>
<td>8 SW SW SE &quot;</td>
<td>x</td>
<td>N45°W; NE</td>
</tr>
<tr>
<td>J. Love; Phelps</td>
<td>11 E½ NE NE &quot;</td>
<td>x</td>
<td>N45°W; NE</td>
</tr>
</tbody>
</table>

**Remarks:**
- Veinlets of spar exposed in prospect shaft. Possibly an extension of Pierce vein. Also called Turtle prospect. Near Eichorn.
- Several prospect shafts. Traces of fluor-spar found. Near Karber's Ridge.
- Exploratory shaft and diamond drilling. Traces of spar reported. Near Karber's Ridge.
- Reported small production of gravel spar. Near Karber's Ridge.
- Prospect shafts on Lee fault zone. Near Karber's Ridge.
<table>
<thead>
<tr>
<th>S. Love; McAllister</th>
<th>11</th>
<th>N 1/2</th>
<th>SW</th>
<th>SE</th>
<th>Hardin</th>
<th>x</th>
<th>x</th>
<th>N45°E</th>
<th>50'</th>
<th>C</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jarrells; S. Love</td>
<td>12</td>
<td>NE</td>
<td>SW</td>
<td>SE</td>
<td>&quot;</td>
<td>x</td>
<td>N27°E; SE</td>
<td>60'</td>
<td>C</td>
<td>B</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>&quot;Lee; Hillside Fluorspar Mines Co.</th>
<th>14</th>
<th>N 1/2</th>
<th>NW</th>
<th>NW</th>
<th>&quot;</th>
<th>x</th>
<th>N50°–58°E; 75°–85°SE</th>
<th>3½'</th>
<th>35°–150'</th>
<th>O</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gintert; Crystal Fluorspar Co.</td>
<td>17</td>
<td>NE</td>
<td>NE</td>
<td>NE</td>
<td>&quot;</td>
<td>x</td>
<td>N60°E</td>
<td>40°–125'</td>
<td>O</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Diamond; Geo. Carnett</td>
<td>17</td>
<td>NW</td>
<td>SE</td>
<td>NE</td>
<td>&quot;</td>
<td>x</td>
<td>E–W±; 60–65°S</td>
<td>2½'</td>
<td>10'–300'</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Frohock; Williams &amp; LaRue</td>
<td>18</td>
<td>SW</td>
<td>NE</td>
<td>NE</td>
<td>&quot;</td>
<td>x</td>
<td>N70°E; SE</td>
<td>6'</td>
<td>48'</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Hamp; Aluminum Ore Co. &amp; Contractors</td>
<td>18</td>
<td>N, line</td>
<td>NW</td>
<td>&quot;</td>
<td>x</td>
<td>x</td>
<td>N45°–55°E</td>
<td>40'</td>
<td>C</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Joyce; Thurmond and Gibbons</td>
<td>21</td>
<td>SW</td>
<td>NE</td>
<td>SE</td>
<td>&quot;</td>
<td>x</td>
<td>N70°E; SE</td>
<td>6'</td>
<td>48'</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Turner; Saylor &amp; Potts</td>
<td>21</td>
<td>NE</td>
<td>SE</td>
<td>NW</td>
<td>&quot;</td>
<td>x</td>
<td>N45°–55°E</td>
<td>40'</td>
<td>C</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Renfro; Barnett, Hastie</td>
<td>23</td>
<td>NW</td>
<td>NW</td>
<td>SW</td>
<td>&quot;</td>
<td>x</td>
<td>x</td>
<td>22'</td>
<td>O</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Rose; W. M. Rohrer</td>
<td>30</td>
<td>E 1/2</td>
<td>NW</td>
<td>SE</td>
<td>&quot;</td>
<td>x</td>
<td>x</td>
<td>N–S±</td>
<td>40'</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

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- indicates data including information more recent than 1942.
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<th>CHARACTER OF DEPOSIT</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>J. Oxford; Rigsby, Martin and Frailey</td>
<td>Sec. 1/4 1/4 1/4 County</td>
<td></td>
<td>Thin veinlets of fluorspar exposed in fault zone in creek. Prospecting and churn drilling done nearby. Near Cadiz.</td>
</tr>
<tr>
<td>Dutton; Rock Creek Mining Co.</td>
<td>T. 11 S., R. 9 E.</td>
<td>17 SW SW SE Hardin</td>
<td>N55°E; NW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 0</td>
</tr>
<tr>
<td>Eureka</td>
<td></td>
<td>20 SW NW SE</td>
<td>N55°E; NW</td>
</tr>
<tr>
<td>Martin</td>
<td></td>
<td>23 SW NE SW</td>
<td>N40°E; NW</td>
</tr>
<tr>
<td>Terns; R. S. Terns</td>
<td></td>
<td>33 SW SW</td>
<td>38°</td>
</tr>
<tr>
<td>Simmons; Big Creek Mining Co.</td>
<td></td>
<td>35 SW SE SW</td>
<td>B C</td>
</tr>
<tr>
<td>Wall; Inland Steel Co.</td>
<td></td>
<td>35 NW SE SW</td>
<td>D C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>34 W1/4 SW SE</td>
<td>C C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 NE NE SE Pope</td>
<td>C C</td>
</tr>
</tbody>
</table>

**FLUORSPAR DEPOSITS OF ILLINOIS**
<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shelby; Spiller</td>
<td>9 S1/2 NW SE &quot; x N52°E; 62°SE 31/2' 35' B A On Lusk Creek fault zone. Several shallow shafts and adits. Production small. Some prospecting at point 800 feet north. Near Raum.</td>
</tr>
<tr>
<td>McGuire; Wm. Bowman</td>
<td>9 NE SE SW &quot; N50°E 50' On Lusk Creek fault zone. Small production. Much sphalerite present in one shaft. Near Raum.</td>
</tr>
<tr>
<td>Hobbs; Rogers</td>
<td>11 NE SE NE &quot; x 32' O Prospects shaft found calcite veinlets but no fluor spar. Near Eichorn.</td>
</tr>
<tr>
<td>D. C. Baker</td>
<td>11 SW NW SE &quot; x N55°E 30'-100' O Old workings. Small production reported. Near Eichorn.</td>
</tr>
<tr>
<td>Sheldon; Hubbard &amp; Cummins</td>
<td>11 E1/2 SW &quot; x x N35°E 1' 16'-55' C O Many abandoned shafts. Small commercial production from narrow vein. Near Eichorn.</td>
</tr>
<tr>
<td>Cowsert</td>
<td>11 SE NE NW &quot; x N37°E O O Exploratory work only. Near Eichorn.</td>
</tr>
</tbody>
</table>

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<thead>
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<th>NAME; Latest Operator Recorded</th>
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<th>CHARACTER OF DEPOSIT</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stewart; Fluorspar Products Co.</td>
<td>x x</td>
<td>Strike and dip of ore body or fault</td>
<td>Series of shafts on Stewart vein. Ore of high purity. Commercial production. Near Eichorn.</td>
</tr>
<tr>
<td>Balfour</td>
<td>x</td>
<td>Depth of shaft</td>
<td>Prospect shaft. Traces of fluorspar on dump. Near Eichorn.</td>
</tr>
<tr>
<td>Holloman</td>
<td>x</td>
<td>Galena</td>
<td>Old prospect shaft reportedly found veinlet of fluorspar. Near Eichorn.</td>
</tr>
<tr>
<td>Parkinson</td>
<td>x</td>
<td>Sphalerite</td>
<td>Old shaft and open cut. Barite only mineral observed. Near Shetlerville.</td>
</tr>
<tr>
<td>Stockton; Barnett, Karber and Adams</td>
<td>x</td>
<td></td>
<td>Water pumped down to 140' in 1942. Reported no sign of workable ore to that depth. Also known as Grand Pierre or Stogdon mine. Near Eichorn.</td>
</tr>
<tr>
<td>Location</td>
<td>Coordinates</td>
<td>Details</td>
<td></td>
</tr>
<tr>
<td>----------------------------------</td>
<td>-----------------</td>
<td>-------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Jefferson; Crystal Fluorspar Co.</strong></td>
<td></td>
<td>T. 12 S., R. 7 E.</td>
<td></td>
</tr>
<tr>
<td>Twitchell; Fluorspar Products Co.</td>
<td></td>
<td>23 NW SW NW Hardin, x N30°E; 80°ESE, 4' 260' B B</td>
<td></td>
</tr>
<tr>
<td>Rahn-Crystal; Crystal Fluorspar Co.</td>
<td></td>
<td>24 NE NE NE, x N22°E, near vertical 3' 115' O O</td>
<td></td>
</tr>
<tr>
<td>Rahn; Rahn</td>
<td></td>
<td>24 E1/2 NW SW, x 20' 90' O O</td>
<td></td>
</tr>
<tr>
<td>Pell; Cave in Rock Spar Co.</td>
<td></td>
<td>24 N1/2 NE NW, x N22°E; 85°ESE, 4' 20' B O</td>
<td></td>
</tr>
<tr>
<td>Tri-State; Fluorspar Products Co.</td>
<td></td>
<td>25 NW SW SW, x N15°E O O</td>
<td></td>
</tr>
<tr>
<td>S. Rotes</td>
<td></td>
<td>27 NE SW NE Pope, x 20' O B</td>
<td></td>
</tr>
<tr>
<td>Rotes; Skinner &amp; Randall</td>
<td></td>
<td>27 NW SE SW, x N25°E 1/2' 40' B A</td>
<td></td>
</tr>
<tr>
<td>Cox; Beecher Williams</td>
<td></td>
<td>36 NE NW NW Hardin, x N20°E 4' 70' B O</td>
<td></td>
</tr>
</tbody>
</table>

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b Indicates data including information more recent than 1942.


Two prospect shafts and some diamond drilling. Near Eichorn.


Extensive shallow prospecting and mining. Has been worked as open pit with dragline. Intermittent small production. Near Eichorn.

Intermittent small production. Also known as Miller mine. Near Eichorn.

Old prospect shaft in bottom of gulley. Minor fluorspar shows on dump. Also known as Black Jack shaft. Near Shetlerville.


Small production reported. Near Eichorn.
<table>
<thead>
<tr>
<th>NAME; Latest Operator Recorded</th>
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<th>CHARACTER OF DEPOSIT</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sec. ¼ ¼ ¼ County</td>
<td>Vein in rock</td>
<td>Weathered gravel spar*</td>
</tr>
<tr>
<td>Lacey; Big Creek Fluorspar Co., A. B. Mann</td>
<td>6 SW NW NW Hardin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>McClusky; Saylor, Gibbs &amp; Frits</td>
<td>7 NW NE NE</td>
<td>x x</td>
<td>NE</td>
</tr>
<tr>
<td>Berry; Yingling Mining Co.</td>
<td>9 NE SE SW</td>
<td>x x</td>
<td>N55°E; NW</td>
</tr>
<tr>
<td>Peckerwood</td>
<td>9 SW SE SW</td>
<td>x x</td>
<td>N68°E</td>
</tr>
<tr>
<td>Montgomery</td>
<td>16 NE NW NW</td>
<td>x x</td>
<td>N45°E</td>
</tr>
<tr>
<td>Interstate No. 2; Rosiclare Lead and Fluorspar Mining Co.</td>
<td>17 NE NW NE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooper; Collins</td>
<td>17 S½ NE SW</td>
<td>x x</td>
<td>N20°E; 80°NW</td>
</tr>
<tr>
<td>Cullum; Ralph Cullum</td>
<td>17 NE NW SW</td>
<td>x x</td>
<td>N50°E; SE</td>
</tr>
<tr>
<td>Township &amp; Section</td>
<td>Mine Name</td>
<td>Location</td>
<td>Symbol</td>
</tr>
<tr>
<td>-------------------</td>
<td>----------------------------</td>
<td>---------------</td>
<td>--------</td>
</tr>
<tr>
<td>T. 12 S., R. 8 E.</td>
<td>Interstate No. 1; Rosiclare Lead &amp; Fluorspar Mining Co.</td>
<td>17 C NW SW Hardin</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Gibbons; G. &amp; L. Fluorspar Co.</td>
<td>17 SW NW SW</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Jackson; J. M. Jackson</td>
<td>18 NW SW NE</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>F. Twitchell; Frank Twitchell</td>
<td>18 SW SE SW</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Indiana; U. S. Fluorspar Co.</td>
<td>19 W½ NE SW</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>Lavender; C. H. Stone</td>
<td>19 NW SE SW</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>Dubois; Crown Fluorspar Corp.</td>
<td>19 NE SW SW</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>Preen; A. B. Mann</td>
<td>19 NW NE NW</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>Clement-Dyspeck; Rosiclare Lead &amp; Fluorspar Co.</td>
<td>21 SW SW</td>
<td>x x</td>
</tr>
</tbody>
</table>

Old workings on Illinois Furnace fault between Cullum and Gibbons shafts. Near Rosiclare.

On Ill. Furnace fault. Shaft slopes 30°–45° from horizontal. Formerly there was a 55' vertical shaft at this place from which a small commercial production was obtained. Near Rosiclare.

Minor production of gravel spar. Near Rosiclare.


Former commercial production. Numerous abandoned shafts and open cuts in vicinity. Also known as Rogertown & Hillside No. 2 mine. Near Rosiclare.

Reported minor production. Near Rosiclare.


Small production of gravel spar. Many abandoned shafts and test pits. Also known as Red Tipple mine. Near Rosiclare.

Linear series of shallow workings. Probably an extension of Eureka vein.

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<th>CHARACTER OF DEPOSIT</th>
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<tbody>
<tr>
<td>Sec. 1/4 1/4 1/4 County</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T. 12 S., R. 9 E.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Hill; Bryan & Wallace | 11 NE SE SE Hardin | N55°-60°E 2' 12'-60' O C | Small production. Barite common. Near Cave in Rock.
| Frayser; Cache Mining Co. | 13 SW NE NE | N58°E 3' 110' O O | Small production from extension of Underwood deposit. Shaft not known to have encountered the ore body. Near Cave in Rock.
| Rogers; Kamm & Guard | 13 NE SW NE | N55°E 2½' 38' O O | Probably continuation of Winn ore body. Near Cave in Rock.
| Underwood; Cache Mining Co. | 13 SE NW SE | N58°E 3' 45' C C | Small production, some gravel spar. Near Cave in Rock.
| Patrick; Alco Lead Co. | 16 SW NW NW | N40°W A B | Property produced galena, cerussite, and smithsonite. Fluor spar very minor. Worked by large open pits with power machinery. Near Cave in Rock.
| Palmer; Alco Lead Co. | 17 NW SW NE | 40' C O | Workings principally shallow open cuts. Minor production of cerussite; fluor spar apparently lacking.
| Tower Rock; Jones & Ginn | 17 SE SW SE | N35°E 10°-120° C O | Small production. Fluor spar mostly in narrow veinlets in silicified fault zone. Also known as Iron Hill mine. Near Cave in Rock.
<table>
<thead>
<tr>
<th>Location</th>
<th>Township, Range</th>
<th>Direction</th>
<th>Distance</th>
<th>Grade</th>
<th>Grade</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little Jean; James Wardrop</td>
<td>T. 13 S., R. 7 E.</td>
<td>N70°W; S</td>
<td>13'</td>
<td>75'</td>
<td>C</td>
<td>Old workings followed vein with much barite and minor spar. Commercial production of barite reported 1918–1922. Near Golconda.</td>
</tr>
<tr>
<td>Compton; Illinois Fluorspar &amp; Lead Co.</td>
<td>T. 14 S., R. 6 E.</td>
<td>N45°E; 60°SE</td>
<td>60’–300’</td>
<td>B</td>
<td>C</td>
<td>Small production reported. Near Bay City.</td>
</tr>
</tbody>
</table>

Symbols are: A = Abundant; B = Moderate; C = Minor; O = None.

Indicates data including information more recent than 1942.
NOTE: changed to Alcoa Aluminum Company January 1, 1948.
Mining Company to Inland Steel in 1945, and Company as of July purchased its subsequent mineral and Fluorspar by Rosiclare Leo Mining Company.