THE UNIVERSITY OF MISSOURI STUDIES
VOLUME III., NUMBER 1

SCIENCE SERIES
GEORGE LEFEVRE, Editor

# THE BARITE DEPOSITS OF MISSOURI

AND

# THE GEOLOGY OF THE BARITE DISTRICT

WILLIAM ARTHUR TARR
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# INTRODUCTION

The barite industry of Missouri is more important than that of any other state in the United States. Missouri has furnished from 60 to 80 per cent of the barite produced in the United States for the last few years, and has been an important producer for a much longer period. This production has been maintained largely by the southeastern Missouri district, supplemented by a small and sporadic production from the central district. Various papers relating to the deposits have been published from time to time, but their geology has never been worked out in detail. Since the barite industry is very important and shows promise of becoming still more so, a detailed study of the geology of the deposits has seemed appropriate. Especial emphasis has been laid upon the mode of occurrence and origin of the barite, and any conclusions reached may have an important value in estimating the future of the industry.

The field work was done during the summer of 1916. Most of the time spent on the work was given to the southeastern district, as the geology of the central district was known. However, the few occurrences of barite there were examined. The areal geology was mapped over the larger part of the southeastern, or Washington County district, as it will be called in this report, since the deposits are largely confined to Washington County. Many citizens of Washington County contributed information while the field work was in progress, and the writer gratefully acknowledges their aid. He wishes to thank especially Mr. W. A. Buddecke, president of the Point Milling and Manufacturing Company, Mineral Point, Missouri; Mr. H. S. Bowler, superintendent of the Point Milling and Manufacturing Company; and Dr. E. K. McKenzie of the Point Milling and Manufacturing Company. Acknowledgment is also made for advice

given by Professor R. D. Salisbury, University of Chicago, and Professor E. B. Branson and Mr. D. K. Greger of the University of Missouri. Acknowledgment is also due to the writer's wife for making the necessary chemical analyses.

*History of the industry.*—The writer has been unable to fix exactly the date when barite was first mined in Missouri, but it seems to have been about 1860. In the Washington County district barite, or "tiff" or "heavy spar," had long been known because of its association with the galena. Schoolcraft, in his report on the lead mines of Missouri published in 1819 (page 190), comments on the abundance of barite in the lead mines of the district. He says:

"Sulphate of Barytes (Heavy Spar)—Mine à Burton (Potosi), Old Mines, Mine Shibboleth, and numerous other mines in Washington County, Missouri are characterized by sulfate of barytes. In those mines it forms the matrix of the lead ore; though it is sometimes found unaccompanied by ores of any kind, and the quantity which is found at Potosi alone is sufficient, according to our present ideas of its uses, for the supply of the whole world. It is generally found in compact or tabular masses, very white, heavy, and glistening. Sometimes it is crested, columnar, prismatic, or lamellar; and frequently the surface of the crystals are yellow, from an ochery oxide of iron. All the barytes I have observed in Missouri are perfectly opaque."

Schoolcraft suggests on page 101 that the barite might be used as a flux. Litton[1] in his report on the lead mines of southeastern Missouri mentions the minerals of the following metals as being the only ones that were important: Pb, Fe, Cu, Ni, Co, Zn, and Mn. Apparently the mining of barite had not yet begun at that time.

Broadhead[2] in a report on Miller County mentions the finding of barite crystals, and also comments on the use of barite as a pigment, but does not indicate that he was aware of its being mined for that purpose in Missouri. In a later report[3] Broadhead mentions in considerable detail the use of barite in paints, but fails to state definitely that it was being mined in Missouri,

[1]Litton, A. Dr., Mo. Geol. Surv., p. 12. 1855.

[2]Broadhead, G. C., Repts. of Geol. Surv. of Mo., p. 133. 1855-1871.

[3]Broadhead, G. C., Geol. Rept. of Mo., pp. 15, 50. 1872-1874.

tho he states (page 334) that about five years previously (1869) a man named Turner had a barite mill on the Osage River, about half a mile above the Bois Brale River. The product of the mill was shipped to St. Louis. This would indicate that Broadhead knew of the production of barite in Missouri. Bryant[4] gives the date of operation of this mill as 1866. Turner is said to have received $120 per ton for the refined product. He worked the mill for fifteen years, and when the price of barite dropped to $60 a ton, he sold out and left. It appears certain that active mining of barite was in progress in the 70's because Missouri is credited with a production of 8,000 tons in 1882. Such a large production would indicate that the industry had become thoroly established by that time.

Thruout this early period Virginia was the leading producer, but by 1893 Missouri was producing nearly an equal amount. In later years Missouri came more and more to the front, and in 1914 furnished about 65 per cent of the total product of the United States.

The history of the industry has been somewhat fitful. There have been periods of temporary activity, as at the present time, most of these periods following a marked increase in the price of barite. Complete statistics for the production of Missouri by years are not available. The following table shows the total production in the United States since 1882, and such figures for Missouri as are obtainable.

| | MISSOURI | UNITED STATES |
|---|---|---|
| 1882 | 8,000 Tons | 22,400 Tons |
| 1883 | | 30,240 |
| 1884 | | 28,000 |
| 1885 | | 16,800 |
| 1886 | | 11,200 |
| 1887 | | 16,800 |
| 1888 | | 22,400 |
| 1889 | 7,558 | 21,460 |
| 1890 | 9,882 | 21,911 |
| 1891 | 12,000 | 31,069 |

[4]Bryant, F. C., Eng. and Min. Jour., vol. 85, p. 317. 1913.

| | | |
|---|---|---|
| 1892 | | 32,108 |
| 1893 | | 28,970 |
| 1894 | | 23,335 |
| 1895 | | 21,529 |
| 1896 | | 17,068 |
| 1897 | | 26,042 |
| 1898 | | 31,306 |
| 1899 | | 41,894 |
| 1900 | | 67,680 |
| 1901 | 20,950 | 49,070 |
| 1902 | 31,334 | 61,668 |
| 1903 | 23,178 | 50,397 |
| 1904 | 25,498 | 65,727 |
| 1905 | 26,761 | 48,235 |
| 1906 | 28,869 | 50,231 |
| 1907 | 44,039 | 89,621 |
| 1908 | 16,319 | 38,527 |
| 1909 | 34,815 | 58,377 |
| 1910 | 22,978 | 42,975 |
| 1911 | 21,500 | 38,445 |
| 1912 | 24,530 | 37,478 |
| 1913 | 31,131 | 45,298 |
| 1914 | 33,317 | 51,317 |
| 1915 | 39,113 | 108,547 |
| 1916 | 58,223 | 221,952 |

These figures are those of the United States Geological Survey and are not exactly in agreement with those of the state geological survey. However, they are probably as accurate, because actual figures of production are hard to obtain with the present method of mining and selling the barite. The 100 per cent increase in 1915 and 1916 is notable.

## GEOGRAPHY OF THE WASHINGTON COUNTY DISTRICT

### LOCATION OF THE BARITE AREAS

The barite deposits of Missouri occur in two areas, the more important being the Washington County district, and the less important the central district. The first lies mostly in Washington

County but includes a few square miles of St. Francois County to the east. The total area of the district covered by the geological map is about 230 square miles, about 50 square miles of which had been mapped before the writer began his work. The area includes all of townships 37 N., R. 2 and 3 E.; 38 N., R. 2 and 3 E.; 39 N., R. 3 E.; the southern part of T. 40 N., R. 2 E.; and a small part of T. 40 N., R. 3 E.; nearly half of T. 39 N., R. 3 E.; the southwest sections of T. 39 N., R. 4 E., and the northwest corner of T. 39 N., R. 4 E. The entire area lies northwest of the St. Francois Mountains and upon the Ozark Plateau. It is some eight or ten miles to the nearest peaks of the mountains from the southern border of the district.

The Central district includes parts of Moniteau, Morgan, Camden, Miller and Cole counties in the central part of the state south of the Missouri River. The deposits are scattered over these counties, probably the most important ones being in Morgan, Miller, and Cole counties. The geography and geology of this district will be discussed separately.

### TOPOGRAPHY

*Relief.*—The Washington County district lies on a plateau in which streams have developed a mature topography. The highest points are in the southern part of the area, where several of the ridges rise to an elevation of about 1,250 feet. East of the ridge west of Hopewell and Summit, on the Iron Mountain Railroad, higher parts of the surface have a common elevation of about 1,000 feet. North of the high ridge, referred to above, the surface declines to about 1,100 feet west, northwest, and north of Potosi. The ridge between Mine à Breton Creek and Amaux Creek reaches 1,100 feet and the highest point at the northern side of the area is 1,050 feet. This indicates that the surface was originally a plain sloping to the north; and into it the streams have cut their valleys to depths of from 100 to 300 feet, the deeper valleys being those of the major streams to the north.

The lowest point of the area is a little less than 550 feet above sea level. This is on Big River where it flows out of the barite area. This is also the point where Mineral Fork, the largest stream entirely within the area, enters Big River. This gives a maximum difference in elevation for the area of about 700 feet. The average relief, however, is about 200 feet.

The region, as a whole, is completely dissected, there being no areas that are not entirely in slope. The ridges do not have flat tops and generally are very narrow, some of them being so narrow that the drainage from the two wheel tracks of a wagon road flows into widely separated creeks. The crests of these long ridges are marked by numerous small knolls and sags.

*Plateaus and escarpments.*—There is a marked escarpment, due to the Gasconade formation, which begins nearly two miles west of Hopewell, and follows a slightly northwest direction to a point southeast of Old Mines, thence swinging northwest and going out of the area due north of Richwoods. West of this escarpment the surface declines from an elevation of about 1,250 feet at the south to about 1,050 feet at the north, and the plateau to the east of the escarpment has an elevation of about 1,050 feet at the south and about 850 feet at the north. This difference of about 200 feet on opposite sides of the escarpment is just about the thickness of the Gasconade formation as found over the larger part of the area. The dip of the beds is not parallel to the slope of the surface, altho on the whole the beds dip to the north. The escarpment is due to the great resistance of the Gasconade formation.

Marbut,[5] in his discussion of the physical features of this region, has called this the Potosi Escarpment, the plain to the east the Summit Platform, and the upland to the west the Salem Platform. The latter extends to the western part of the state and includes practically all of the Ozark Plateau. In his map of the physiographic belts and platforms (plate 2 of the above report) Marbut has the Summit Platform stopping at about the northern end of Washington County. There would seem to be little reason for so limiting it for the region to the north is certainly a continuation of it. He correctly interprets the Potosi Escarpment as being due to a resistant member of the Ozark Series, but of course, he could not tell which formation it was, since the geology of the region had not been worked out.

[5]Marbut, C. F., "The Physical Features of Missouri," Mo. Geol. Surv., vol. X, p. 37. 1896.

Standing upon a bluff, or any other high point in the eastern part of the area, one can readily see the Salem Platform and the Potosi Escarpment. The even crests of the ridges are a feature which is striking from almost any high point in the region. except where the Potosi Escarpment comes into view. As the surface represented by the crests of the ridges bevels the edges of the slightly dipping beds, it seems clear that the present drainage system has developed the mature topography from a former peneplain or base-leveled surface. Evidence from other parts of the state supports this view. This point will be more fully discussed later.

*Drainage.*—The entire area is drained by Big River except a few square miles in the vicinity of Richwoods which are drained by Little Indian Creek. Big River forms a part of the eastern boundary of the area and also flows across it for a few miles. The streams of the southern part of the region flow southeast into Big River, which flows in a northeasterly direction south of the area, coming just to the southern boundary near the southeastern corner. The east-central part of the area is drained by Mill Creek and its various tributaries. Mill Creek flows northeast and joins Big River just south of Blackwell. The western part of the area is drained by several creeks which finally unite near the western border to form Mineral Fork, a large stream that flows northeast across the area and joins Big River. The extreme southwestern part is drained by the North Fork, a branch of the Fourche à Renault Creek; while Mine à Breton Creek with its branches, Bates Creek and Swan (locally called Swine) Branch drain the west-central part of the area. Amaux Creek, Mill Creek, and Old Mines Creek flow into Mineral Fork from the south and Clear Creek and Rocky Branch from the north. Calico Creek and Ditch Creek drain the northeastern part of the area.

While several of the streams are large, they have not developed flood plains of any extent. Small strips of alluvium are found along only the larger streams. Rarely is the valley of the Mineral Fork, for instance, more than a quarter of a mile wide, and its average width is from 300 to 500 feet. Patches of alluvial plains are found on the inside of the larger bends of Big that it affected the Ozark region also is shown by the rejuvenated streams and the presence of a few patches of the Lafayette gravels (a late Tertiary residual deposit).

## SOILS

The soils are mainly residual, with smaller areas of alluvial soils along the streams. Residual soils predominate thruout the area, but they are especially well developed in the Richwoods area, the area from Old Mines to Fertile and Blackwell, and that to the east of Potosi. In these regions the relief is less than elsewhere and it is here that most of the farming land is found. It is not intended to convey the idea that residual soils are found in these areas only, but that they are deeper here than elsewhere. All the hills have a cover of residual soil, but much of it contains so much chert and quartz that it is of little value for agricultural purposes.

### *Alluvial soils*

In some places the larger streams have laid down thick deposits of alluvium, altho in many places the finer silts and clays form only a thin veneer over the cherty gravels below. In many sections seen along Mineral Fork, Mine à Breton, Bates, and Little Indian creeks there was less than a foot of soil over the gravels. The alluvial soils on Big River are much thicker, and are, or were, very fertile. This river flows thru the southeastern Missouri lead belt, and formerly the sludge waters from the concentrating mills were allowed to flow directly into the stream. In times of high water this material was deposited on the floodplain and proved to be very deleterious to the crops. A court order finally forced the mining companies to stop the practice.

The bringing of the large loads of coarse gravel down to the larger streams and the consequent filling up of their channels is bringing about a situation which is becoming a serious matter for those who own the bottom lands. In many places stone retaining walls built 15 to 25 years ago are nearly buried in stream gravels. Frequently the front of the advancing gravel bed is two feet high and every flood moves it farther out on the bottom lands. The advance of the gravels is not unlike the advance of a sand dune. The alluvial soils are mainly silts, which are in places sandy.

The smaller valleys contain a certain amount of alluvial soil, but in the main their soils are thin and stony. The origin of the soils is interesting as they are in large part due to side wash from the slopes, which carries the finer materials down into the valleys. Here the water sinks into the coarse gravels, leaving the fine articles of sand, silt, and clay behind to form the soil. To this is added the material deposited by the stream in times of flood.

### *Residual soils*

Residual soils will be classified according to the formations from which they were derived. This will enable the soils from different types of rocks to be compared, and will permit of ready reference to each type.

*Elvins soil.*—The areas which were underlain by the Elvins dolomite and shales are so limited that little is known as to the character of the soils derived from them. Some of these areas are along Fertile Creek and the soil is a grayish to reddish sandy loam, but it is probable that it contains some transported material and therefore does not represent the true character of the residual soil.

*Potosi soil.*—Since the Potosi dolomite underlies more than half of the area there was ample opportunity to observe its soil. Likewise the major part of the barite deposits as well as the old lead diggings are found in the mantle rock from this formation; hence it was studied in detail.

The surface layer over most of the area varies from dark gray or black thru gray to reddish, while the deep red of the lower part of the mantle rock is exposed at the surface in only a few places. In those areas that have recently been cleared the Potosi soil is usually an ash-gray. The underyling residual material is everywhere red, usually of a very deep shade. The Potosi soil may or may not contain the drusy quartz which is so abundant in the dolomite. The mantle rock ranges in thickness from nothing up to 20 feet, the average being about 10 to 12 feet. In most instances the upper foot or two is free from quartz and chert, especially where the slope is gentle enough to prevent rapid erosion. Where erosion is rapid, the quartz is at the surface, and not infrequently barite is abundant there also. This is especially true of the outlying areas where barite is just beginning to be produced. The soils of the Potosi are fertile and are tilled wherever the topographic position of the land permits.

*Proctor soil.*—There is practically no difference in color between the Proctor and the Potosi soils. As the Proctor dolomite contains very little chert, its soils are relatively free from it, unless they contain some which is residual from the overlying Gasconade dolomite and sandstone. The Proctor dolomite is less resistant to weathering than the other formations and forms gentle benches on the less steep slopes. The soils are very fertile, and are tilled over most of the area where the Proctor formation is found. Since the soil derived from the Proctor formation is usually free from chert it is tilled on the crest of a hill or on the sides.

*Soils from the Gasconade and Roubidoux Formations.*—The soils from these formations are gray and black at the surface but below they are yellow and brown where the other formations are red. Almost without exception these soils are full of chert, sandstone, or quartzite. The exceptions are the occasional flat areas on the crest of the ridges. Here the soils are sometimes relatively free from chert and are of an ash-gray color. They are generally only a foot or eighteen inches thick. With sufficient rain they make very good soils. Since there is much sandstone in these formations, the soils from them are largely sandy loams. Pines are numerous on such soils.

### *Wind-blown soils*

It has been mentioned above that all the soils, especially those on the crests of the ridges, may have an ash-gray color. This color is rarely more than a few inches thick and gives way to a clay loam below. Examination with a microscope shows that the particles are more or less rounded altho they are very fine. Since they are found especially upon the crests of the ridges it is believed that the material is largely wind-blown.

## CLIMATE

The climate of the Ozark region is not very different from that of most of Missouri. The average annual rainfall is 43.66 inches. The rainfall shows considerable variation from year to year, and severe droughts are known. The average snowfall is about 18 inches. The mean annual temperature is 65 degrees, but a fraction of a degree higher than the average for the state. The daily range is usually great, being occasionally about 50 degrees. This wide range of temperatures would be very effective in weathering were it not for the protection afforded by the deep mantle rock. The fact that the chert thruout the area is reduced to small fragments is due to these temperature effects.

## VEGETATION

The region is covered by a heavy forest growth, which includes the following kinds of trees: red pine, cedar, juniper, post oak, white oak, sycamore, cottonwood, maple, willow, hackberry, sassafras, persimmon, pawpaw and many others. In addition to the trees there are many small shrubs and vines, among them the blackberry, raspberry, blueberry, dewberry, and others producing edible fruits. Grass is fairly abundant, especially on the open glades. The farmer allows his stock to run in the open woods, and they are usually in good condition. Most of the bottoms are under cultivation and much hay is raised in addition to wheat, oats, corn, cane, and some tobacco.

## CULTURE

*Inhabitants.*—The area covered by this report was settled very early. The first settlers were the French, who came there about 1725, following the discovery of lead in the region of Old Mines, six miles north of Potosi, and at Mine Renault, eight miles northwest of Potosi. The Spanish followed in 1769, but few of them remained after the purchase of Louisiana by the United States in 1803. About the year 1800 settlers from the eastern part of the United States came to the region, and in large part their descendants still live there. About Old Mines the greater part of the population still speaks French, tho English is spoken there also.

There are various classes of people, but the majority of those who live in the country are very poor. In those parts of the district, however, where the farm lands are good, the people are a very prosperous class. A large part of the people depend wholly on the barite industry. These are known as "tiff-diggers." During the winter and in dry weather the poorer farmers also dig "tiff."

The principal occupations of the people are farming, digging barite, and making ties and barrel staves.

## GENERAL GEOLOGY OF THE WASHINGTON COUNTY DISTRICT

### OUTLINE OF THE GENERAL GEOLOGY

All the formations of the region are of Cambrian age. They include the Davis, the Derby, and the Doerun formations as defined by Buckley,[6] which, however, are all included in the Elvins formation of Ulrich.[7] Above the Elvins formation are the Potosi, the Proctor, the Gasconade, and the Roubidoux formations. The entire group belongs in what is known as the "Ozark Series."

These formations include all the members of Ulrich's "Ozarkian System,"[8] and the formations immediately above and below it. His "Ozarkian" includes the upper part of the Cambrian, as commonly defined, and the lower part of the Ordovician.

The formations are largely dolomites, altho some contain shale, chert, and sandstone, and there are a few conglomerates. There is practically no limestone in the entire group. Fossils are almost unknown, and, since there is considerable lithologic similarity among the formations, differentiation is extremely difficult. The boundaries must be drawn rather arbitrarily and their accuracy will depend upon the familiarity of the observer with the formations involved.

[6]Buckley, E. R., Mo. Bur. of Geol. and Mines, vol. 9, Pt. 1, pp. 33-49, 1908.

[7]Ulrich, E. O., "The Copper Deposits of Missouri," Bull. 267, U. S. G. S., p. 23.

[8]Ulrich, E. O., Bull. Geol. Soc. Am., vol. 22, pp. 281-680. 1911.

## *Geological Section*

| *Arrangement of E. R. Buckley* | | | *Arrangement of E. O. Ulrich* | | *Arrangement in this paper* | |
|---|---|---|---|---|---|---|
| Cambrian | Upper Cambrian | Unconformity<br>Jefferson City<br>Roubidoux | Canadian | | Jefferson City<br>Robidoux<br>Unconformity<br>Gasconade | Ordovician |
| | | Unconformity<br>Gasconade<br>Unconformity<br>Proctor<br>Eminence<br>Potosi | Ozarkian | | Unconformity<br>Proctor<br>(Eminence?)<br>Potosi<br>Unconformity<br>Elvins | Upper Cambrian |
| | | Doerun<br>Derby<br>Davis | Elvins of Ulrich | Upper Cambrian | | |
| | Middle Cambrian | Bonneterre dolomite<br>Lamotte sandstone | | | | |

The great preponderance of carbonate rocks indicates that the formations were offshore deposits. The considerable amount of sandstone found in the upper formations points to a shifting of the shore line, so that at times the area was nearer to the shore than it was at other times.

## STRATIGRAPHY

### *Elvins formation*

The Elvins formation has a limited distribution in the area. In nearly every case its exposures are due to structural changes. The various outcrops are in the extreme southeastern corner of the area; a small section on the eastern boundary; a rather large section along Big River and Mineral Fork in T. 39 N., R. 3 E.; and the region along the two forks of Calico Creek. In most of the places where the formation outcrops its position is due to faulting and folding.

There are good exposures of parts of the formation along the larger streams. The bluffs of Big River, near where it is joined by Mineral Fork, afford excellent exposures. The outcrop in the extreme southeastern corner is along Big River also, and furnishes a fair exposure, altho the major part of the bluff is covered with talus. The members of the lower part of the Elvins formation are well exposed along Blays Creek after it crosses the fault that brings these beds up alongside the younger members. There are fairly good exposures along Mineral Fork and for a short distance up Old Mines Creek. Nowhere is the complete section shown. Two partial sections were made, of which one is given below. The thickness of the formation is 139 feet 9 inches on the bluff of Big River and 135 feet on Fertile Creek.

Wherever the Elvins formation is found, the slopes are rocky and only thinly covered with soil or mantle rock. The formation is exposed as cliffs along the larger streams. Cedars predominate on all outcrops of this formation. It is rather striking to see them on one side of a fault plane with oaks on the other side at the same elevation.

*Petrography of the formation.*—In composition the Elvins formation is one of the most variable formations of the region.

It consists predominantly of dolomite, calcareous dolomite, shale, conglomerate, and some sandy, glauconitic dolomite. The shale, sandy dolomite, and conglomerate predominate in the lower part of the formation (the Davis shale of Buckley's report), but are interbedded with dolomite and calcareous dolomite. The character of the upper part is shown by the following partial section taken at the bluff on Big River near its junction with Mineral Fork:

PARTIAL SECTION OF THE ELVINS FORMATION, BEGINNING AT THE TOP

| | |
|---|---|
| Dolomite, yellowish, fine-grained, finely porous, rather mottled, thick bedded; weathers into angular blocks 3 or 5 feet square and 1 foot thick | 4 ft. |
| Dolomite, mottled gray, contains numerous fragments of quartz and some crystals of calcite, thick-bedded; weathers into very large blocks | 4 ft. |
| Dolomite, light to dark gray, fine-grained, has nodular structure and fine, wavy bedding planes; weathers into beds from 1 inch to 1 foot thick | 11 ft. |
| Dolomite, light gray, very fine-grained, nodular, platy, thin-bedded | 6 ft. |
| Dolomite, light gray, fine-grained, massive, contains fragments of calcite an inch or more across | 2 ft. |
| Dolomite, light colored, thin-bedded, platy, contains irregular fragments of calcite | 1 ft. 6 in. |
| Dolomite, light gray, medium to fine-grained | 3 ft. 6 in. |
| Dolomite, light gray, very dense, hard, contains small amount of pyrite, upper part contains masses of calcite; shows bedding planes; weathers to elongated angular fragments on a flat surface; would probably weather platy | 9 ft. 6 in. |
| Dolomite, yellowish-gray, medium to fine-grained, slightly porous, contains crystals of calcite; weathers into blocks 1 foot or more square | 3 ft. |
| Dolomite, gray, shaly, fucoidal, fine-grained; weathers rapidly and forms re-entrants | 4 ft. |
| Dolomite, dark gray, massive, medium-grained | 3 ft. |
| Dolomite, gray, mottled, fine-grained; weathers to a thick bed in angular blocks 1 foot square | 1 ft. 9 in. |
| Dolomite, gray, weathers to a buff color, very dense; shows suggestions of thin bedding; shows fucoids in abundance, weathering taking place around them | 3 ft. 3 in. |
| Dolomite, gray, shaly, medium to fine-grained, very tough, some beds slightly porous; weathers to irregular shaped fragments an inch or two in diameter; middle parts weather platy | 6 ft. |

| | |
|---|---|
| Dolomite, pink, medium-grained, weathers to a very rough, pitted surface | 1 ft. 3 in. |
| Dolomite, gray, porous, dense, medium-grained | 6 in. |
| Dolomite, gray, thin-bedded, weathers rough and nodular, rather argillaceous | 1 ft. 6 in. |
| Dolomite, yellowish-gray, medium-grained, weathers to a very rough pitted surface | 2 ft. |
| Dolomite, buff colored, weathers dark gray; fine to medium-grained; thin bedded, beds up to 6 inches in thickness; some beds contain scattered grains of glauconite; others contain small grains of purite; some beds are porous | 18 ft. |
| Dolomite, fine-grained, dense, tough, weathers yellow, surface weathers gray | 8 ft. |
| Slope covered by talus | 40 ft. |

The striking feature of the Davis member is the abundance of edgewise and intraformational conglomerates (only one of these is really an edgewise conglomerate) in its lower part. Buckley recognized fifteen of these conglomerate beds in the section of the Davis formation in the "Lead Belt," but the number in this area is unknown because of the limited outcrops of this part of the formation. There are seven or eight of them in the lower 80 feet of the formation. The "edgewise" conglomerates are interbedded with the same kind of materials of which they are composed, thus proving them to be intraformational conglomerates as noted above.

The dolomites of this lower part range in texture from fine to medium-grained. The fine-grained ones are very dense and tough, and break with a rudely conchoidal fracture as a rule. Most of them are medium-grained and distinctly granular. The colors are usually light shades of gray, but with pinkish and greenish phases. The weathered rock usually assumes a buff, grayish, or yellowish color.

The accessory minerals of the dolomite are calcite, quartz, glauconite, iron, pyrite (in small nodules), a few grains of galena, and clay. The glauconite is more abundant in the shaly, sandy portions near the lower part of the section.

The dolomite contains calcite (sometimes in areas up to one and one-half inches across) which weathers faster than the dolomite, thus giving the rock a pitted surface. The calcite crystals are hosts to numerous crystals of dolomite. These beds do not contain much glauconite or sand.

The dolomites are in beds ranging from an inch up to several feet in thickness. Some parts are very thin-bedded and shaly, while others are massive and weather into large angular and rounded blocks. The conglomerate layers are distinctly lenticular, as are also many of the dolomite and shale beds. Ripple marks were found on all the beds comprising this lower, or Davis, member. Most of them are two or three inches across. Buckley[9] reports that some of the beds contain sun cracks.

Fossils are not abundant, as a rule, but a bed was found in which cystoid stems were numerous. Some distance above this bed a thin platy dolomite contains an abundance of lingulas. Buckley (ibid., p. 38) reports that trilobites are also found in some of the beds, but none were seen in the rocks of this area. The so-called fucoids are found rather abundantly in the dolomites. They are frequently of large size; several inches long and nearly an inch across.

The shales are little exposed, but those seen were blue to bluish-gray and very thin-bedded. They are only slightly calcareous, except along certain layers which contain fucoids. All the shales contain some magnesium carbonate. They are in beds four to five feet thick interbedded with the dolomite. They were not observed in association with the sandy dolomites. They weather to thin plates of a yellow color. One bed broke down to an ash-gray soil.

The sandy dolomites are found in the lower part of the section, except in the southeastern part of the area, where the upper dolomite beds of the Elvins formation contain thin lenticular layers of sandy dolomite. The color varies from yellowish-red to greenish-red. Texturally, they are medium to fine-grained, the latter predominating. They consist essentially of dolomite, glauconite, quartz and clay. There is an abundance of dark green grains of glauconite in these beds. Under the microscope the glauconite grains are seen to be round, while the associated grains of sand (less than 15 per cent of the rock), are angular to subangular. The glauconite in thin section is pale green. The

[9]Buckley, E. R., Mo. Bur. of Geol. and Mines, vol. 9, Pt. 1, p. 38. 1908.

grains are about .3 to .4 mm. in diameter. On weathering the glauconite is partially replaced by limonite.

These sandy beds are very thin, but each layer shows still finer laminations which are caused by variations in the amount of glauconite present, and by the crystallinity of the dolomite, some layers having a medium granular texture, while others are fine-grained. Ripple marks are abundant in these beds. The sandy beds are usually not more than a few inches thick.

The "edgewise" conglomerates are interesting since they indicate shallow water. The conglomerates are rarely more than a foot in thickness and most of them are only four to six inches. As noted above, most of them are lenticular, and are found especially in the lower part of the formation. The conglomerates are greenish-red to greenish-gray in color. Some are fairly dark, but the majority are of the lighter shades. The rock consists of pebbles of the underlying, thin-bedded glauconitic, sandy dolomites, the pebbles ranging from one inch to four or five inches in length and from a quarter to a half inch in thickness. They are rudely oval in outline. The corners are rounded off, but not very perfectly (Pl. III, A).

Most of the pebbles are rudely parallel to each other and to the bedding planes; but in some of the beds, especially in those higher up in the formation, they lie in all possible positions.

There does not appear to be any difference in the crystallinity between the pebbles and the matrix. The pebbles are distinguished in the unweathered conglomerate by being darker in color than the matrix. Under the microscope the pebbles are not only darker, which is due to their containing more kaolin, but the grains are also smaller than those in the matrix. One of the pebbles contains distinct evidence of organic remains which are indicated by the arrangement of the constituents of the dolomite around them. On weathering, the matrix is attacked first, leaving the pebbles as rather prominent surface features. In one instance the pebbles in the upper part of the conglomerate bed were well rounded instead of being flat. The matrix of this bed weathered to a yellow color.

These conglomerates do not belong to the type described by Grabau,[1] for there is no evidence of any kind that the beds have

[1]Grabau, A. W., "Principles of Stratigraphy," p. 530.

been moved by sliding. The pebbles are all more or less rounded, showing water action, and the horizontal position of the majority of them shows that they were deposited by water. They were undoubtedly formed in shallow water after the muds have been partially hardened. The waves then broke up the crust, partially rounded the fragments, and buried them in a carbonate mud.

*Upper part of the Elvins.*—Beds that Buckley called the Derby and Doerun formations are here regarded as the Upper Elvins for reasons given later. They are dolomites or slightly calcareous dolomites from top to bottom. There are some shaly beds, but these are relatively free from more than a thin film of clayey material. No sandy lenses were observed in the area along Big River or Mineral Fork like those in the dolomites in the southeastern corner of the area. The prevailing color is some shade of gray, a light gray shade greatly predominating, altho occasionally some beds are bluish-gray. Near the top of the formation the beds are buff, the topmost layers having a distinctly pinkish cast. Mottled beds are rather numerous, and the mottling is due to dark bluish-gray nodules of dolomite in a matrix of soft light gray dolomite. These darker parts are sections of fucoids.

The beds vary in texture from very dense, fine-grained dolomites to coarse-grained ones. The majority are fine to medium-grained and have a distinctly granular appearance. Some of the beds, especially those in the upper part of the formation, are very soft and porous, the pores ranging from a fraction of a millimeter to three millimeters in diameter. The buff colored beds near the top are especially characterized by porosity. The porous beds contain many small grains of limonite, which indicates some previously existing pyrite.

The beds are rather pure dolomite, and, like the lower part of the formation, contain occasional areas of calcite which weather faster than the dolomite.

The beds range in thickness from an inch to 8 or 10 feet, the thickest beds being near the top. A peculiar undulatory structure was observed in these beds. The structure resembles large ripple marks, 10 feet from crest to crest, with an amplitude of 2 feet. The crests are composed of hard reddish-gray dolomite, and the hollows are filled with a bluish, shaly dolomite. The surface of many of the beds is covered with fucoidal markings, or is very rough, due to a nodular structure. One bed, about 38 or 40 feet from the top, is dense and hard, and rings sharp when struck with a hammer. It contains small irregular masses of quartz. This bed is persistent, having been seen in several parts of the area. The pink, porous dolomite at the top of the Elvins formation shows splendid cross-bedding (Pl. V, A), indicating very shallow water conditions at the close of the period.

No fossils were found in the upper part of the formation.

The weathering of the beds produces a reddish mantle rock where it is thick enough not to be affected by the organic acids from the surface. It is usually very thin, and the underlying rock is often exposed. The dolomite weathers out into small rectangular fragments where thin-bedded, and into large rounded boulders where massive.

The following composite analysis shows the composition of the Elvins dolomites:

| | |
|---|---|
| $SiO_2$ | 6.20 |
| $Al_2O_3$ | 1.10 |
| $Fe_2O_3$, $FeO$ | .87 |
| $MgO$ | 20.01 |
| $CaO$ | 28.70 |
| $CO_2$ | 42.77 |
| $H_2O$ | .42 |
| | 100.07 |

*Age and Correlation.*—The age of the Elvins formation is unquestionably Upper Cambrian. Only a few fossils were found and they were brachiopods and cystoid stems. The latter were very abundant in some of the lower beds. The brachiopods were identified by Mr. D. K. Greger of the department of geology at the University of Missouri, and the following species were found: *Eoorthis remnicha texana, Obolus matinalis, Lingulella similia,* and *Obolus ismene?* These fossils are regarded as Upper Cambrian in age.

The base of this series of rocks is not exposed in the area studied. They are evidently not so thick as they are in the "Lead Belt." The top of the formation is drawn where the pink, porous dolomite ends, and the bluish-gray crystalline drusy dolomite of the Potosi begins. This upper limit is easily and accurately determined.

Buckley[2] subdivides the Elvins formation of Ulrich[3] into three parts, which he calls the Davis, the Derby, and the Doerun. The Davis formation, at least, is the equivalent of the lower part of the Elvins formation as described by Ulrich, and according to Buckley is 170 feet thick. It includes the conglomerate beds which are described above as being in the lower part of the Elvins formation. This formation in the Flat River region contains a so-called boulder bed near the central part. This bed is entirely lacking in the Washington County area. Likewise, there is very little shale in the upper part of what would be the Davis formation, so that it is impossible to draw a line between the Davis formation and the overlying Derby dolomite.

The Derby formation, which is about 40 feet thick, is described by Buckley as follows:

"This horizon is characterized by massive beds of hackly dolomite, which, upon weathering, break down into large polygonal blocks often 20 feet in their greatest diameter. Weathering proceeds rapidly along joint planes of which there are two especially prominent systems nearly at right angles to each other.

"As a whole this formation is a fine-grained, crystalline, slightly calcareous dolomite. Soft, porous beds alternate with those that are hard, dense, and brittle. In color the dolomite varies from a light gray through yellowish gray to reddish brown. The pitted character of the weathered surface of some of the beds appears to be due to the solution of the more calcareous areas of the dolomite."

Buckley describes the Doerun formation as a "horizon which consists chiefly of argillaceous dolomite." There are "alternating beds of argillaceous dolomite, finely crystalline dense

[2]Buckley, E. R., Mo. Bur. of Geol. and Mines, vol. 9, Pt. 1, pp. 33-49. 1908.

[3]Ulrich, E. O., Bull. 267, U. S. G. S., pp. 22-26.

dolomite and soft finely porous dolomite." It is about 50 to 60 feet thick and possibly thicker.

It was found to be impossible to separate satisfactorily these two members from the underlying formation and from each other in the Washington County area, hence they are grouped together and called by the name first given to them by Ulrich, the "Elvins." He states (ibid, p. 23):

"This name is proposed for the shales, shaly limestones and more or less earthy dolomites that in St. Francois County intervene between the shaly top of the underlying Bonneterre limestone and the cherty limestones of the Potosi group above.

"The bed of pink dolomite assigned to the base of the Potosi in the foregoing section contains no chert nor drusy quartz, and in that respect differs decidedly from the overlying beds of the formation. It may therefore be regarded as more properly referable to the Elvins formation. This is not here, for the reason that it or a similar bed inaugurates the Potosi sedimentation in areas where the Elvins formation is missing."

This pink bed is here included with the Elvins for it is more distinctly related lithologically to the formations below than to those above. No evidence was found to indicate that the relationship between the Elvins formation and the Potosi dolomite was other than one of conformity. Both Ulrich and Buckley thot they might be unconformable locally, but did not cite the evidence. Ulrich[4] states that the "Elvins" is in unconformable contact with the base of the Ozarkian system (the Potosi). In the paper cited, Ulrich defines his Ozarkian system and places its base between the Elvins formation and the Potosi formation. The structural, faunal, and petrological differences of these two formations are certainly great. Whether the break between them is sufficiently great to call it the line between two systems future studies will determine.

### *Potosi formation*

The Potosi formation covers about one-half the area mapped. It is nearly continuous from the southern end to the northern in the eastern half of the area, except where the streams have

[4]Ulrich, E. O., Bull. Geol. Soc. Am., vol. 22, p. 623. 1911. Also pp. 628-633.

cut down to the Elvins formation. The other extensive area lies along Mineral Fork, Mine à Breton, and Bates creeks.

The eastern area constitutes the Summit Platform as described above. It also includes the more important farming areas in the district. This is due largely to the fact that the Potosi weathers to hills with less relief than any other formation having much areal extent in the district.

The exposures of the Potosi in the western part of the district are due to the fact that the larger streams have cut thru the overlying formations. About eight miles to the southwest of the area mapped Hazel Creek has cut down to and exposed the Potosi along its bottom.

The bluffs along Mineral Fork, Old Mines Creek, and Mine à Breton Creek have many excellent exposures of the Potosi formation. Many of these exposures are 75 to 100 feet or more high, and where the stream is cutting at the foot of the bluff, as is common, there is no talus to obstruct the exposure of the lower portion. These bluffs afford opportunity to study the formation. Good exposures are also found along Big River where it flows across the Potosi formation.

The mantle rock is thicker over the Potosi dolomite than over any of the other formations unless it be the Proctor dolomite which is very similar to the Potosi dolomite in many respects. As a rule, the soil and subsoil derived from the Potosi dolomite are free from quartz and chert, but where the slopes are great enough to favor rapid erosion, these materials become abundant, and on the sides of the sharper valleys the Potosi formation itself outcrops. The soil is fertile and covered with a heavy growth of oaks of various kinds.

*Petrography.*—The Potosi formation is dolomite from top to bottom and contains a large amount of drusy quartz, chalcedony, and chert. The dolomite is distinctly granular and the greater part is medium-grained, with a few fine-grained beds. The remarkably uniform granularity is striking, and the similarity of this formation to the Proctor dolomite would make it difficult to differentiate between the two formations, if it were not for the ever present drusy quartz of the Potosi. There are many small cavities in the rock lined with quartz, dolomite, or more rarely calcite crystals.

The predominating color of the formation is light bluish-gray, but dark grays, buffs, and in some places red and pink are seen. It weathers to a rather dark gray, with occasional reddish and buff members.

The Potosi formation consists of beds ranging from a foot or so in thickness up to 9 or 10 feet. While they appear massive, some of them weather into thinner beds, but in no instance thinner than 6 or 8 inches. The weathered surface of some of the fine-grained beds is very smooth and appears to be due to temperature changes rather than to solution. Where solution is important the resulting outcrop is very rough and hackly, the surface being marked by many irregular depressions. In a few places stylolites, up to an inch or more in length, appear in the lower part of the formation.

The microscope shows that the crystals of dolomite are anhedral, with very irregular outlines, and that they are strongly interlocked. The grains all show considerable kaolin. They average .3 to .5 mm. in diameter. Steidtmann[5] has recently called attention to the fact that dolomite grains are anhedral where they are in contact with each other and rhombohedral where in contact with calcite. Using this as a criterion, no calcite would be present in the dolomite, a fact borne out by the analyses.

The composition of the Potosi dolomite is shown by the following analysis:

| | |
|---|---|
| $SiO_2$ | 2.03 |
| $Al_2O_3$ | .14 |
| $Fe_2O_3$ / $FeO$ | .54 |
| $MgO$ | 20.98 |
| $CaO$ | 30.30 |
| $CO_2$ | 45.35 |
| $H_2O$ | .30 |
| | 99.64 |

The Potosi dolomite contains an abundance of silica, not only in the form of drusy quartz, but as chalcedony, and to a less ex-

[5]Steidtmann, E., "Results of a Study of Dolomitization," Science, vol. 44, pp. 56-57. 1916.

tent as chert. In two or three localities a small amount of flint was observed and rarely some bright green chert was found. Both the flint and the green chert are near the top of the formation. The chert is dense, gray to white in color, and breaks with a conchoidal fracture. It is in masses up to two or three feet thick and several feet long. It is not in continuous beds, and the smaller masses are very irregular. There is little banding in the chert. The drusy quartz and chert are either in distinct beds, or parts of individual beds of dolomite. Many beds of the latter are entirely free from either form of silica.

It is the drusy quartz and chalcedony that distinguish the Potosi formation from all other formations in this area. They are found in very irregular masses of various shapes; in large honey-combed masses, two to two and one-half feet thick; and in veins.

The drusy forms are similar to geodes, tho differing from them in some respects. The majority of the drusy cavities are of such a shape as to have the inner surfaces dominantly convex instead of concave as in geodes (Pl. V, B). These convex surfaces are covered by the crystals of minerals which are in the cavities. They have an infinite variety of shapes. As a rule the larger cavities, those more than two inches long, do not contain dolomite or calcite, tho these minerals are in the smaller openings. The quartz crystals are of various sizes, from very minute ones that cannot be distinguished with the naked eye, to those nearly half an inch in diameter and an inch to an inch and a quarter in length. The quartz and chalcedony are in alternating layers from a fifth to one hundredth of an inch thick (Pl. III, E). There are as many as 40 to 50 in a single banded zone in some cases. On a few specimens thin bands of limonite were found coating the quartz layers and covered by chalcedony. No limonite was seen on a freshly fractured surface, hence it is probably due to a slight infiltration along cracks or porous bands.

The large honey-combed masses of drusy quartz have the appearance of a series of pipes coalescing at intervals. The central part of the pipes, in fresh specimens, contains dolomite, around which the quartz is deposited (Pl. III, D). Chalcedony is usually lacking in these honey-combed masses. The first mineral to be deposited was the quartz. In some specimens there is a very thin band of chalcedony, but this is not common. The contact between the dolomite and the quartz is sharp. Most of the dolomite grains present crystal faces to the quartz. There is no difference in crystallinity between the crystals in contact with the quartz and those at a distance from it. These so-called pipes are really triangular columns of quartz and chalcedony, which have the appearance of having been flattened or compressed. They are in beds up to two feet and a half thick. They weather out into large angular blocks.

Where the quartz is in veins it shows essentially the same features as in the cavities, chalcedony having been deposited first and then the quartz. The quartz crystals grow out from opposite sides and may or may not fill the vein. In all cases quartz is the last mineral to be deposited and chalcedony the first. It was probably the rate of deposition that determined which mineral would be deposited, the slower growth producing quartz.

There is a set of veins later than the chert and drusy quartz. They are similar to the others save that, as a rule, they are without chalcedony. They are of the same age as the quartz which cements the rare chert breccias.

The Potosi formation contains a number of cave deposits. None of the caves were found with sufficient exposure to determine their size or shape or the extent to which they were filled. The materials in them were angular grains of quartz, angular fragments of chert, and crystals of quartz with their faces unscratched. These cave deposits do not appear to be very large, but they are associated with the ore deposits. They were apparently formed at a period when the region was above ground water level, probably during the interval between the formation of the Potosi and the Proctor dolomites.

The Potosi formation is generally reported as being about 300 feet thick and such is probably its thickness in the eastern part of this area, but north of Kingston towards Richwoods it is apparently not more than 100 to 150 feet thick. Whether this is due to faulting followed by erosion before the Proctor dolomite was deposited could not be determined, as there were no single beds which could be used as a datum plane to determine the possible displacement. However, there is one feature which is strong evidence of faulting, and that is the lack of continuity of the heavy honey-combed masses of quartz. These appear to belong near the top of the formation, but in many places are missing at the horizon where they should be found. This might be explained by faulting and erosion, as noted above. If there was faulting it occurred before the deposition of the Proctor dolomite, for this formation is very persistent in thickness over the area. If faulting occurred, an unconformity exists between the Proctor and the Potosi formations.

*Age and correlation.*—No fossils were found in the Potosi dolomite so its exact age is unknown, but its position in the series suggests that it is Upper Cambrian. Ulrich[6] places the Potosi formation at the base of the Ozarkian in Missouri. In an earlier paper[7] he includes it in the Potosi group, as a part of the Gasconade limestone. He called it the Lesuer limestone, a name proposed by Keyes for this formation, but not until after Winslow had given it the name of "Potosi", hence "Potosi" has priority. Ulrich, in his revision of the Paleozoic systems, states that Buckley's use of the term for this formation is best and he adopts it. The formation is very easily recognized and is fairly easily delimited.

*The Eminence chert.*—A question arises as to the possible presence of the Eminence chert in this area. Ulrich recognizes it as a formation of not less than 200 feet in thickness in Shannon County to the southwest. There it is a very cherty dolomite.

In the Washington County district there is at the top of the Potosi formation a band of very cherty dolomite, often several feet thick. This member is rarely more than 25 feet thick, and in most places only 5 to 10 feet. It was not mapped during the field work, for lithologically it would be considered as the top of the Potosi dolomite or as the base of the Proctor formation. The color and texture of the dolomite associated with the chert are the same as those of the formations above and below. It may be that the formation was formerly present in considerable thick-

[6]Ulrich, E. O., Bull. Geol. Soc. Am., vol. 22, p. 622; also. pp. 628-633. 1911.

[7]Ulrich, E. O., Bull. U. S. G. S. 267.

ness and largely removed before the deposition of the Proctor, but this has not been proved. The apparent erosion and faulting in the Potosi formation, as explained above, is in favor of its having been so. If the cherty horizon does represent the Eminence chert, it is much thinner in this area than farther south. Since the chert is so very different from the drusy quartz of the Potosi formation, the cherty horizon was considered as the base of the Proctor in the mapping. If it actually represents the Eminence, as seems to be the case, its thickness should be taken from that of the Proctor. It is, however, too thin to map on the maps of the scale used. For the reasons given in discussing the thickness of the Potosi formation and the presence of the Eminence chert, it seems probable that an unconformity exists between the Potosi formations and that during this erosion interval the larger part of the Eminence formation was removed.

*Economic importance.*—The Potosi formation is of greater economic importance than any other formation in the area, as the larger part of the barite is obtained from it. Nearly 200 years ago lead was discovered in the mantle rock derived from the Potosi dolomite and it has produced lead ever since, altho the amount produced now is small. In the early days of the lead industry, the only areas prospected were those where drusy quartz or "mineral blossom" was found. A connection between the drusy quartz and occurrence of lead was recognized.

### *Proctor formation*

The Proctor dolomite is found in more or less connected areas over the western half of the district. Altho its outcrops are scattered, it ranks next to the Potosi formation in areal importance. It outcrops extensively farther up the valleys in which the Potosi formation appears, is found on the slopes above the Potosi formation where the latter appears in the valleys, and occupies the crests of those ridges not capped by the Gasconade formation.

Beginning four miles southeast of Potosi, the Proctor dolomite forms a continuous outcrop to the northern part of the county. About a mile southeast of Potosi the ridge is so low that the Gasconade formation is wanting and the outcrop there is continuous with the outcrops along Mine à Breton and Bates creek. It joins these outcrops again ten miles to the north along Mineral Fork. It outcrops along the north side of Mineral Fork from the western border of the district near Aptus to a point near Kingston where it turns northwest towards Richwoods. Here it divides, one outcrop following Little Indian Creek, and the other running due north to the north side of the county. To the east of Old Mines, the Proctor has been entirely cut away along the road to Shibboleth, but to the northeast towards Fertile there is an extensive outcrop. There is also a small area of Proctor dolomite exposed along the North Fork of the Fourche à Renault where it leaves the area in the southwestern part.

The Proctor dolomite is from 80 to 125 feet thick, yet its outcrops are rather broad over the entire area. This is due to the lithological character of the formation. It is entirely free from chert and hence is easily eroded. It forms the base of the Potosi escarpment along its eastern outcrop, but to the west its rather wide outcrops are due to the fact that it is largely the upper formation on the ridges. Around Fertile and Richwoods the low relief explains the rather extensive outcrops. However, the Proctor formation does not form a marked shelf on the slopes where it outcrops, altho this would be expected. This shelf actually is present in a few places. Its failure to appear widely is probably due to the fact that the Proctor dolomite inherited a rather heavy mantle of residual chert and sandstone from the Gasconade formation. The presence of this material also made the determination of its upper boundary difficult.

*Petrography.*—The Proctor dolomite is a nearly pure dolomite. As a rule, the color is some shade of gray, varying from light to dark, and in places with a bluish cast, but buffs and rarely pinks are also found. There is much variation in color both vertically and locally. The rock is crystalline, altho there is considerable variation in the size of the grains. Probably medium-grained texture predomintes, but there are many fine-grained phases. Everywhere the rock contains numerous small cavities, rarely two inches long and usually not more than about an inch. They are very irregular in shape and are lined with crystals of dolomite, calcite, and, rarely, quartz. Many of the dolomite crystals are of a beautiful rose color, and are about an eighth of an inch in diameter. The crystals of the dolomite are largely anhedral with irregular outlines, but an occasional rhomboidal face appears. Large crystalline masses of calcite are found thruout the formation. The grains of both these minerals show dust-like particles under the microscope. Other constituents are barite, glauconite (rare), pyrite (rare and altered to limonite near the surface), and scattered masses of chert.

The chert is in places rarely more than 5 to 6 inches in diameter and most of it is in pieces less than an inch across. The shape of these masses is very varied. The chert is very dense and usually is white or light gray in color. It is not possible to say that chert is especially abundant in any one part, and, on the whole, it is a minor constituent of the formation.

The barite appears in veins, as irregular masses, and as disseminated grains. Its occurrence will be discussed fully later.

The composition of the Proctor formation is shown by the following chemical analysis:

| | |
|---|---|
| $SiO_3$ | .86% |
| $FeO$, $Fe_2O_3$ | .15 |
| $Al_2O_3$ | Trace |
| $CaO$ | 30.38 |
| $MgO$ | 21.36 |
| $CO_2$ | 46.62 |
| $H_2O$ | .32 |
| | 99.69% |

The formation is thick-bedded, the beds being from 2 feet to 10 or 12 feet thick. In this area the beds are essentially horizontal. Near the base in one or two localities the weathered layers have a suggestion of being thin-bedded, but, on the whole, the beds are massive. On Clear Creek some of the beds show cross-bedding on a minor scale. Near the base there are abundant stylolites, some two inches long. They are parallel to the bedding planes in so far as their position was determined. They are especially well developed at the old diggings about two and one-half miles northwest of Potosi, and along Rocky Branch, a tributary on the north side of Mineral Fork. At the former locality they are apparently later than the barite. Joints are rather common. The major set strike N. 65° E., and locally are nearly east and west, and the result of the two is the production of rhomboidal blocks, thus making mechanical erosion prominent.

No fossils were found in the formation.

The rock weathers to a rough, pitted surface (Pl. VI, A), usually of a color darker than that of the fresh rock. When it contains enough pyrite it takes on a buff to yellow color, tho this color is not common. The much pitted surface is due, in large part, to the more rapid solution of the calcite spots in the dolomite. The rough surface of the weathered rock is also due to the abundant grains of dolomite that stud the surface. Here the more rapid removal of the smaller grains has left the larger grains on the surface. This type of weathering produces a "sandy" surface, and when the products are not removed too rapidly they produce what the miners call "sand rock." This is merely the disaggregated product of the dolomite.

*Age and correlation.*—The Proctor dolomite is regarded as of Upper Cambrian age. Buckley[8] suggests that there is an unconformity at the top of the formation, and Ulrich also believes there is one. Whether there is one or not cannot be determined in this district, as not a single exposure was seen which showed these formations in contact. As stated above (page 39), there is evidence for thinking that an unconformity exists at the base of this formation. The Proctor dolomite is one of the few formations in the Ozarks which has persistently held its formational name. It corresponds to Swallow's[9] Fourth Magnesian Limestone. All others who have had occasion to give a section of the stratigraphy in the Ozarks have called it the Proctor formation

*Economic importance.*—The Proctor dolomite ranks next to the Potosi formation in the production of barite. Doubtless some barite from this formation is being mined from residual clay over

[8]Buckley, E. R., Geol. of the Disseminated Lead Deposits of St. Francois and Washington Counties, Mo., Bur. of Geol. and Mines, vol. 9, pt. 1, 1908.

[9]Swallow, G. C., First and Second Ann. Repts. Mo. Geol. Sur., pp. 114-131. 1855.

the Potosi dolomite. No lead occurs in the Proctor formation.

*Gasconade formation*

The Gasconade formation includes dolomite, chert, sandstone, and a little shale. The exposures are so poor and few that a detailed section could not be made.

The Gasconade formation is chiefly in the southwestern and middle western parts of the area, with various isolated exposures in the central and northern parts. The southwestern area occupies the upland country called the Salem Platform. One part extends to the north between Bates and Mine à Breton creek, and another between the North Fork of Fourche à Renault and Bates creeks. The other extension of the area is to the east along the divide between the streams that flow south to Big River and those that flow north to Mine à Breton. One spur extends to within a mile of Summit on the Iron Mountain Railroad. The long narrow ridge which the Old Mines road follows is capped by the Gasconade formation. Just south of Old Mines, where Old Mines Creek heads, the Gasconade outcrop divides, one part extending about two miles northeast along the ridge, and the other part turning to the west along the high ridge that lies between Mine á Breton and the southern tributaries of Mineral Fork. A branch of the latter follows the ridge between Mill Branch and Old Mines Creek nearly to Mineral Fork. To the east of Old Mines Creek, toward Fertile, there are isolated patches of the Gasconade formation capping the higher hills and ridges. From Aptus north to Richwoods there is a large area of the formation, and a smaller area to the north of Little Indian Creek. Most of the higher hills and ridges that are underlain by the Proctor dolomite contain a considerable amount of residual chert and sandstone from the Gasconade formation, which once covered the region.

The Gasconade formation is largely confined to the highest hills and ridges. It remains here because of its great resistance to erosion. This formation, with the Roubidoux, is the principal surface rock thruout the central part of the Ozarks.

*Petrography.*—The Gasconade formation includes dolomite, chert, sandstone, and shale. Some of the dolomite is shaly, some sandy, and all of it is more or less cherty. The sandstone shows conglomeratic phases here and there, and there are two or three layers of chert breccia.

The dolomite consists essentially of dolomite and calcite, with chert and glauconite and rarely pyrite as accessory constituents. The calcite is often in masses a couple of inches in diameter. The color ranges from bluish-gray to buff or yellowish-gray. A few beds are pinkish and here and there some are almost white. The dolomite varies in texture from coarsely crystalline to very fine-grained, with some beds that are porous. The microscope shows the typical anhedral grains of a dolomite, the grains having irregular boundaries. The chemical composition of the Gasconade dolomite (composite analysis) is as follows:

| | |
|---|---|
| $SiO_2$ | 2.94% |
| $Fe_2O_3$, $FeO$ | .52 |
| $Al_2O_3$ | .16 |
| $CaO$ | 31.40 |
| $MgO$ | 18.10 |
| $CO_2$ | 45.70 |
| $H_2O$ | .43 |
| | 99.25% |

The sandstone consists of angular grains of quartz with some chert fragments. Most of the quartz grains show crystal faces, only a few being rounded. On the other hand the chert particles are well rounded and white. They weather out leaving small round or oval cavities in the sandstone. In places the chert fragments are large enough to make the rock conglomeratic. There are also some equally large quartzite pebbles in a sandstone bed near the top of the formation. The sandstone is cemented with silica in many places and thus becomes a quartzite. In other places the cement is hematite and limonite, while rarely it is dolomite or calcite. The sandstone is usually some shade of red, white, gray or yellow. It is medium to fine-grained, save in the conglomeratic phase.

A little shale was noted near the base of the Gasconade. It was dark gray in color on a weathered outcrop, and was very thin-bedded. Only one exposure was found.

The dolomite and sandstone show several important structural features, such as ripple-marks, cross-bedding, mud-cracks, oolites, and stylolites. Mud-cracks, oolites, and stylolites were found in the dolomite, and the other features in the sandstone. Ripple-marks, seven inches from crest to crest and one inch in amplitude, were seen. Cross-bedding is common, especially in the upper part of the formation. Some of the mud-cracks were at intervals of from four to six inches. Some were from one-half to one inch wide, while others were only one-eighth of an inch wide. The stylolites were rarely over one inch long.

The chert is found (1) in layers interbedded with the other members of the formation, especially dolomite; (2) in nodules of large size along the bedding planes; and (3) as small irregular masses and nodules in the dolomite. Most of it is white or light gray, but dark grays and blacks are seen, and the weathered product is usually stained some shade of yellow or red by the iron oxides. The chert is always dense and tough, breaking with a straight to subconchoidal fracture, rarely with a perfect conchoidal fracture. Much of the chert is banded, the bands being concentric in some instances, in others rudely parallel to the bedding planes or lamellae. Rarely the chert is in rounded elliptical forms, 8 to 15 inches in diameter. These forms show splendid bands which are accentuated by differential weathering. They are well exposed in the beds of some of the streams flowing on the Gasconade formation. Not infrequently there are narrow elongated cavities lined with drusy quartz in the bands of the chert. These shapes are strongly suggestive of lithophysae, but are not so continuous as the concentric shells of the latter.

Oolitic chert is a common constituent of the Gasconade formation. This fact is a great help at times in locating the lower limit of the formation. The oolites are silicious, and the microscope shows that most of them are perfectly rounded, but some are elliptical, and all are more or less embedded in chalcedony and quartz. They average from .4 to .5 mm. in diameter. In places they are cemented with limonite and hematite. The oolites show several well developed zones, but have no nucleus. The central part of some is dark gray crystalline quartz. In polarized light the areas between the oolites show the dark cross characteristic of chalcedony. The outer band or zone is more coarsely crystalline than any of the other zones, and is the same as the chalcedony surrounding the oolite. Thins sections of the dolomite adjacent to the oolitic chert in the same bed showed original structures that could be interpreted as oolites which now are replaced by anhedral grains of dolomite.

Another type of chert of unusual interest is one that appears to be oolitic but is merely composed of well rounded fragments of chert, many of them almost spherical. These were thought to be oolites at first but the unusual size of some that were found later showed that such was not the case. The microscope confirmed the conclusion that they were merely rounded fragments of chert.

Most of the fossils in the Gasconade formation are in the chert. They are well preserved but are very difficult to get out in perfect condition. They are gasteropods and fragments of orthoceras.

Beds of chert-breccia at least three feet in thickness appear in the lower part of the Gasconade formation. Their exact horizon is not known, for very few exposures of more than a few feet were seen. The breccia weathers out in large masses, some of them are as large as 10 by 6 by 3 feet. It consists of angular fragments of bluish-gray, translucent chert, up to four inches in diameter, which are embedded in a dense white chert. The fragments lie at all angles in the matrix.

The dolomite and chert members of the formation are persistent, but the sandstones are lenticular. There are sections of the Gasconade formation more than 200 feet thick in which not a single sandstone bed appears. In other places, sandstone beds are numerous and show all the characteristics of such beds. They are rarely continuous for more than a few miles, and most of them pinch out in less than one or two miles.

Some of the dolomite is very thin-bedded, there being beds of a half inch or less in thickness, and those of two to four inches are common. Some beds are several feet thick, but this is not the rule. In the Central district, where the Gasconade formation is well exposed, thin beds predominate. The very thin beds are shaly..

Fossils, aside from those in the chert, were found in a shaly member of the Gasconade formation about 75 feet from the base. These were found on a small tributary of Rocky Branch. They were mainly linguals. Associated with them are fucoids. The trilobites and especially the gasteropods are much more numerous in the chert than in the shaly member.

The dolomite weathers into angular blocks or else into platy forms. Much of the sandstone weathers into large blocks, some of which are quartzitic. These sometimes show case-hardening. The chert weathers into all kinds of shapes and various sizes, the breccia fragments being the largest. Temperature changes break it up into very small fragments.

*Age and correlation.*—The Gasconade formation is probably Lower Ordovician in age. While only a few fossils have been found in it, those which appear (gasteropods, trilobites, and brachiopods) are Lower Ordovician species. In central Missouri there is a sandstone at the base of the Gasconade formation called the Gunter sandstone, which is included with the Gasconade formation. In the Washington County area this sandstone was not recognized. The sandstone members of this and the overlying formation, the Roubidoux, are lenticular in character, and it is not strange that the Gunter standstone does not extend to Washington County.

This formation is very persistent over a large part of the Ozarks. Ulrich[1] places the Gasconade in the Ozarkian, between the Saratogan and the Upper Ozarkian, with an unconformity above and below. If such unconformities exist they are not to be seen in this region.

### *Roubidoux formation*

There is a very small amount of the Roubidoux formation (largely sandstone) in the district, its total area being probably not more than a quarter of a square mile. It is in the extreme southwestern corner of the area on the ridges above the North

[1] Ulrich, E. O., ibid, p. 608, pl. 27.

Fork of the Fourche à Renault. It is confined to the very crests of the ridges in sections 29, 30, 31, 32, and 33, T. 37 N., R. 2 E. Probably residual materials from the Roubidoux are on some of the other ridges, but it is difficult to be sure when the only means of identifying the formation are petrological ones, and since there are members in the underlying formations which are somewhat similar.

*Petrography.*—While the Roubidoux formation in other parts of Missouri consists of dolomite, sandstone, quartzite, and chert, the only member found in this area is a conglomeratic sandstone. No doubt much of the chert on the crests of the divides is also residual from the Roubidoux formation for some of it answers to the descriptions of the chert from that formation.

The sandstone is medium-grained with some pebbles of quartz and chert which make it conglomeratic. The color is mostly white with a yellowish tint, weathering to a red. Much of the rock is quartzitic.

The chert fragments in the conglomerate phases are as much as two inches across, and are angular. They are embedded in rounded grains of limpid quartz.

The sandstone is cross-bedded, ripple-marked (with ripple marks up to three inches from crest to crest), and exhibits many mud-cracks. These features are characteristic of it wherever seen. The thickness is unknown since at no place was it seen in section, but it is thin.

The formation breaks down to a sandy soil. Many large boulders show concentric rings due to oxidation. Angular boulders and fragments result from temperature effects on the sandstones and quartzites.

*Age and correlation.*—From its position, and from fossils found elsewhere, the formation is known to be Lower Ordovician. Swallow called it the Second Sandstone. Nason[2] in 1892 used the name Roubidoux for it, but was under the impression that it was the First Sandstone of Swallow's classification.

[2]Nason, F. L., "Report on Iron Ores," Mo. Geol. Sur., vol. 2, pp. 85-115, 1895.

Winslow[8] in 1894 called it the Moreau sandstone, while Ball and Smith in 1903 called it the St. Elizabeth. Since Ulrich's report in 1905, the name Roubidoux has been applied to it.

## STRUCTURE

The minor structural features of the area have been noted under the descriptions of the formations and something as to their general attitude was stated in discussing the physiography (pages 9 and 10) but details of structure and its effects have not been given.

The structure of the formations is, on the whole, simple. The rocks depart but slightly from a horizontal position over the larger part of the region, except in two localities where they are much disturbed. One of these, the Stony Point area, is in the extreme southeastern corner of the area; the other, the Fertile area, is at the junction of Mineral Fork and Big River.

In general the beds dip gently to the north, northwest, and west. The top of the Proctor dolomite at its highest outcrop west of Hopewell is 1,080 feet, while its elevation on the west side of the area on the North Fork, is about 1,000 feet, giving a westward dip of about 11 feet to the mile. The same horizon on Bates Creek has an elevation of about 1,020 feet, and on Mineral Fork, about 10 miles farther north, about 950 feet, giving a dip of 7 feet to the mile. On Little Indian Creek the elevation is about 750 feet, showing a dip of 25 feet per mile for the last eight miles. From near Fertile to Aptus there is a westward dip of about 13 feet per mile. These average dips indicate something as to the larger features of the structure. Northeast of Little Indian Creek the formations dip to the southwest more steeply.

### *Folding*

There are no marked or extensive areas of folding in the region. Departures from horizontality may be divided into (a) minor undulations and (b) major folds.

(a) *Minor undulations.*—Most of the formations show minor warpings even in small outcrops. These are usually slight

[8]Winslow, A., "Lead and Zinc Deposits," Mo. Geol. Sur., vol. 6, p. 331, 1894.

distortions of the beds developed during their consolidation. They are rarely more than 40 or 50 feet in length. The Potosi dolomite exposed along Mine à Breton and Mineral Fork shows such undulations well. Probably some of these minor deformations are due to solution, followed by a settling of the beds above.

(b) *Major folds.*—There is really but one important fold in the area and that is slight in comparison to the folds in many regions. This is an anticline which extends from the Richwoods region to the southeastern part of the area near Kingston, where it apparently turns eastward and follows, rudely, the course of Big River. In the Fertile region many faults complicate the problem, but the major tendencies in the deformation are still evident.

The dip of the beds on the west side of the anticline in the Richwoods area is rarely 3 degrees, but it is sufficient to bring the Potosi formation high enough so that it is exposed by erosion east of Richwoods. The dip of the beds to the east is probably similar, altho evidence of the eastward dip was found in only one locality. That was on Calico Creek near Fletcher, where the dip is 2 to 3 degrees.

The axis of the anticline begins about a mile west of the northeastern corner of Washington County, and follows a course about 23 degrees east of south to a point near Kingston where faults replace it. Extending slightly to the south of east is a poorly defined anticline which may be a continuation of the above, but appears to be a separate fold. On Maddis Creek the Elvins formation dips 4° S., 15° W. As a result the bluff on the opposite side of Big River consists almost entirely of the Elvins formation. Farther northeast near Vineland on the Iron Mountain Railroad there is a sharp downward fold to the northeast. Whether this is the northern side of the anticline is not known, but such appears to be the case. These two folds appear to intersect and end near Kingston, for the rocks to the west and those to the southeast do not show evidence of deformation. The Richwoods anticline is the direct cause of the mining of barite in that region, as it made possible the exposure of the Potosi dolomite, and, to a certain extent, the Proctor dolomite, the two formations which are economically important in the district. The downward cutting of Calico Creek and its eastern branch has exposed the upper part of the Elvins formation along these streams.

The folding accompanying the development of these anticlines appears to have been sharp. The beds on Maddis Creek soon assumed a nearly horizontal position, as did those on the Calico near Fletcher. The same thing was apparently true in the sharp monoclinal fold near Vineland. This feature is well shown in Furnace Hollow, the small valley opposite Kingston. About a quarter of a mile east of this valley the beds dip southwest with a dip of about 1½°. East of the creek about 300 feet they dip 8°, while in the creek bed they dip 15° S. W. Within about 500 feet along the bluff west of the valley the beds have again assumed their slight westward dip. This shows that the anticline is a broad fold with sharp almost monoclinal flexures on each side. It should be noted also that the anticline along its southern half, from Calico Creek to Mineral Fork, plunges rather strongly to the southeast. This accounts for the rapid rise of the Elvins formation above Furnace Hollow.

The beds involved in the faulting in the Stony Point area dip rather steeply near the faults, but, since the present attitude appears to be due to the faults, their position will be discussed in connection with the faults.

### *Faults*

In each case where faulting was observed in the area, the throw was not great, altho in some cases the displacement was more than 100 feet. There are only two such faulted or disturbed areas, the Fertile area and the Stony Point area.

*The Fertile area.*—Faulting in this locality has produced a more extensive outcrop of the Elvins formation than there would have been normally. The faults enclose a block about four square miles in area. Not all of the faults delimiting this block have been definitely located, as the map shows, but their presence is demanded by structural relationships. In every case the fault planes dip steeply. A dip of 76° was determined in two localities, but as far as could be determined it is greater than this in other places. In all cases the fault planes dip away from the fault block. Along Fertile Creek, the fault planes and fault breccias are well exposed. The part of the fault plane exposed still retains the polish produced by the movement (Pl. VI, B). The best exposure was one where the fault plane has a strike of N. 46° E. and dips 76° S. E. Another good exposure on Fertile Creek shows a strike of N. 80° E. and a dip of 75° S. The other faults are more nearly vertical than these two.

The fault on the north side of the block, the Mineral Fork fault, stands out prominently on the face of the bluff on Big River in the southeast quarter of Sec. 22, T. 39, R. 3 E. The north end of the bluff is made up largely of the Potosi dolomite while the south end is entirely of the Elvins formation. Since the Potosi soils are red and the upper part of the bluff has sufficiently gentle slopes to retain some soil, its color is red, and it is locally known as the "Red Bluff," and that part occupied by the Elvins formation is known as the "Gray Bluff."

The total throw at the eastern end of the block is less than that of the central part. A short cross fault running from northeast to southwest separates the two parts. The total throw is about 100 feet. The Kingston fault, striking southeast of Kingston, is a differential fault, the greatest movement having been at the northern end where it intersects the hidden fault on Mineral Creek. Much difficulty was found in locating, even approximately, this fault and the one on the east side of this particular block. The actual fault planes were not located and the structural relationships were the only available means of determining their existence. There is a strong probability that the Kingston fault is a continuation of the sharp flexure in Furnace Hollow. There may be a connection between the two anticlines and this faulted zone, which is located at their intersection and southeast of it.

*The Stony Point area.*—These faults were worked out by Buckley and belong to a large distributive fault called by him the Big River fault. The downthrow is on the northwestern side. On the corner of the area included in this map there are two rudely parallel faults. The extreme southeastern corner is occupied by the lower part of the Elvins formation (the Davis of Buckley), and in the area between the two faults the upper Elvins formation outcrops. These beds dip about 30° N. W. and strike N. 75° E. The lower member dips about 20° N. W. along the fault plane, but on the bluff of Big River, a quarter of a mile south, the beds dip very little. None of the above faults have any apparent effect upon or relation to the mineral deposits.

Altho the faults discussed above are the only ones actually determined, it is believed that there was a period of faulting much earlier than that in which these faults were developed. The Potosi dolomite is very variable in thickness in the area, ranging from an apparent thickness of a little more than 100 feet in the region about the Calico, to nearly 300 feet in the southern part of the area. In the Fertile region also it does not have anything like its maximum thickness. It is believed by all who have studied in the region that there is an unconformity between the Potosi and the Proctor formations. That the deformation which produced this unconformity was accompanied by faulting is not improbable; nor is it improbable that in the subsequent erosion all surface evidences of the faulting disappeared. This sequence of events would cause the Potosi formation to have a variable thickness. If such faulting occurred, it certainly preceded the deposition of the Proctor dolomite, for this formation is nearly uniform in thickness. As shown in discussing the formation (page 37), there are apparent discrepancies in the bedding in the Potosi formation, as well as in thickness, which suggests that there had been faulting and subsequent erosion.

*Time of the faulting.*—There may have been two periods of faulting. If there is an earlier one it accompanied the deformation at the close of the Potosi, while the last one is certainly post-Gasconade. As a matter of fact it is probable that faulting took place as late as the last uplift in Tertiary times, tho it may have occurred earlier. The later faults are unmineralized, so they must have occurred after the period of mineralization. Spurr[4] believes that there have been two periods of faulting or fracturing in the Lead Belt of southeastern Missouri, one of which is distinctly older than the period of mineralization. It is evidently impossible to fix the time any closer than is suggested above.

[4]Spurr, J. E., Econ. Geol., vol. 10, p. 472. 1915.

### *Joints*

Massive, bedded, sedimentary rocks, such as the dolomites and limestones of this region, are well adapted to exhibiting joints, but the limited exposures give little opportunity to observe them.

There does not appear to be a definite direction along which the majority of the joints strike. They range from north and south to N. 70° W. Practically all the strikes of the major joints that were determined were in this zone. Most of the minor joints are at approximately right angles to the major joints. In one locality triangular blocks were produced by three sets of joints, one striking nearly east and west, and the other two at about 45° to the first.

The strike of the barite veins is only in small part concordant with that of the joints. Very large veins were closely associated with these prevalent directions of the joints, but the barite veins were very irregular in direction.

## GEOLOGICAL HISTORY

Since the base of the Elvins formation is not exposed in this area it cannot be stated whether it is conformable with the formation (Bonneterre) immediately below. The lower part of the formation was deposited in a shallow sea at some distance from the shore because it contains some intraformational conglomerates and sandy dolomite. The sand grains in the sandy dolomites are well rounded and rather uniformly scattered thru the crystalline dolomite, showing that materials had not been perfectly sorted when deposited in the dolomite. The shale is interbedded with the dolomite. Dolomite beds that are shaly are rare. As carbonate rocks predominte, either the land which furnished the materials must have been low or the Elvins formation of this locality was deposited some distance off shore. That the last may have been the case is indicated by the fact that the lower part of the Elvins, 25 miles to the southeast, contains a large amount of shale. It is probable that the land, Ozarkia, to the south was also low-lying, for a great dolomite formation had been deposited in that region in the preceding epoch. The presence of so many intraformational conglomerates in this part of the Elvins formation suggests a broad area submerged by a shallow sea. This water was probably so shallow that a slight disturbance of the sea-level was sufficient to shift the bottom above or below the water. Such exposure would permit the muds to become hardened and mud-cracks to develop. These small blocks resulting from the mud-cracks would then be easily broken up and slightly rounded by the waves before they were completely buried in more calcareous muds. The conglomerate beds were developed in situ from the materials of the previously existing beds. The bottom of the sea was undulating as is shown by the lenticular beds.

The dolomite in places may be a chemical precipitate. Fossils are found in the lower part of the formation and there they may have played an important part in furnishing a source for materials. The upper part, however, with its thick beds, is more suggestive of a chemical precipitate. The calcium carbonate was probably first precipitated by bacterial and chemical processes, and then changed to dolomite while still a soft mud. The very shallow waters, as shown by ripple-marks, mud-cracks, etc., were also favorable to the development of dolomite and limestone by aiding bacterial and chemical changes.

No evidence of an unconformity between the Elvins and the Potosi formations was found in the area, for not a single exposure of the contact was seen. Both formations are parallel at all points where their position was determined. Others have concluded that there was an unconformity at the top of the Elvins formation, but this is based on rather meager evidence.

The Potosi seas were relatively quiet and free from terrigenous muds, as the formation consists of a very pure dolomite thruout. Its origin was the same as that of the carbonate rocks described above. The writer believes that the large amount of silica, in the form of drusy quartz and chert, was largely deposited as silica at the same time the dolomite was deposited and later took its present form. A very small part was probably introduced by the solutions which deposited the barite.

In this region the Potosi dolomite seems to have graded up into the Eminence chert, if it is present, without a break. As far as the evidence goes the Eminence might be considered a part of either the Potosi dolomite or the Proctor dolomite. It is unnecessary to try to distinguish among them further. An unconformity may exist between either the Potosi and the Eminence formations, or between the Eminence and the Proctor formations.

The Proctor dolomite was deposited in a quiet sea and at a considerable distance from the shore. The presence of the massive beds tells the same story of undisturbed waters existing when the Potosi dolomite was being deposited. The waters evidently did not contain much silica, which was due either to the fact that the land was far distant, or that the silica-bearing water had been deflected into another part of the sea. The Eminence formation of Shannon County with its abundance of chert may be the time equivalent of the Proctor because of this deflection.

The Proctor dolomite is overlain by the Gasconade formation. In Washington County the lower part of the latter is dolomite and chert, with possibly a little sandstone, a sequence which does not involve a very great change, altho one probably occurred. In central Missouri a sandstone member, the Gunter, is known to occur at the base of the Gasconade formation. This would suggest that the shore-line, for a time at least, was near the area of deposition, altho a sandstone might be deposited at a distance from the shore if the sea were shallow. Such a change was probably due to deformation and favors the view that an unconformity exists at this lower limit.

It is, of course, possible that the sandstone was the first member deposited upon an eroded surface by an advancing sea. This also would mean an unconformity. Nearly all who have studied these formations believe that there is an unconformity between the Gasconade and the Proctor formations, and the writer is in accord with this belief.

The Gasconade formation represents an epoch during which there were several changes, perhaps temporary, in the relationship of the land to the sea. For the larger part of the time the waters were shallow and far enough from land to receive little in the way of terriginous sediments. When such sediments were deposited they were sands, shales not appearing in this group of rocks. This would seem to indicate a rapid shifting of the shore-line. Likewise, the extreme local character of the sandstone beds demands changes which are rather abrupt. Other evidence of shallow water are mud-cracks, ripple-marks, and cross-bedding. As the materials of the sandstone beds are angular and have crystal faces, their source must have been near at hand. The presence of the quartz with crystal faces is interesting. It may have been derived from the igneous rocks of the land to the south which presumably included the present area of igneous rocks in southeastern Missouri. The most probable source would have been the rhyolite of the latter area which contains a considerable amount or more or less idiomorphic quartz as phenocrysts. The Potosi may have been another possible source, the drusy quartz furnishing the grains. In this case it would have been the erosion of this member from previously existing areas that furnished the material. An examination of the gravels and sands in small streams and along the roads in areas underlain by the Potosi formation showed materials very similar to those in the Gasconade sandstone, except that the Gasconade material was better sorted. The limestone and chert have an origin similar to that of the dolomite described above. The chert breccias, however, suggest conditions different from those indicated by the other members of the formation. To the writer, their origin appears very similar to that of the conglomerates of the Elvins formation. The steps in their production are similar, thus involving conditions of shallow water.

There is unquestionably a break between the Gasconade and Roubidoux formations in this region, because wherever the latter is found, its base is a conglomerate, in places coarse, but, for the most part, consisting of materials less than an inch in size. These materials indicate considerable transportation as they are well rounded. The ripple-marks and cross-bedding tell of shallow water. Sufficient silica has been introduced into the rocks to convert many beds, or parts of beds, into quartzite.

The upper part of the Roubidoux formation has been removed from this area. That the Jefferson City formation was once in this region, but has been removed, is very probable. It would also seem very likely that other younger formations may once have covered the district.

That the Mississippian and Pennsylvanian systems, especially the latter, were once over this area is doubtful. Since that time the surface of the area has been exposed to erosion, save for a few brief intervals. Possibly the Cretaceous sea came in from the south, but if such was the case any deposits of that time have been removed. Evidence has been cited above to show that no great amount of movement occurred at the close of the Cretaceous period. Again it is very probable that during the Tertiary there were some deposits in this region or to the south. The Lafayette formation may have been the only formation of this period, and its presence is conjectural. Even if once present, it was a terrestrial deposit and does not represent a period of submergence.

The area was probably subjected to its last uplift in late Pliocene times and since then the erosive work of the streams has been the dominant geological work going on, unless, as has been suggested, there were movements in the Pleistocene. The recent deposits along the streams are so insignificant as not to merit mapping.

## GEOGRAPHY AND GEOLOGY OF THE CENTRAL DISTRICT[5]

### GEOGRAPHY

The producing part of the Central district is located chiefly in Morgan and Miller counties in the central part of the state, but small deposits of barite are found in Moniteau and Cole counties. It is reported that some barite is found in Camden County south of the above area, but it is not of much importance.

[5]The following notes on the geology and physiography are taken from the following reports on the geology of Moniteau, Morgan and Miller Counties, to which the reader is referred for the more complete descriptions of the areas:

Ball, S. H., and Smith, A. F., "Geology of Miller County, Missouri," Mo. Bur. of Geol. and Mines, vol. I. 1913.

Marbut, C. F., "Geology of Morgan County, Missouri," Mo. Bur. of Geol. and Mines, vol. VII. 1907.

Van Horn, F. B., "Geology of Moniteau County Missouri," Mo. Bur. of Geol. and Mines, vol. III. 1905.

Barite has been reported also from many of the counties in the northern part of the Ozark Plateau, where it is of mineralogical rather than economic interest.

*Topography.*—The district lies on the northern or northwestern slope of the Ozark Plateau. This slope, the Salem Platform, is now dissected, the greatest relief being along the Osage River, which cuts thru the region from the western to the easttern side. As a matter of fact the dissection along the Osage River has been the determining factor in exposing the barite deposits. This is due to the fact that the deposits are confined mainly to the lower geological formations and these have been exposed by the river.

The topography is mature over most of the district. The streams have not developed flats of much size, not even the largest streams. The higher portions of the region have a relatively slight relief and are splendid agricultural lands, but the portions along the Missouri and the Osage Rivers and their larger tributaries are very rough, and not well adapted to agriculture, although the large part of the acreage is so used.

*Drainage.*—The Missouri and the Osage Rivers receive the drainage of the district, the major part going through the Osage, a large navigable stream with an extremely tortuous course. Other large streams are Moniteau and Moreau Creeks that drain into the Missouri, and the Niangua, Anglaize, Gravois, Saline, and Big Tavern Creeks that flow into the Osage. All the large streams are at grade and the small ones have steep gradients which enable them to handle the load of chert and gravel produced by the weathering of the carbonate rocks. The majority of these streams have developed meandering courses.

## GEOLOGY

The rocks of this district belong to the Cambrian (Proctor), Ordovician (Gasconade, Roubidoux, Jefferson City, and St. Peter), Mississippian (Burlington), and Pennsylvanian systems. The time interval represented by them is long, and much of it is represented by unconformities. The first four formations are regarded as of Cambrian age by some geologists, while others put the Jefferson City formation and part or all of the Gasconade formation in the Ordovician system. The St. Peter sandstone is Ordovician in age.

The St. Peter formation and the Mississippian and the Pennsylvanian systems are not very widespread in the district, their outcrops being confined mainly to the northern part.

A little barite has been reported from the Burlington limestone, but the deposits are of minor importance. The barite diggings that are of importance are associated with the Gasconade, Roubidoux, and Jefferson City formations.

The rocks are all essentially horizontal, there being few notable departures from this position. Such simple structure is known to exist over a large part of the Ozark Plateau, broken here and there by slight folds or a few faults. There are some faults of 150 feet throw in the Gasconade formation, but only very small or broad and gentle folds are known.

Since the barite is mainly in the Gasconade, Roubidoux, and Jefferson City formations the general characteristics of these formations only are given.

*The Gasconade formation.*—The Gasconade formation, 240 feet to 290 feet thick, is composed of beds of (1) cherty and non-cherty dolomite; (2) beds of chert; and (3) occasional beds of sandstone. Dolomite greatly predominates. The lithological features are uniform over a large part of the area, the principal variation being in the sandstone which occurs as a rule in lenses. The dolomite is crystalline, mostly gray in color, and with massive beds alternating with thin ones. As a rule thin beds are finer in grain than the massive ones. The chert is in nodules, layers, and small masses, and as beds, some of which are several feet thick. A few of these beds are brecciated. The chert, which is disseminated, always occurs along certain beds in chert horizons. White is the predominating color, but some of it is also grayish-yellow, bluish-white, and even black (flint). Some oolitic chert occurs, especially in Miller County.

The sandstone consists of well-rounded grains of quartz of medium size, such sandstones being principally in Miller County. Aside from the Gunter sandstone, the sandstone lenses are rarely more than two feet thick. The Gunter member at the base of the Gasconade ranges from 5 to 35 feet thick. It is composed of well-rounded grains of quartz, is fine to coarse-grained, and usually white or yellow in color with some red phases. It exhibits ripple-marks and cross-bedding.

The sandy phases weather to a sandy soil and, as a rule, form ledges because they weather more slowly than the dolomite on each side of them. The thin-bedded dolomite weathers fastest, but because of the large amount of chert the entire series weathers very irregularly. The result is a soil which is always some shade of red, in which there is more or less chert, the amount depending largely on the gradient of the surface on which it is accumulating. Ball and Smith state that in Miller County the Gasconade soils are thin. The upper portion of the formation is relatively free from chert, hence the soils resulting from its decay are excellent for agricultural purposes. In places they are deep without containing any chert, as on the east branch of Gravois Creek.

There seems to be an unconformity at the base of the Gasconade in Miller County; but Marbut suggests that this apparent unconformity may be due to the solution of the surface of the Proctor dolomite at its contact with the Gunter sandstone. There does not seem to be an unconformity between the Gasconade and the Roubidoux formations in this district.

*The Roubidoux formation.*—The Roubidoux formation consists of a very complex series of dolomite, cherty dolomite, chert, and sandstone beds. Most of the beds are not persistent. Their total thickness ranges from 70 to 160 feet.

The dolomite ranges from fine to coarse-grained, but on the whole it is fine-grained. Marbut notes a change in the texture from the rather coarse-grained dolomite in the lower part of the formation to the very fine-grained Cotton Rock at its top. As a rule, the lower portion is gray, of some shade, while the Cotton Rock (local name for the upper part of the Jefferson City) is yellowish to buff. The chert is distributed as in the Gasconade formation except that it is more abundant and may be in beds up to 30 feet in thickness. There is far more oolitic and brecciated chert than in the Gasconade formation. The chert ranges from dense white, gray, or black chert (flint) to a more or less porous material. Cellular and honey-combed masses are common. As in the other formations it is found consistently along certain horizons and in any of its numerous modes of occurrence. The sandstone is in beds up to two feet or more in thickness. The texture is fine to medium-grained, with occasional conglomeratic phases. The quartz grains are well-rounded, as a rule. The conglomeratic phases contains many well-rounded fragments of chert. The sandstones are cemeted with silica, dolomite, and rarely with iron oxides. The quartz grains are covered with a coat of chalcedony, giving the beds an oolitic texture. Ripple-marks, cross-bedding, and sun-cracks are common features. Sun-cracks are found also in the dolomite. The formation is evidently a shallow-water deposit.

The structure of these beds is the same as that of the Gasconade below. All the beds are essentially horizontal with a general northward dip, and are broken occasionally by small faults.

The Gasconade grades upward into the Roubidoux without a break, so far as known.

*The Jefferson City formation.*—The Jefferson City formation is from 200 to 250 feet thick. It consists dominantly of dolomite; contains chert nodules; and in places is interstratified with thin beds of chert, sandstone, and shale. The dolomite is (1) very hard, dense, and fine-grained; or (2) soft, argillaceous, and arenaceous, as in the Cotton Rock; or (3) coarse, vesicular, and hackly. The Cotton Rock is very fine-grained and dense but relatively soft. It has an earthy texture and usually breaks with a conchoidal fracture. The color is white, gray, yellow, or buff. Most of the beds are only a few inches in thickness, and the weathered surfaces are very thin. The hackly, pitted dolomite is very uniform and persistent over most of the district. It is in beds five or six feet thick. The dense phase is represented by a few beds.

The chert is much less abundant than in the formation below. It is in nodules, irregular masses, and beds. The beds are rarely as much as two feet in thickness and most of them are only three to six inches thick. The colors are the same as in the other formations. Oolitic and brecciated chert are occasionally found. As a rule, the nodular variety which is abundant in this formation is associated with the Cotton Rock. The nodules are of various shapes but are characteristically flattened, many of them being one to two inches thick, eight to twelve inches long, and four to six inches wide. All the chert occurs along definite horizons.

The sandstone beds vary from one inch to five feet in thickness. Usually they are thin and inconspicuous. They consist of well-rounded grains of quartz which are fine to medium-sized, the whole being usually well stained with iron oxide. In places they are well cemented; in other localities they are very friable. They contain chert at many points, and cross-bedding is common in them. The Jefferson City formation weathers to a red or brownish-red soil which contains considerable chert on the slopes. It is sufficiently deep over most of the outcrops of the Jefferson City to form good agricultural land; in fact, it is the best soil derived from any of the formations in this area.

The formation, as a whole, is horizontally bedded, although it is locally slightly folded, a feature that is very common in all the formations the writer has seen in Missouri. All these slight undulations are small and are doubtless the result of unequal shrinkage, aided by crystallization.

The fact that these three formations are all conformable, have similar characteristics, and grade into each other suggests that they are in reality one formation, and that names have been applied to members only. The present names and divisions are inheritances from the work of Swallow, whose divisional lines were purely lithological. From what the writer has seen of these formations, they could all be included under one name, and then would present more characters of unity than many other formations which have had their limits established through structural and faunal evidence. Subdivision is to be desired, but there should be reasonably definite lines of demarcation.

There is a marked unconformity at the top of the Jefferson City formation. The shallow-water sea in which it was deposited was changed to land which was eroded and then depressed sufficiently to receive the St. Peter sandstone.

*Summary.*—These formations indicate shallow seas. The larger part of them is dolomite, but there is also much chert and some sandstone. All three formations contain these several sorts of rock in varying amounts. The lenticular character of the sandstones is evidence of the shifting of the areas of deposition, while the sun-cracks, cross-bedding, and ripple-marks give ample proof of shallow water. The abundance of chert is significant in view of the absence of shale. This is, however, a characteristic of the Cambrian and Ordovician formation of the Ozark region.

## ECONOMIC GEOLOGY

### MINERALOGY OF THE BARITE DEPOSITS

The mineralogy of the deposits is comparatively simple. Only a few minerals are found with the barite. Sulfides, oxides, carbonates, silicates, and sulfates are the groups represented. The usual mineral association is quartz, pyrite or marcasite, limonite (pseudomorphic after pyrite or marcasite), galena, sphalerite, and barite. While any one or all, save barite, may be missing at a given locality, these minerals are characteristic of the district. The most typical combination in the material mined is quartz, limonite, and barite.

#### *Sulfides*

The sulfides found are chalcopyrite, galena, marcasite, pyrite, and sphalerite.

*Chalcopyrite.*—A small amount of this mineral was noted in a few localities in the district. A little was found at the Eye mine on the North Fork of the Fourche á Renault and also at the New Diggings south of Mineral Point. Considerable chalcopyrite is found in some of the barite diggings in Morgan and Cole Counties, especially where work is being done on veins.

*Galena.*—Aside from the iron sulfides, galena, commonly known in the district as "lead" or "mineral," is the most abundant sulfide. It was discovered near Potosi and Old Mines about 1720 and has been mined more or less continuously ever since. Some barite diggings do not contain any galena, but most of them contain at least an occasional specimen. In fact the major part of the district is covered with the old abandoned holes of the lead mines. Occasionally the barite miners find as much as 100 pounds of galena in the old diggings which they are now searching for barite. Very large masses of galena have been reported, but even small masses are rare today. The galena always shows evidence of attack by ground waters, and in fully half of the specimens seen there was a layer of gray or white cerussite around the galena. When it occurs in the clay it rarely shows crystal faces, but, in the barite where it is protected from ground water, crystal faces are retained. A bluish tarnish is a very common feature of the galena found in the residual clays. The cube modified by the octahedron is the predominating form of crystal. Single crystals, five and six inches across, are found in outlying districts where only a small amount of mining has been done. Only a small amount of galena is found with the barite in the veins. The galena is always later than the quartz and the iron sulfides, and in all instances where it is found with sphalerite they are contemporaneous.

*Marcasite.*—Marcasite, now largely changed to limonite and hematite, is common in the district. As its determination is in part dependent upon its crystal form, some marcasite may have been mistaken for pyrite, which is more abundant. Marcasite is found in fairly large masses in places. Fragments of what appeared to be vein material weighing many pounds and covered with marcasite crystals an inch or more in length, were found on some of the steeper slopes. As noted above, most of the marcasite has been altered to limonite or hematite, but the crystal form of marcasite has been perfectly preserved. Marcasite and pyrite are found in the same deposit, but never immediately associated, so their relative age is unknown. Marcasite may be older than the galena or sphalerite, but since crystals of it have not been found associated with these minerals it is possible that the marcasite is later than these minerals. It antedates the barite. At the Eye mine marcasite was one of the latest minerals to be deposited.

*Pyrite.*—Pyrite, usually in well-developed crystals, is abundant in the district. In the residual deposits it is altered, in large part, to limonite and hematite. Many masses of limonite were found which still contain a kernel of unaltered pyrite, and in the veins the pyrite is usually unchanged. As a rule the pyrite lines the cavities in which it was deposited and its inner side is covered with crystal faces. Crystals, usually cubes modified by octahedrons an inch or more in diameter, are quite common. An interesting mode in which pyrite occurs is as stalactites. These may be four or five inches in length and up to one-quarter of an inch in diameter, although the majority are two or three inches long and about one-sixteenth of an inch in diameter. They are distinctly cylindrical and are usually hollow. The larger ones show distinct growth-rings. They are always pendant and are so close together as to resemble very closely the organ-pipe coral. A similar type of limonite occurs among the secondary iron ores of Missouri and is called "pipe-ore" because of this resemblance. In one or two places these stalactites were completely cemented along a plane thru which the stalactite passed. This plane of cementation was at right angles to the stalactites and suggests that the water level in the cavity stood at that point for a time.

The pyrite is found to be later than the quartz when both minerals are present. It is always older than the barite. Its relationship to the marcasite has been discussed above.

*Sphalerite.*—Sphalerite is found only in vein deposits. Here some large masses are found, but more commonly it occurs as smaller masses in a gangue of barite. Galena may accompany it but not in large quantities. At the Eye mine the sphalerite and pyrite are intergrown, in part, but more commonly the sphalerite is later than the pyrite. Rarely, the sphalerite occurs as small ruby crystals. Where sphalerite is abundant pyrite is a minor associate. In some localities the sphalerite is disseminated thru the dolomite, replacing it. In all cases it is older than the barite.

### *Oxides*

The following oxides were observed: quartz, chalcedony, chert, limonite, and hematite.

*Quartz.*—Quartz is a common associate of barite. As a rule, only the barite found in the formations above the Potosi exists without it, but there are considerable areas in the Potosi formation in which there is little quartz in immediate association with the barite. This may be either where the barite occurs in veins or where it is disseminated. The quartz, usually drusy and nearly always containing some chalcedony, has been deposited on the sides of the cavities and openings, which may later have been filled with barite. Some of the quartz crystals are nearly one and a half inches in length and they range down to minute sizes. There is a great deal of quartz in beds in the Potosi, which upon weathering becomes associated with the residual barite. The mass of fragments of drusy quartz with the clay is called "moory" by the miners. It is also known as gravel, but the latter may include fragments of chert, etc. Where veins approach or cross these beds the interstices in the drusy quartz are commonly filled with barite. The numerous openings furnish a convenient place for deposition.

*Chalcedony.*—The cryptocrystalline, fibrous variety of quartz known as chalcedony is a frequent and common associate of the drusy quartz. Alternate layers of chalcedony and quartz is the dominant mode of occurrence. These layers are very thin; 50 or more occur in three-quarters of an inch. The chalcedony is usually the first to be deposited, and, as shown in the weathered specimens, preserves perfectly the rhombohedral imprints of the dolomite crystals upon which it was deposited. In a few cases there is a layer of chalcedony immediately under the sulfides or barite. The chalcedony is always white unless it has been stained by iron oxides since weathering out of the dolomite. There is an abundance of chalcedony only in the Potosi formation; none is seen in the formation above it

*Chert.*—Chert is not found in immediate association with the barite, except in the residual deposits, where it has been concentrated by the weathering of the dolomite. It is more abundant in the Central district where the barite occurs in the cherty Lower Ordovician formations. The barite diggings in the Jefferson City formation contain a great deal of chert

*Limonite.*—Limonite, dark-brown or almost black, is very common in the barite diggings of the Potosi and Proctor formations. It occurs as a layer under the barite and ranges from a thin film to an inch or more in thickness. The larger part of it is pseudomorphic after pyrite and marcasite, hence its distribution is similar. It is possible that some of the limonite has been deposited from ground water. No specific instances of this were noted. The limonite (locally called "iron") causes trouble in mining when it adheres to the barite. If much of the barite shows limonite, the diggings are abandoned. Some very large masses of limonite were seen in the Richwoods district. The color of the yellow soil is due to this mineral.

*Hematite.*—Hematite is not very common in the barite deposits proper, except that the red color of the clay in which they are found is due to it. Occasionally masses of limonite with a coat of hematite were found. This is a clear case of dehydration. The brilliant red color of the Potosi and Proctor residual clays is due to this mineral. They contain 12.04 per cent of ferric oxide, largely in the form of hematite.

### *Carbonates*

The following carbonates were found: calcite, dolomite, malachite, smithsonite, and cerussite.

*Calcite.*—Calcite was never observed in the residual deposits. It is found in some solution or vein deposits. The most notable occurrence is one on Indian Creek where there are honey-colored crystals of calcite weighing 50 pounds or more. Some of the crystals are well-developed. scalenohedrons, although limited space has often prevented facial development. In this occurrence part of the calcite was earlier than the barite and part was later. At the Eye mine some small crystals of calcite were found which were rounded scalenohedrons. When the veins are exposed to weathering at the surface the calcite soon disappears. Considerable calcite is found in some of the mines in the Central district.

*Dolomite.*—Dolomite was not observed in the veins or the residual deposits, except in so far as it was a constituent of the surrounding rock. It lines a great many cavities in the dolomite some of which have been filled with barite. That this has been the case is shown by the fact that one surface of the barite has casts of the dolomite crystals. The barite under the clay is usually more or less mixed with a dolomite sand (the "sand rock" of the miners) which is the result of the disaggregation of the dolomite under the influence of weathering agencies.

*Malachite.*—Malachite is found in small slender crystals, radiating clusters, and as a green powder. It appears at several diggings in the district. In no instance does it amount to more than a bit of evidence that some copper is present in the deposit.

*Smithsonite.*—Smithsonite in waxy botryoidal crusts on sphalerite, barite, and dolomite is quite common in those deposits which contain sphalerite. The crusts are seldom more than one-eighth of an inch thick. Smithsonite is especially abundant in the zinc mines near Fletcher, Missouri.

*Cerussite.*—Cerussite is often found as a thin white to gray coating on galena. This is especially true where the galena is still in close association with the dolomite.

### *Silicates*

Kaolin is the only silicate that occurs with the deposits.

*Kaolin.*—Kaolin is, of course, the chief constituent of the clay and is of various shades of red and yellow from the iron oxides. Nearer the surface it is black or gray from organic matter. It is very plastic and shows an exceptional shrinkage on drying. It cracks irregularly with a conchoidal fracture. Deposits 20 feet thick are found in some localities.

### *Sulfates*

Barite is the only sulphate found in the district.

*Barite.*—Barite is the most important mineral in the district. It will be described very fully because of its great importance. It has the following compositions: $BaSO_4$; $SO_3$=34.3% and BaO=65.7%. It crystallizes in the orthorhombic system. The usual forms are tabular crystals parallel to the base and bounded by a short prism on the sides. Crystals were found which show both the macrodomes and the brachydomes in combination with the above. On some crystals a series of these domes was recognized. The crystals are elongated parallel to the brachyaxis or to the macroaxis. Some of those collected are simple and perfect, while others are very complex.

The usual form of the barite is in crested, divergent groups of tabular, curved crystals. This is known as crested barite. (Pl. III, D and Pl. IV, A and B.) These crested masses are often six or eight inches long, with crests extending from end to end. In other instances there are large concretion-like or cone-shaped masses whose surfaces are covered with small, more or less divergent crests. Upon these there are still other very small groups of crests, usually about an eighth of an inch long. These cone-shaped masses are large and commonly weigh 200 pounds or more. (Pl. VII, A.) They are nearly always found adjacent to the dolomite. Many of the massive pieces contain small cavities lined with crested crystals. The size of the tabular plates in the various masses varies widely. In some of the small concretionary masses they are so small that the barite has an almost granular appearance, while in others the blades of the crests are several inches long. The so-called "chalk-tiff" is a finely granular, porous variety of barite. "Ball-tiff" is concretionary barite which is finely crystalline, but in which the tabular faces are curved.

Crystals of barite were found in only four or five places in the Washington County district. Many small but perfect crystals were found at the Eye mine. They occurred in a red clay. On the southwest quarter of Sec. 29, T. 38 N., R. 2 E., clusters of rather large but simple crystals were found. In the Central district crystals weighing several pounds were found in red clay in a cave at the Wilson diggings near Henley. (Pl. IV, D.) They were all comparatively simple. The private collection of Mr. F. A. Sampson of Columbia, Missouri, was studied, but this also is composed of comparatively simple forms. Most of Mr. Sampson's collection came from the Central district where especially fine crystals have been found. In the collection of the University of Missouri, there are many specimens of the unique barite crystals from Pettis County, Missouri, which have a white or opaque border, often nearly an inch wide (Pl. IV, E.) around a transparent to translucent interior. This white border was analyzed by Luedeking and Wheeler[6] and found to have the following composition:

| | |
|---|---|
| $BaSO_4$ | 87.2% |
| $SrSO_4$ | 10.9% |
| $CaSO_4$ | 0.2% |
| $(NH_4)_2SO_4$ | 0.2% |
| $H_2O$ | 2.4% |

[6]Luedeking, Charles, and Wheeler, B. A., Am. Jour. Sci., 3d series, vol. 42, p. 495.

The presence of the ammonium sulfate is unique.

A glassy variety of barite was found in a cavity lined with crested barite near Richwoods. The barite occurred as small botryoidal aggregates, continuous with the edges of the crests. It is perfectly transparent and closely resembles hyalite. The small globules break with a conchoidal fracture. A cave at Morrillton, Franklin County, Missouri, is said to have furnished many very beautiful specimens of blue barite crystals.

Barite has a hardness ranging from about 2.5 to 3.5 or 4, and a specific gravity of 4.5. The luster ranges from vitreous to resinous or pearly. Much of the "rosin-tiff" is a variety with a resinous luster. This barite has no value, as the reddish color which it has cannot be removed in the bleaching process. This color is due to the iron oxides which impregnate the barite. The barite, as a rule, is white, though some of the crystals are colorless. Due to the iron oxides in the clays, the barite in them is always more or less stained. The colors range thru many shades of yellow and brown to white. Opaque varieties are the best for most of the uses of barite.

## OCCURRENCE OF THE BARITE

There are four common modes of occurrence of the barite, but all are not of equal economic value. In discussing them, their genetic relationship rather than their economic importance will control the order in which they will be taken up. The four types are: (a) veins; (b) disseminated deposits; (c) cave deposits; (d) residual deposits. The last is the most important economically.

### *Veins*

The vein deposits are very slightly developed and poorly known. The development work that has been done has not been carried far enough to determine the extent of the barite, except where some other economic mineral has been associated with the barite to act as an incentive for further exploratory work. Usually this mineral was sphalerite, more rarely galena, or the two together. Any barite so produced is considered as a by-product. In many cases it is not even sold unless the price is high and the mine located near a shipping-point. The barite under these circumstances is to be considered as a gangue mineral.

*Croppings.*—There are few croppings of the barite veins because of the thick mantle rock in the region. They are generally found in the bottoms of the streams or along very steep slopes where there is very little, if any, soil. In neither instance are they sufficiently exposed to permit an extensive, detailed study. There are no surface features of importance on any of the croppings; the vein materials are merely uncovered by the streams. On the slopes fairly good sections of the deposits may be seen.

*Character of the veins.*—The veins are apparently not very strong, altho they appear to be fairly extensive. Judging by the extent of the residual deposits, they are persistent in length, and appear to be quite numerous. How far down they extend is unknown. There are many small veins, ranging from thin sheets a few inches long up to two inches wide and ten feet long. (Pl. VII; B.) In some of the deeper mines of the region large masses of barite are found associated with sphalerite or galena at depths of 100 feet or more.

*Form and structure.*—The veins are tabular but very irregular along their outcrop. In spite of their irregularities, they have a persistent direction of strike, in general, nearly north and south. A few veins varied as much as 45° from north. The vein material extends from wall to wall and usually is massive. Where quartz and pyrite or limonite are present, these minerals are deposited in the above order on the walls and give that part of the veins a banded appearance. Quartz alone may give a banded character to the vein. The divergent masses of barite lie at all angles. Cavities are of common occurrence in the veins and are always lined with crested barite. (Pl. IV, A.). When sphalerite and galena are present they are either attached to the walls or to the previously deposited quartz or pyrite. The barite fills the remaining space. There are many branches shooting out from the small veins into the dolomite. These show by their irregular shape and relation to the wall rock that they are largely replacements, the deposition of which probably began along fissures and fractures of the rock. A noticeable feature is the numerous small veinlets that are connected with these replacement branches.

*Relation to the wall rock.*—The vein material was deposited, in part, directly on the walls of the fissure and, in part, it replaces them. The veins are mainly filled fissures however, and rarely replacements. The cavity walls were irregular, due to the fact that they are often solution cavities. They are often lined with crystals of dolomite which are continuous with and intergrown with the crystals of the dolomite of the country rock. The cavities were in existence before the deposition of the barite and other minerals and are not due to replacement.

In a few instances a fault breccia cemented with barite was observed. These breccias were original and the open spaces afforded a passage for the solutions which brought in the substances. Specimens showing casts of these angular fragments are often seen.

*Geological distribution.*—The veins are the most widely distributed geologically of any of the deposits, as they occur in all the formations from the Potosi to the Jefferson City. They are most abundant in the Potosi and the Proctor formations and the Gasconade ranks next. They become less abundant in the higher formations. If there were more deposits in Morgan, Miller, and Cole Counties, where the vein type predominates, the upper formations, the Gasconade and Jefferson City, would be more important producers of barite.

*Areal distribution.*—Little can be said as to the actual areal distribution of the veins. Evidence was gathered which indicates that they are essentially continuous with the areas where residual barite is produced. In only a few instances were the larger veins seen, and then they were in the areas of residual barite. The smaller veins are very numerous and are in the same areas as the larger ones, altho small sporadic veins may be seen almost anywhere in the upper part of the Potosi.

*Value.*—Only a small production is made from the veins, because of the difficulty and cost in mining. They will become more important as the residual deposits are exhausted.

### *Disseminated barite*

Barite is widely scattered thruout the Potosi formation and to a certain extent the Proctor also. It occurs as small masses of very irregular shape and outline (Pl. IV. C) and in the same beds as the veins, altho it is not directly connected with them. The barite either fills the numerous small cavities which are so abundant in the Potosi and the Proctor formations or it replaces the dolomites. In both formations the disseminated barite is much more abundant near the larger veins. Because the small openings in the dolomites are so numerous, it is probable that these furnished the location for the deposition of the barite, but doubtless many were enlarged by the solutions and replacement deposits were produced. The distribution of the disseminated barite is almost identical with that of the veins, and from this it is to be inferred that these types of barite deposit are genetically connected.

*Cave deposits*

The presence of solution cavities in the Potosi and Proctor has been mentioned in the descriptions of these formations. In addition to these cavities which are filled with sandstone and conglomerate, there are some which are more or less filled with barite, calcite, and minor amounts of sulfides. Such cavities occur in the Central district in considerable numbers.

Very little information was to be had about these caves because only a small portion of any given one was exposed. The socalled "circle" near Henley, Missouri, is a cave deposit of exceptional size. The open cut is now about 250 by 285 feet and at the steepest face about 30 feet high. The barite generally fills in the openings between large blocks of dolomite which lie at all angles to the bedding planes on the sides of the cave. These blocks are roughly cubical and may be 15 to 20 feet on a side. Partially filled openings contain a deep, extraordinarily plastic clay of a chocolate brown color, in which occur tabular crystals of barite weighing several pounds each. These crystals also are in large clusters weighing 200 to 300 pounds. The barite here is pure white and very free from iron. It occurs in masses up to ten inches thick and several feet long. (Pl. VIII, A and B). Veins of barite dipping 60° or more occur along the sides of the cave. They represent cracks developed around the circle by the caving in of the top. While there may be a good many of these caves in the Washington County district only a few of them were found. The barite is deposited on the bottoms of the cavities, and where the cavity is not completely filled there is an abundance of crested forms. A globular mass 5 by 4 by 2 feet was exposed in one of these caves near Cruise. How much more was present is unknown. The order of deposition is the same as that in the veins, viz., (1) quartz, (2) pyrite, (3) galena and sphalerite (if present), and (4) barite. This invariable order over all the district points to uniform conditions during the deposition of the barite. None of the solution cavities seen, aside from the caves, were very large and the majority were only a foot or two across. They are not continuous along one plane but are nearly horizontal for a few feet and then follow an inclined or vertical passage to a lower horizontal plane. This is what would be expected in so uniform a rock as the Potosi or the Proctor dolomite. Joints did not have a very important influence on the location of the cavities. The presence of these solution cavities in both the Proctor and the Potosi formations points to an unconformity between the Proctor and the Gasconade, as well as between the Proctor and the Potosi. However, they might have been developed much later, as such solution cavities occur in the Jefferson City and other formations above the Proctor.

### *Residual deposits of barite*

The residual type of occurrence is the most important type of all and has been the most important since the mining of barite began in Missouri, about 1870. This is because the barite is in more concentrated form in the residual clays and because it is also more easily extracted.

*Croppings.*—It would be expected that a material which occurs in surface clays would be exposed wherever the slope of the surface was such as to permit the removal of much of the associated clay. Such croppings are not numerous at the present time in the areas that have been worked for barite for 30 or 40 years, but in the outlying districts, as for instance that on Hazel Creek, on Wilson Creek (northwest of Potosi), and at Richwoods, the barite is found at the surface. In many fields on slopes which have been tilled for 75 years or more, the barite has been regarded as a nuisance, and has been more or less removed along with the other stones, largely chert. Barite was seen in the surface material in wheat fields, corn fields, and meadows. In many instances these surface deposits are yielding splendid returns to the owners, who are engaged in digging and hauling the barite to the market while the present high prices last. This surface barite sometimes appears in masses weighing 1,000 pounds or more, but more commonly it is in small pieces averaging two or three pounds, with larger pieces fairly common. It differs in no way from that found deeper down.

*Character of the residual deposits.*—The residual deposits are the most important and extensive in the district. Probably 98 per cent of the production of the barite comes from them. They are not all of equal value at the present time and neither do they all produce the same grade of barite, but these variations in production are largely the result of transportational factors. The grade of the barite produced in the outlying districts mentioned above is essentially the same as that produced elsewhere. Likewise, the amount of the barite in these areas is about the same. In the old diggings the returns to the miner are much less than they were formerly, altho these diggings are being rapidly extended into comparatively new adjacent areas.

*Form and structure.*—Typically the barite occurs as loose fragments scattered thru a deep red clay, more or less mingled with drusy quartz and chert (Pl. IX, A); or as rather large masses in the disaggregated dolomite at the bottom of the clay. In the Central district the residual barite is confined to the clay immediately over the dolomite. It really has the form of a bedded deposit, since the ore is widespread and is in the essentially horizontal surface clays. Its structure is also that of a disseminated bedded deposit, as the barite is found scattered thru the clay.

This clay is almost invariably a deep red color, almost purplish-black, in some instances, and in other places a lighter shade of red. The clay is remarkably plastic. It is very fine and is free from grit, in spite of the great abundance of drusy quartz present. This is significant in showing that the dolomite is quite free from quartz, except the drusy variety. Upon exposure to the air the clay shrinks greatly. This enables the miners to readily remove it from the barite. After removal from the pits the barite is spread out on boards or on the ground and allowed to lie there in the sun for a day or so, to thoroly dry it. It is then cleaned by putting it in a "rattler," a small box on rockers with a perforated bottom, and by rocking it the clay is slowly knocked off. The very high degree of plasticity is significant as indicating the presence of colloids. A part of the colloids might be ferric oxide, judging by the color. The following are several typical sections taken in different parts of the area. They illustrate the structure of this material very well.

*On road east of Potosi*

| | | |
|---|---|---|
| 1. | Light to dark gray soil | 5 to 10 in. |
| 2. | Buff to tan clay | 6 to 18 in. |
| 3. | Pink to light red clay | 6 to 12 in. |
| 4. | Deep, dark red clay (may contain quartz or chert) | 1 to 12 ft. |

*One and one-half miles north of Mineral Point*

| | | |
|---|---|---|
| 1. | Yellow soil | 1 ft. |
| 2. | Light reddish clay | 1 ft. |
| 3. | Red clay with mingled fragments of barite and quartz | 3 ft. |

*Race track diggings, one and one-half miles northwest of Potosi*

| | | |
|---|---|---|
| 1. | Gray soil | 1 ft. |
| 2. | Red clay | 2 ft. |
| 3. | Red clay and gravel (quartz and chert) | 8 in. |
| 4. | Red clay and barite | 2 ft. 6 in. |

*Section two miles northeast of Richwoods*

| | | |
|---|---|---|
| 1. | Black soil | 1 ft. |
| 2. | Yellowish clay ("mulatto") | 1 ft. |
| 3. | Red clay and gravel | 1 ft. |
| 4. | Dark red clay and barite | 2 to 3 ft. |

*Section in Mud Town diggings, east of Old Mines*

| | | |
|---|---|---|
| 1. | Yellowish soil | 6 in. |
| 2. | Yellow to red clay | 1 ft. |
| 3. | Dark red clay and barite | 2 to 4 ft. |

The sections given above show the mode of occurrence of the barite as it was seen in thousands of holes in the district.

Water is found in some of the diggings. In generally owes its presence to the gravel layers in the clay, or else it is found just above the dolomite.

There is a tendency for the barite to follow what the miners have very appropriately called "leads." A good lead of barite is conscientiously followed by them. These leads are apparently residuals from solution cavities or veins. That they might be from the former appears likely since they do not go downward except at intervals. However, the fact that the material in the lead may have been concentrated from a vertical dimension of many feet makes it appear just as probable that a vein furnished the barite. A drift three feet square usually includes all the workable barite.

*Relationship to the other types.*—Due to its great insolubility the barite in the residual clays has accumulated with them as the dolomite was dissolved and carried away by the ground waters. The barite is in the dolomite in veins, disseminated masses, and cave deposits. During weathering the dolomite has been removed from the barite in all these different kinds of deposits, allowing the barite to accumulate along with the clay. The residual barite has a very intimate relationship with the other types of deposits as it is dependent upon them.

*Geological distribution.*—There is a remarkable persistence in the geological distribution of the residual barite deposits. In the Washington County district the barite is found only in the Potosi and the Proctor formations, and of these two formations the Potosi contains by far the greater part. The contact of these two formations passes through or adjacent to the best deposits. Further, the upper part of the Potosi formation contains these deposits more abundantly than the lower portions, altho the deposits at Fletcher are well down in the formation. This feature is apparently due to the faulting and erosion already suggested as occurring in the Potosi.

In the Central district the most important deposits are in the Gasconade, but the Roubidoux and Jefferson City formations also contain some barite. In all cases most of the barite comes from the residual clay over the formations.

*Areal distribution.*—The areal distribution of the barite deposits in the Washington County district is the same as that of the Potosi and Proctor outcrops. Not all outcrops are overlain by barite deposits, however, for little barite is found in the lower part of the Potosi, except as noted above. The lower part of the Potosi formation found east of the Iron Mountain Railroad is nearly barren of any deposits.

The most productive areas are as follows: (1) around Potosi and in the area to the northwest of the town; (2) from the Potosi branch of the Iron Mountain Railroad north along the western and eastern sides of the railroad to Big River; (3) around Shibboleth, Old Mines, and Racila; (4) on the Amaux branch of Mineral Fork; (5) around Kingston and up the Mineral Fork for two or three miles above the village; (6) to the east and northeast of Richwoods; (4) around Fletcher on the Calico; and (8) on Hazel Creek, about 20 miles southwest of the barite district proper.

Some of these areas have been worked since the beginning of the barite industry in this district, about 1870, and are still producing considerable quantities of barite. In the main they are the areas which are near the railroad. With the present high price of barite many of the old diggings are being reworked. Six or eight miles from the railroad the diggings are worked only when the price of barite is high, unless good roads for winter hauling are available. Such districts are Old Mines and Kingston. These areas still produce much good barite. The Richwoods district, the Wilson Creek diggings northwest of Potosi, and the Hazel Creek district are as yet but slightly developed. They contain some excellent deposits which are unfavorably located for transportation.

In the Central district, the mines on Gravois Creek southeast of Versailles are the most important. A small sporadic production comes from around Brouses in Miller County. Another area is to the northwest, west, and southwest of Henley.

## CONCENTRATION OF THE BARITE BY WEATHERING

The present workable deposits of barite owe their origin to the ordinary processes of chemical weathering, aided to a certain extent by mechanical weathering. Chemical weathering is dependent upon the relative solubilities of the materials attacked, and their differential removal produces a segregation of those substances which are the least soluble. The greater the difference in solubility the more readily is the segregation brought about, and great insolubility means more complete concentration. The disturbing factor in the chemical concentration is mechanical erosion. If it is especially active, the concentration becomes a question of size and specific gravity, and upon a steep slope even these factors mean merely a retardation of complete removal.

In discussing the origin of the barite deposits all these factors must be considered. Barite is a very insoluble mineral of high specific gravity. Most statements of its solubility place it at 1 part in 400,000. Smith[7] gives the molar solubility as .00013 grms. Landolt-Bornstein-Meyerhoffer[8] give the solubility in water at 18.3° as $2.4x10^{-4}$. These figures show that barite has a very low solubility in water, and, therefore, this is a favorable factor in its residual concentration.

*The weathering*

The weathering of a rock is due to the combined action of mechancial and chemical processes. The mechancial agents are mainly temperature changes. These become less and less effective as the thickness of the mantle rock increases, until they finally cease. Where the slope of the surface is sufficiently great for the water to remove the residual particles mechanically almost as fast as they are produced, the underlying rock is exposed more or less continuously and temperature effects are important. Over most of this area there is a thick mantle rock, the result of the rather gentle slopes in the areas underlain by the Potosi and the Proctor formations. In a few places, usually those adjacent to the larger streams where erosion is more active, there is essentially no residual clay.

On the other hand chemical changes usually proceed slowly and are favored by a slow movement of the surface waters and a

[7]Smith, Alexander, General Inorganic Chemistry.

[8]Landolt-Bornstein-Meyerhoffer, Physikalisch-Chemische Tabellen, p. 223.

fairly rapid movement underground. Gentle slopes with a less active run-off and a porous substratum greatly further chemical action. This action is aided by the presence of a porous zone at the contact of the dolomite and clay. There is much water in this zone and most of the miners avoid going to bed rock unless they find excellent barite there. Most of the mines are located on these areas of gentle slope.

Aside from conditions of slope the chemical character of the material subjected to weathering is very important. While all minerals are more or less resistant to weathering, certain ones are especially resistant to the ordinary ground water solutions. Some of these are kaolin, iron oxides, barite, and quartz. On the other hand, the carbonate minerals are comparatively soluble, especially in bicarbonate solutions. This is the dominant type of solution in the region under discussion, and, as the rock associated with the barite is dolomite, it is readily attacked by such solutions.

If the surface of the dolomite were exposed, mechancial forces in breaking up the rock would aid the egress of the solutions. The solutions would also take advantage of the joints which had been caused by deformative earth movements or original changes in volume during the consolidation of the rocks. Under such favorable conditions chemical weathering should proceed rapidly, but as soon as sufficient mantle rock had accumulated the entire process would be checked. As the water removed more and more of the dolomite the accumulation of the insoluble particles, kaolin, quartz, etc., would proceed until a thick deposit of clay would result. Thru it would be scattered any fragments of insoluble materials that were in the dolomite.

In the Washington County area the solutions attacking the dolomite first dissolve the smaller, more readily soluble grains. The loose larger grains and the friable rock resulting from such action are called "sand rock" by the miners. Its granularity is suggestive of such a rock.

As noted above, when water is present it is rather consistently found at the contact of the clay with the dolomite. Some occurs in the usual gravel layers in the clay, but the larger part moves along the contact. Thus the zone of greatest solvent action is at the surface of the rock to be removed. While there are enlarged joints and fissures which extend downward into the dolomite a considerable distance, the action of the ground water is confined to the exposed surface of the dolomite. At a distance of a few inches from this friable, granular dolomite, solid, perfectly fresh dolomite is found. This shows also the degree of imperviousness of the dolomite. It was found that there was 1.94 per cent of insoluble material in the dolomites (exclusive of the Elvins), the most of which enters into the residual clays. The chert, quartz, barite, etc., in the dolomite remain behind and soon become an essential part of the residual mantle rock. The deep red color of the residual clay is due to the complete state of oxidation of the iron in the dolomite. This color of the clay is in part confirmatory of Steidtmann's[9] recent statement that dolomites contain isomorphous ferrous oxide. However, careful tests showed that there was no ferrous iron in the Potosi dolomite.

As these materials are brought nearer the surface by the erosion of the overlying material they pass into the zone where temperature changes are effective and there the larger fragments are slowly disaggregated into the smaller pieces which are usually found. Thruout the district the largest masses of barite are found adjacent to, or still in the bed rock, while higher up smaller fragments are the rule. The same is true of the chert.

### *Source of the barite*

That the barite in the residual clay was derived from the underlying dolomite is proven by many facts. The following are the most important of these lines of evidence:

(1) On the steeper slopes where the veins are exposed, or partially exposed, the material which had accumulated on the surface in the few pockets of clay was identical with the barite in the vein. Absolute proof was shown in these instances.

(2) Many pits have been sunk to the dolomite, following the barite downward, and the barite in the dolomite is found to be identical with that in the clay in every way, save size, that in the dolomite being in larger masses.

(3) The barite and quartz in the clay usually show casts of dolomite crystals. This proves that they were deposited on

[9]Steidtman, E., Science, vol. 44, p. 56. 1916.

the dolomite, which has since been removed by solution. There is no evidence that the solutions attack the barite, for it shows the typical crested forms and perfectly smooth lustrous cleavage faces when the clay has been removed. Likewise, the quartz shows no evidence of solution.

(4) The breccias furnish proof of the former relationship of the barite and the dolomite. Where barite has cemented breccias and they have been exposed to weathering, the dolomite has been removed, leaving the sharp outline of the dolomite fragment in the barite (Pl. III., C).

(5) The rudely linear distribution of the barite mines suggests that the barite was derived from an underlying vein. The "leads" are very spotty; one man may be getting out fine barite while his neighbor a few feet away finds only poor material. This suggests derivation from a vein.

(6) The fact that the barite still retains the pyrite (usually limonite now) or quartz on which it was deposited is evidence that it was derived from the veins, for the order, whether both are present or not, is always the same as in the veins.

(7) That the barite, quartz, etc., have developed in the clay is improbable for the following reasons: (a) The clay is remarkably plastic and impervious; thus, the passage of solutions thru it would be almost impossible. (b) The barite does not show any signs of enlargement, such as inclusions of clay, or changes in form from that found in the veins. (c) It is well known that barium salts are absorbed by plastic clays, and it is therefore unlikely that they could have migrated thru the clay to the centers of crystallization. (d) It is still more unlikely that the order of deposition of the quartz, pyrite, and barite would be the same in the clay as in the veins.

In this connection it is important to note that in the other barite deposits in this country, in Virginia, Pennsylvania, North Carolina, Georgia, New Jersey, Tennessee, and Kentucky, the first deposits worked were residual accumulations in clay. Below these surface deposits, in most instances, veins or vein-like masses were found. In most of the states mentioned the main production is now from these veins. In the Canadian deposits veins have furnished the barite from the surface down, because any residual material once there has been removed by the Pleistocene glaciation.

### *Conclusion as to concentration by weathering*

The present workable deposits of barite are found in a deep red clay, which was derived from the underlying dolomite thru the normal process of chemical weathering, aided by mechancial disintegration.

That the barite and associated minerals were derived from veins and replacements in the underlying dolomite is shown by the close similarity of the features of the materials in the veins to the features of the materials in the clay.

## ORIGIN OF THE BARITE

### CONCENTRATION FROM THE SURROUNDING ROCKS

Chemical and mechancial weathering will account only for the concentration of the material in the residual clay. The fundamental question is, what was the origin of the barite in the underlying formations which in this case are carbonate rocks? The suggestions for the origin are reducible to two propositions: (1) the barium was concentrated from the surrounding rocks and deposited in the veins, caves, etc.; (2) the barite was deposited by deep-seated solutions as veins, replacements, and cave deposits. These suggestions will be discussed in the order mentioned.

Ever since the study of ore deposits began, there has been one school of geologists who have believed that the surrounding rocks have furnished at least a large part of the materials found in the various veins, replacements, etc. The list includes the names of most of the leading geologists of the past and many of those of the present day. Many have held that this was the dominant process in the concentration of our metallic and non-metallic mineral deposits; others recognized that there were limitations to the theory and believed that some deposits, especially of the metals, were best explained as having been formed from solutions rising from considerable depths and probably originating from igneous rocks. There are those who believe that this is essentially the only means of deposition.

Most men at the present time believe that many metallic deposits are more or less directly related to igneous rocks; the nonmetallic deposits are still commonly thought to have been concentrated by meteoric waters. Barite deposits belong in the latter class. Essentially all who have studied them have advocated their concentration by meteoric waters. Lindgren includes the barite deposits in two different divisions in his "Mineral Deposits." One type he puts with those deposits which are concentrations from surrounding rocks. Here he places most of the economically valuable deposits. Before taking up the evidence of such an origin, it will be worth while to summarize briefly the prevalent views as to the origin of barite deposits.

Professor T. L. Watson[1] has given much time to the study of the barite deposits of the Appalachian region from Virginia to Georgia. He recognizes the residual type of the surface clays; and below, veins and replacements, often of large size. He concludes that the barite has originated by the concentration of the barium salts from the surrounding rocks. Various sulfides are found with the barite and in some instances are sufficiently abundant to mine, while the barite is not saved. All are thought to have been derived from the adjacent rocks.

Hayes and Phelan[2] concluded that the deposits at Carterville, Georgia, were concentrated from the limestone. Stose[3] is of the same opinion as to the origin of the barite at Waynesboro, Pennsylvania. C. H. Warren[4] describes the barite deposits at Five Islands, Nova Scotia, and concludes that they are due to solutions which obtained their barium from the surrounding, and at one time, overlying rocks.

Winslow and Buckley both concluded that the barite in Missouri was concentrated by descending waters which gathered the barium from the dolomite and limestone of the area. Ball and Smith[5] believe that the lead and zinc deposits of Miller County, Missouri, are due to descending solutions which obtained the

[1]Watson, T. L., Mineral Resources of Virginia, pp. 305-327. 1907.

[2]Hayes and Phelan, Bull. 340, U. S. G. S., p. 458, 1908.

[3]Stose, G. W., Bull. 225, U. S. G. S., p. 515.

[4]Warren, C. H., Econ. Geol., vol. 6, pp. 799-807. 1911.

[5]Ball and Smith, "Geology of Miller County, Missouri," vol. 1, pp. 148-188. 1907.

metals from the surrounding rocks. Since barite is a very common gangue mineral, they would presumably advocate a similar origin for the barite, altho they make no such specific statement.

W. S. T. Smith[6] in his paper on the lead, zinc, and fluorspar deposits of Kentucky mentions barite as an important gangue mineral. He decides that all the substances in the veins were derived from the adjacent rocks.

Dickson,[7] after a series of careful analyses of the associated rocks, concluded that the barium in a vein in a quarry near Kingston, Ontario, did not come from the adjacent limestone, which showed only a trace of BaO, but that it came from the weathering of some igneous rocks on the surface that had a high percentage of barium.

This short summary of the conclusions of the various geologists who have studied barite deposits indicates that the prevalent beliefs are that the barite has been derived from the surrounding rocks. In order to examine this critically, and determine if possible, how adequate meteoric waters are to cencentrate barite, it will be necessary to go into considerable detail as to the source of barium and the means of transporting and precipitating it from solution.

*Source of the barium*

Clarke[8] gives the following figures for the amount of barium in the various sorts of rocks in the lithosphere. The average of 793 determinations of BaO in igneous rocks was .102%; in elemental form .092%. Seventy-eight shales had an average of .05% of BaO; 253 sandstones .05%; and 345 limestones showed none. Also a composite analysis of 498 building limestones showed no barium. Clarke gives the figure .09% as the weighted average for the lithosphere. The absence of barium in the composite analysis of the limestones should be noted.

The various geologists who have worked with the barite deposits have usually analyzed the adjacent rocks in an endeavor to find the source of the barium. Following are some of the re-

[6]Smith, W. S. T., P. P. 36, U. S. G. S., pp. 150-154. 1905.

[7]Dickson, C. W., School of Mines Quart., vol. 23, pp. 266-270, 1001-1002.

[8]Clarke, F. W., Bull. 616, U. S. G. S., pp. 27-34.

sults. These are the only instances that could be found where barium has been shown to occur in limestones or carbonate rocks.

Winslow[9] gives the following analyses, made by J. D. Robertson:

| | Locality | Percentage of $BaSO_4$ |
|---|---|---|
| | **Magnesion limestones (Cambrian)** | |
| 1. | Pettis County, near Smithton | .0017 |
| 2. | Pettis County, near Smithton | .0020 |
| 3. | St. Francois County, Desloge Mine | .0040 |
| 4. | St. Francois County, Desloge Mine | .0050 |
| 5. | St. Francois County, railway tunnel, Valle Mines | .0011 |
| | Average | .00246 |
| | **Lower Carboniferous limestones** | |
| 7. | Jasper County, Carthage quarry | .0022 |
| 8. | Jasper County, Carthage quarry | .0020 |
| 9. | Jasper County, Joplin, bluff on Turkey Creek | .0047 |
| 10. | Jasper County, Joplin, bluff on Turkey Creek | .0049 |
| 11. | Jasper County, Webb City, near Sucker Flats | .0037 |
| 12. | Jasper County, Webb City, near Sucker Flats | .0049 |
| 13. | Lawrence County, one-half mile south of Aurora | .0012 |
| 14. | Lawrence County, one-half mile south of Aurora | .0008 |
| 15. | Pettis County, Sedalia quarry | trace |

These analyses, all having less than .005 per cent $BaSO_4$, show how small an amount of this substance occurs in some of the limestones and dolomites of Missouri.

In order to determine whether there was any barium in the Potosi, Proctor, or Gasconade formations of the Washington County district, very careful qualitative tests were made of these formations and not a trace of barium was found. This is confirmatory of many other analyses made for this purpose. It also indicates that the source of the barium in the Missouri deposits must be looked for outside of the surface rocks of the region.

A limestone, described by Ransome,[1] from the Rico district, Colorado, shows a trace of BaO. Smith[2] reports .02 per cent BaO in the St. Louis limestone from the northern part of Crit-

[9]Winslow, Arthur, Mo. Geol. Sur., vol. 7, pp. 480-481. 1894.
[1]Ransome, F. L., 22d Ann. Rept., U. S. G. S., Pt. 2, p. 283.
[2]Smith, W. S. T., op. cit.

tenden County, Kentucky. He reports the analyses of three other limestones in which no barium was found. Watson[3] gives the following analyses of limestones from Campbell and Pittsylvania Counties, Virginia:

| | I | II | III |
|---|---|---|---|
| $BaSO_4$ | .62% | .65% | 1.62% |

I. Crystalline limestone from Hewitt mine, Campbell County.
II. Crystalline limestone from Hewitt mine, Campbell County.
III. Limestone from Ramsay mine, Pittsylvania County.

It is evident that the barium sulfate in the above rocks was introduced into them from the outside, because such amounts of barium sulfate are not found, even in igneous rocks. This conclusion is strengthened by the fact that the samples were taken from barite mines. The presence of metallic sulfides near a vein or ore body would be interpreted by most geologists as due to replacement by the mineralizing solutions. The writer believes this applies here. Watson reports a trace of BaO in a black clay from which some of the barite is mined. Most of the barite in this locality occurs as lenses in limestone which is interbedded with the black clay and some chists of various sorts.

Dickson[4] found only traces of barium in the dense limestone adjacent to a barite vein at Kingston, Ontario. In the weathered portion of the limestone and in the soil, which is in part glacial, he obtained from .03% to .09% of BaO. Igneous boulders on the surface gave from .11% to .30% BaO, a marked difference from the amount in the limestone.

These figures show that limestones at the best contain but a small amount of barium and that the vast majority of them do not show any at all. Lindgren[5] suggests that, when limestones are more carefully analyzed, barium as well as other minor accessory constituents will be found. This appears doubtful because the result of recent analyses fail to show any barium, and at present the chemical analysis of limestones and dolomites is very accurately done.

The other two common sedimentary rocks, shale and sandstone, show considerable amounts of barium, but these rocks are

[3]Watson, T. L., Min. Res. of Va., pp. 316-317. 1907.
[4]Dickson, C. W., ibid.
[5]Lindgren, Mineral Deposits, p. 230.

rare in the Missouri barite region; sandstone, tho more abundant than shale, is very subordinate to the dolomite. Many analyses of shales, sandstones, and clay were found, the average BaO content being about .05%. Slates and quartzites also contain barium as would be expected. Watson[6] reports the unusual amount of 4.46% $BaSO_4$ in the Weisner (Cambro-Ordovician) quartzite. Certainly this barite must have been introduced into the rocks.

Failyer[7] studied the soils of the Great Plains and found that they all contained small amounts of barium, on the average about .06%. The maximum was .11% and the minimum .01%. The source was traced to the feldspathic pebbles in the gravel, which had been largely derived from the Rocky Mountains. Many other soils were examined and almost every one was found to contain barium. The exception was a highly calcareous clay. This exception is worthy of note in view of the general absence of barium from limestone.

Igneous rocks almost universally contain barium. Clarke gives as the average .102% of BaO. Rocks high in potash and low in silica are generally high in BaO, according to H. S. Washington.[8] The amount of barium in some cases reached .80%, for example, in the rocks from the Leucite Hills, Wyoming. This statement is in keeping with the fact that the only important pyrogenetic barium-bearing mineral is celsian, $BaAl_2Si_2O_8$, which is isomorphous with potash feldspar. Analyses of potash feldspar usually show some BaO. Biotite may also contain some barium. Winslow[9] states that barium is much more abundant in the igneous rocks of Missouri than in the dolomites and limestones, but unfortunately he does not give the percentages. The conclusion reached is that igneous rocks are a far more adequate source of barium than any of the sedimentary rocks, especially limestone and dolomite.

[6]Watson, T. L., Ga. Geol. Sur. Bull. 13. 1906.

[7]Failyer, G. H., "Barium in Soils," Bureau of Soils, Bull. 72.

[8]Washington, H. S., "Barium in the Roman Comagmatic Region," Carnegie Pub. 57, pp. 188-191. 1906.

[9]Winslow, Arthur, ibid.

### *Method of concentration*

Practically all geologists dealing with the subject assume that ground water is the transporting agent for the barium. The ability of ground waters to transport barium depends upon their solvent power for the barium salts in the rocks, and their ability to find a passage thru the rocks in order to reach the barium.

*Solubility of barium salts.*—Barium sulfate is the most insoluble salt of barium known to occur in the rocks. Its solubility is generally stated as 1 in 400,000 parts of water. Certainly this solubility is increased by the presence of alkaline bicarbonate and by carbon dioxide in the water, but how much is unknown. That it is not a very important increase is shown by the lack of evidence of solvent effects upon the barite found in the surface rocks, where such solutions are probably most abundant and effective. P. Carlos[1] proved that alkaline carbonates with an excess of $CO_2$ could hold barium in solution in the presence of sulfates. The waters in most carbonate rocks are of this type, but whether they are of sufficient strength to attack and remove the barite is to be doubted for reasons given later. Some men have reported having found barite which showed signs of leaching, but these cases might have been the very irregular surfaces produced by the removal of minerals and rocks to which the barite was formerly attached. It was found that these irregularly pitted surfaces on the Missouri barite represented casts of minerals, and in one case casts of pieces of rocks.

Some men have suggested that barium exists in the various rocks as the carbonate. If this is the case it should be found frequently in limestones and dolomites, and this is not true. Clowes[2] states that a sandstone (Keuper in age) at Beeson Hill, Nottingham, England, contains $BaCO_3$. This is the only instance where the barium salt in a rock was actually found to be the carbonate. It is rather strange that it does not occur more commonly as its solubility also is very low; 100 grams of water at 18° C. dissolve .0023 grams of barium carbonate. The reason for this common occurrence of the sulfate, rather than the carbonate, lies in the

[1]P. Carlos, Jour. Chem. Soc. Abst., vol. 80, Pt. 2, p. 506. 1901.
[2]Clowes, F., Brit. Assoc. Adv. Sci., p. 594. 1889.

fact of the great insolubility of the former, so that when it is possible for either salt to form it is always the sulfate which forms.

The fact that barium chloride is very soluble in water probably explains the presence of barium in strongly saline solutions. It is possible for barium to be transported in such waters in the presence of sulfates as is shown by the analyses of brines. Clarke[3] cites an analysis of a brine from a well at Pomeroy, Ohio, which contains .21 per cent of Ba. Other analyses of chloride brines are given in the same bulletin on pages 184 and 186. It is interesting to note the percentages of barium in these waters.

| | | | | |
|---|---|---|---|---|
| $SO_4$ | .78 | .12 | .. | .02 |
| Ba | .01 | .08 | .42 | .76 |

Three chloride waters from New York, two from the Saratoga Springs and one from an artesian well at Ballston, contain small amounts of barium, as is shown by the partial quotation of the analyses below. These waters contain also a large amount of $CO_2$. Numbers one and two are from Saratoga and number three is from the well at Ballston.

| | 1 | 2 | 3 |
|---|---|---|---|
| Cl | 42.00 | 42.42 | 41.95 |
| $SO_4$ | .08 | ... | .04 |
| $CO_3$ | 18.59 | 19.28 | 18.66 |
| Ba | .09 | 0.12 | .06 |

Bischof[4] gives analyses of three brines from deep wells along the Alleghany River, which show from .91 to 1.25 per cent $BaCl_2$. P. Schweitzer found barium sulfate in a sulfate water from Moberly, Missouri, and also from a chloride water from Saline County, Missouri.

These analyses have been given to show that a few mineral waters contain barium and that it is most commonly found in chloride waters. Acid, carbonate, or sulfate waters rarely, if ever, contain any barium.

The great insolubility of barite and witherite, and their scarcity in all types of sedimentary rocks, especially carbonate rocks, makes it extremely improbable that barium could be ob-

[3]Clarke, F. W., Bull. 616, U. S. G. S., p. 182.

[4]Bischof, Gustave, Chem. and Phy. Geol., vol. 1, p. 377. 1855.

tained from the surrounding rocks in sufficient quantities to form such large deposits as are found. Its transportation by chloride waters is a possibility, but its scarcity in such waters indicates how small the amount available in the rocks usually is.

*Permeability of the rocks.*—In order that such minute quantities of barium as exist in the rocks could be concentrated it is essential that the solutions be able to reach them. The porosity of the rock must be taken into account. Unfortunately, there are no determinations of the porosity of the Potosi or the Proctor, but judging by the large openings scattered thruout the rocks it is about 8 to 10 per cent. But this porosity does not represent the ability of the water to move thru the rock, for the large openings are disconnected and, therefore, the true permeability of the rocks is that of the dense, crystalline dolomite. This must be fully the equivalent of the permeability of granite, or about .5 per cent. This difference between permeability and porosity is not generally recognized and porosities are taken that are commonly too high.

Recent experiments made by a graduate student under the writer's direction show that pressures of 1500 pounds per square inch will not force water thru a limestone with a porosity of .5 per cent. A pressure of 2800 pounds per square inch broke the rock but failed to force any water thru it.

Actually the movement of water thru rocks is mostly along the divisional planes and not thru the body of the rock. The evidence to support this contention is to be seen on every hand in the field. The irregular erosion surface of all rocks is seen to be related to the joints and fissures in the rock. The development of solution cavities of all sizes begins along such openings, altho by enlargement they may later come to be disregarded. It is sometimes stated that the bedding planes are the principal passage for solutions, especially in carbonate rocks. This statement should be modified, because the bedding planes in carbonate rocks are marked by clay partings, and clay is relatively impervious. If the formations have undergone a certain amount of deformation the partings along the bedding planes probably become more or less accentuated and are to be included in the larger divisional planes along which the materials may be carried.

Since the actual circulation of the water is confined to these openings, the solvent power of the water is restricted to the sides of the passages, a greatly limited amount of rock as contrasted with that ordinarily assumed to be affected in such considerations. That this is actually the case is proved, as rock absolutely fresh and unaltered is found to within a fraction of an inch of the joint. Even at the surface where solutions have their greatest opportunity of attacking and penetrating the rock they rarely penetrate it for more than a quarter of an inch. The dolomite under the clay in the barite pits is disaggregated to a depth of a few inches at the most. Many instances were noted where sulfides occurred adjacent to the joints, yet were wholly unaltered.

When the actively circulating waters above ground water level are unable to penetrate and alter the rocks more than a fraction of an inch, the slowly moving waters below ground water level will certainly attack them much less. The movement is so slight that the small vugs are usually without water in them, even above ground water level where the circulation is fastest.

It does not seem that ground waters are adequate to concentrate such small traces of barium salts as might exist, since they are able to reach only the portions of the rock adjacent to the joints. Also the above analyses show that the rocks in this vicinity contain almost no barium.

*Deposition of the barite.*—If the barium is transported in solution as the sulfate there is no need to seek for a source of the sulfate. This is an improbable means of transportation, however, as ground waters have little power of transporting barium sulfate.

It is more likely that the barium is carried as the carbonate or the chloride, probably the latter, as is shown by the analyses above. If it is transported as the carbonate it was probably already in existence in that form. In any case it becomes necessary to account for a sulfate radical in the vein solutions. If the vein contains a sulfate radical, it would react with some barium salt, if present, and produce barite. Or, it might be assumed, that the oxidation which produced the limonite so commonly found with the barite formed the sulfate radical which united with the barium. But, since the barite was deposited on the pyrite, the oxidation of the latter did not furnish the sulfate radical. As a great many veins and most of the disseminated barite are not associated with any sulfide whatever, some other source for the sulfate must be sought.

The ordinary carbonate water contains a small amount of the sulfate radical, a part of which may be derived from decaying organic material at the surface (all organisms contain some sulfur) and a part from the breaking down of sulfides in the rocks. Such minerals are almost always present, but generally in very small amounts. Their alteration means the production of sulfates and possibly of hydrogen sulfide.

This sulfate radical would, if barium were present in the solution, unite with it because of the low solubility of barium sulfate. This would permanently remove the sulfate radical from solution, and prevent any further participation in the reactions in that vicinity.

Certainly the amount of sulfate likely to be present in these solutions is sufficient to form barium sulfate from all the barium in the carbonate rocks. But, as has been pointed out, there is not sufficient barium in the rocks to form the large deposits of the district, and likewise the amount of sulfides in the rocks is probably insufficient to produce anywhere near the amount necessary to furnish the sulfide radical which has gone to form the sulfides occurring in the veins.

### *Conclusions concerning the barite*

The Missouri barite deposits are believed not to have been formed by concentration from surrounding rocks, for the following reasons: (1) carbonate rocks, the dominant type in this area, have been shown to contain no barium, save in rare instances where it is not certain that it was not actually introduced into the rocks by later solutions; (2) the waters in such rocks are dominantly carbonate waters which are poor solvents for barium salts; and (3) the rocks of the region are of very low permeability, save along the divisional planes where the activity of solutions is confined to the immediate walls.

*The other minerals of the deposits*

The above discussion has been confined entirely to the barite since it is necessary to account for the presence of that mineral. But the theory which accounts for the concentration of the barite must also account for the presence of the quartz, pyrite, marcasite, galena, and sphalerite as well as the minor amounts of chalcopyrite in the deposits. To discuss each of these in detail is impossible in this paper, but the application of the above principles to these minerals in a group may be made.

*The source of the minerals.*—The quartz could have come from almost any of the formations in the region, save the Proctor, as all but it are decidedly siliceous, that is, they contain a great deal of chert. The presence of the iron sulfides is not so readily explained, but essentially all kinds of sediments contain these sulfides in varying amounts. They are commonly primary constituents of the rocks. Small quantities of lead, zinc, and copper are present in the formations, as shown by Robertson's analyses made at the same time that he determined the barium content of the limestones and dolomites.

The following are his averages:

| | Percentage of zinc | Percentage of lead | Percentage of copper |
|---|---|---|---|
| Igneous | .00901 | .00397 | .00590 |
| Cambro-Ordovician limestone and dolomite | .00425 | .0009 | .00128 |
| Mississippian limestone in Missouri | .00104 | .00115 | .00202 |

These figures are of about the same order as those for the amount of barium present. With such minute amounts it would appear difficult to concentrate them. The problem is less difficult in the Washington County district than in the Central district, because in the former there is less galena and sphalerite in the deposits and also because barite predominates in the veins.

*Transportation.*—The chemistry of the transportation is hypothetical, as can be seen by consulting the reports of Bain, Smith, Siebenthal, and Buckley and Buehler on the Joplin district; of Buckley on the southeastern Missouri deposits; and of other writers on similar types of deposits. The common belief is that the transportation of the metals is possible, and this method is used in explaining the origin of the deposits.

As to the adequacy of solvents it is commonly held that silica is transported in underground solutions by alkaline carbonates. If such be the case, the character of the solutions in these rocks is such as to favor the solution and transference of silica. But the concentration of the quartz as a part of the residual material, even while in the process of concentration it is constantly bathed in an alkaline carbonate solution, is strong evidence against such a conclusion.

The same question of the ability of the solutions to penetrate the rocks when their circulation is so confined as to allow them to act only upon the thin layer adjacent to the divisional planes, is applicable here as it was in the case of the barium, and the conclusion must be the same: that it is improbable, if not impossible.

*Deposition.*—A further bit of evidence against this mode of deposition is suggested by the discussion of these other minerals. They must be removed from the country rock and deposited in veins or replace the dolomite always in the same order. A careful study of the district gave only the following order: (1) quartz, (2) pyrite or marcasite; (3) galena and sphalerite, (4) barite. It is improbable that solutions would always dissolve the same mineral at the same time and have it ready to deposit in the vein when the preceding mineral had been deposited. There is no overlapping of any of these minerals. The galena and sphalerite are simultaneous, but otherwise there is an interval of time between the minerals.

When the factors in the concentration of the barite are considered in connection with the facts regarding the source, accumulation, and order of deposition of the associated minerals, the correctness of the theory that barite deposits have been derived from the surrounding rocks appears to be rather unlikely.

### DEPOSITION BY RISING SOLUTIONS

The view that the barite was deposited by rising solutions, probably derived from igneous rocks below, may also be applied to these deposits. Such solutions should be considered as being hot, altho the temperature would probably be less than 200° C, since deposition took place near the surface.

Most of the ore deposits of the western United States that were deposited at intermediate and shallow depths contain barite as one of the gangue minerals. This is true of mineral veins of this type all over the world. In many instances it is so abundant as to give rise to solid veins of barite, as at Aspen, Colorado, and the baritic veins in the Freiberg district in Germany. These baritic veins may become so rich that they are worked for barite alone, as, for example, in the Erzgebirge in Saxony. In other cases it is a very common gangue mineral. These facts show that barite is a mineral of deep-seated origin in a great many instances. This fact is of even greater significance for it proves that the sulfate radical exists in hot solutions.

Not only is barite found as a gangue mineral in mineral deposits at various depths, but it it found as a constituent of several hot spring deposits. Furthermore, it is associated with radio-active substances in some of these hot spring deposits. This last fact is of note in connection with Boltwood's[5] suggestion that barium may be derived from actinium as an end product.

The discussion of the deposition of the barite by rising hot solutions includes a study of the mode of occurrence of the deposits, the mode of egress of the solutions, the source of the solutions, and the time of mineralization, with the presentation of corroborative evidence.

### *Mode of occurrence of the deposits*

The description of the barite deposits above has presented the features in full, but they can be reviewed here as it is essential to keep the facts of occurrence in mind.

The barite is found in veins, as replacement stringers attached to the veins, as disseminated deposits which are in part filling and in part replacements, as cave deposits which are primarily filling, and as residual deposits. The residual deposits do not need to be considered here, except in so far as retained features from the original deposits are evidence of previous conditions.

[5]Boltwood, B. B., Amer. Jour. Sci., vol. 20, p. 257. 1905.

In the other types two dominant processes are evident; simple cavity filling and replacement. The former may appear in all sorts of open spaces, but mainly in fissures, shrinkage cavities, or solution cavities. Replacement is found to be associated with all these types of openings.

*Cavity filling.*—The cavities originated in several ways. The numerous small openings in the dolomite are original sedimentary features due to shrinkage in volume when the dolomite was formed on the sea bottom, and to a less extent during recrystallization. Most of these small openings are lined with dolomite or quartz crystals, tho the fissures due to shrinkage are only rarely lined with these minerals.

The larger fissures, joints, and fractures are also due in part to this recrystallization, as it causes a decrease in volume and the stresses so set up would find relief in movements which would produce such openings. They are also in part due to deformation. It is the latter that has caused the major joints, fissures, and faults, and the former process that produced the numerous small irregular fractures. It is to be expected that these smaller openings would be less persistent than those produced by deformation because the forces involved are less intense.

The solution cavities were formed after the region had been uplifted above sea level and probably during the periods of erosion now represented by unconformities. According to Ulrich there is one after the Potosi period and another at the top of the Proctor formation. While no evidence as to the upper unconformity could be found in this district, some evidence suggestive of one between the Proctor and the Potosi formations was obtained and it is believed that both unconformities are present. The solution cavities were probably developed while the formations were exposed. The caves filled with sand and chert were probably formed at this time and also the various other solution cavities. Some of these contained broken blocks of dolomite, and less commonly, fragments of drusy quartz and chert, showing that these minerals were in existence before the uplift and erosion. The quartz crystals in the sand were derived from the Potosi dolomite. This is further evidence that the quartz and chert antedated the deposition of the barite.

*Order of filling.*—The barite appears with or without quartz. The deposits in the Proctor dolomite are without quartz, and it is absent from many of those in the Potosi dolomite also.

The solutions deposited pyrite or marcasite, first; on the dolomite as a rule, but on the drusy quartz if any was present. This was followed by the deposition of sphalerite and galena, always contemporaneously if both are present, but either may be found alone. In the Central district chalcopyrite might have been deposited at this time, altho it is of no importance in any of the deposits. The barite follows the others. If all the preceding minerals are missing, which is not uncommon, the barite is deposited on the dolomite. In either case very irregular contacts with the dolomite may result. Possibly there are two generations of barite, but of this there is no certainty. A slight overlapping was observed between the barite and the chalcopyrite, the latter having been deposited near the close of the mineralization period. The group of minerals typical of these deposits is a common one. It is found in many deposits in other regions, where the order of deposition is commonly the same as that above, but this depends upon the depth, the temperature, the solutions, and other variable factors.

*Replacement.*—The very irregular contact of the barite with the dolomite in the disseminated deposits is evidence of replacement. In a few instances the barite had replaced the dolomite between the areas of pyrite, where the latter had not completely covered the vein walls. Thus the barite partly enclosed the pyrite. The boundaries of these masses present the concavo-convex surfaces which Irving[6] cites as evidence of replacement. The numerous stringers connected with the veins are also evidence of replacement as they run out in all directions and do not follow joints, cracks, or other openings. They usually pinch out at a distance of from a few inches to two or three feet. The Potosi and the Proctor formations show no evidence of being differently adapted to replacement. Replacement does not appear to be very important in the Central district, where cave or fissure filling predominates.

[6]Irving, J. D., "Replacement Ore-bodies," Econ. Geol., vol. 8, p. 649. 1911.

If the mineralizing solutions came from below, they must have had some way of reaching the formations. The barite is practically restricted to the upper part of the Potosi dolomite and to the lower part of the Proctor formation.

Evidence that the Potosi dolomite was uplifted, faulted, and eroded before the deposition of the Proctor dolomite (and Eminence), and that at the close of the Proctor there was another period of erosion has been given above. These intervals during which the region was land favored the development of the solution cavities found in these formations.

The faults are believed to have furnished the channels along which the mineralizing solutions rose, and since they were confined to the Potosi formation, the solutions were unable to rise further because of the overyling impermeable Proctor formation, and were thus forced to spread out along the contact of the two formations. Here they availed themselves of the open spaces afforded by the drusy quartz masses and the other openings in the dolomite as well as the larger solution cavities. The latter furnished channels along which they might pass to reach the smaller fissures and openings, as well as a place for deposition. The major deposition occurred in the Potosi formation since it contains many more open spaces of all kinds. The veins were formed by replacement or filling of the fault planes and other fissures.

That the deposition of the barite occurred before the last period of faulting is proved by the fact that the Elvins, where it is in fault contact with the Potosi dolomite, contains no barite. Deposits of barite are found in the Potosi dolomite within a few hundred feet of the fault, but no deposits are known to occur in the Elvins formation.

### *Source of the solutions*

It is believed that the solutions which deposited the barite and associated minerals were derived from a deep source, presumably igneous rock. If such were the case, the solutions were hot and contained in addition to the various metals, carbon dixoide, sulfate radical, hydrogen sulfide, and possibly chlorides. The only minerals present which are of any diagnostic value are the barite and the marcasite. The former according to Lindgren and W. H. Emmons is characteristic of modern and shallow deposits. Descriptions of hundreds of deposits give proof of this conclusion. Marcasite, according to Allen, Crenshaw, and Johnson,[7] is found only in shallow deposits and is formed at relatively low temperatures only.

Therefore, deposition must have occurred relatively near the surface and may have been influenced by the mingling of the deposited solutions with oxygen-bearing meteoric waters. The shallow depth is further evidenced by the occurrence of the deposits in the solution cavities. The materials added during the process of replacement must have aided in changing the character of the solutions. That the last stages of deposition were characterized by an abundance of sulfuric acid or sulfates is proved by the large amount of barite then deposited.

*Time of mineralization*

The time of mineralization cannot be fixed because there are no formations younger than the Pennsylvanian system in association with the rocks which contain the ore bodies. Even these beds are so high up and far from the border of the mineralized area that they do not add much to the determination of the time of mineralization. In the Washingtin County district the mineralization rarely extends above the Proctor dolomite. In the Central district, however, deposits extend up into the Jefferson City formation, and possibly certain occurrences of lead and zinc in the Coal Measures can be included in this group. Those in the top of the Jefferson City formation are younger than Ordovician. If the deposits in the Coal Measures belong to this group, the mineralization is later than the Paleozoic period. This conclusion is doubtful.

The mineralization occurred, then, in the interval following the Ordovician, as the Jefferson City formation is of Ordovician age. It is known that there were intrusions of igneous rocks later than these rocks in Missouri; for example, the pegmatite

[7]Allen, P. T., Crenshaw, T. L., and Johnson, J., "The Mineral Sulfides of Iron, with a Crystallographic Study by P. S. Larson," Am. Jour. Sci., 4th ser., vol. 33, pp. 169-239. 1912.

dike in the southern part of the Central district. How much later this was intruded is unknown, but the writer suggests that the movement of the igneous material came during the deformation of the Cretaceous. If this is correct, the mineralization in the other district as well as that in the Central district can possibly be connected with this deformation.

*Corroborative evidence*

In the study of these deposits, many features have been determined which are not described in previously published accounts of barite studies. These facts led to a careful search of the literature to determine to what extent other deposits of barite belonged to the class of deposits made by the concentration of the materials from the surrounding rocks, and to what extent they possessed the characteristics of those deposits known to owe their origin to igneous rocks.

*Mode of occurrence of barite in other deposits.* Some of the points to be considered are the common mode of occurrence of barite in those mineral veins where the origin is accepted as being due to deposition by hot solutions ascending from igneous rocks, its mineral associates in those deposits, and in what rocks they are found. As to the first point, barite is in practically every case among the very last of the gangue minerals to be deposited. The barite veins at Aspen, Colorado, are an exception, but Spurr[8] states that the usual order of mineral deposition is reversed at Aspen. The conditions there are abnormal. As an excellent example of barites having been deposited last, the Freiberg deposits may be cited. There the third and youngest series of veins are baritic. As a rule, the recognition of the order of deposition of the minerals in a given deposit is rather difficult, especially where deposition was rapid and the minerals overlap, or where periods of deposition occurred. This is responsible for the common, indefinite statement that certain minerals were among the last to crystallize.

In most mineral deposits the mineral associates of barite invariably include galena, sphalerite, and pyrite, while quartz, fluorite, calcite, dolomite, siderite, rhodocrosite, marcasite, and

[8]Spurr, J. E., Econ. Geol., vol. 4, p. 301. 1909.

chalcopyrite are very common. In special types of deposits other minerals occur. A tabulation of 26 Canadian *barite* deposits showed the following mineral associates. These deposits contained essentially the same minerals as listed above but not in the same abundance.

| | Occurrence in deposits |
|---|---|
| Calcite | 10 |
| Fluorite | 6 |
| Hematite | 6 |
| Galena | 3 |
| Quartz | 2 |
| Copper ores | 2 |
| Pyrite | 2 |
| Sphalerite | 1 |

There is a marked similarity between the mineralogy of the Missouri deposits and that of the various ore deposits which contain the metals. In this connection, the lack of barite in southeastern Missouri deposits and its rare occurrences in the Joplin area and the Upper Mississippi Valley region are very striking.

The rocks, in which mineral deposits containing barite as an abundant gangue mineral are found, include all the types of igneous, metamorphic, and sedimentary rocks. In the United States igneous rocks predominate in association with those deposits which contain the most barite as a gangue mineral.

*Similarity to shallow vein deposits.*—Lindgren has presented the data of shallow deposits made by ascending thermal waters in genetic connection with igneous rocks in chapter 22 in his "Mineral Deposits." He points out that hot springs are known to deposit barite. He gives several examples, such as the hot springs at Carlsbad and Teplitz. To these may be added the interesting radio-active hot spring in Japan that is depositing barium and lead sulfates from a water which contains also free hydrochloric acid.[9] Altho not hot springs, those described by Headden[1] are interesting because they are radioactive and are depositing a large amount of barite.

[9]Yokachiro, Okamoto, Chem. Abstracts, vol. 7, p. 2369, 1913.
[1]Headden, W. P., Proc. Colo. Soc., vol. 8, pp. 1-30. 1905.

Many saline springs deposit barite after their waters have mingled with sulfate waters. Examples of such springs are those at Clausthal, Germany, and the brines in the colliery at Nottingham, England, described by Clowes.[2]

The features cited by Lindgren as characteristic of shallow veins are (1) the filling of open fissure, (2) crustification, and (3) splitting and chambering in short irregular veins. Deposition below impervious beds is often noted. Gold and silver deposits are most common, but large deposits of lead and zinc are known. Base metal minerals are pyrite, occasionally marcasite, chalcopyrite, and rarely alabandite and arsenopyrite. Quartz is especially common, often as chalcedonic varieties; calcite, dolomite, barite, and fluorite are locally the abundant gangue minerals, while siderite is rare.

Recalling the descriptions of the Missouri barite deposits, it will be seen that they are remarkably similar to these veins, in structure, shape, and mineralogy. The greatest difference is that there are no visibly associated igneous rocks. This, however, cannot be taken as proof that none exist below. The dike in the Central district proves that there has been movement among the underlying igneous rocks in geological times later than the deposition of the rocks enclosing the ore bodies. Other dikes later than the Cambrian rocks are known to occur in southeastern Missouri. That the Missouri ore deposits might be genetically connected with igneous rocks, tho the latter are not visible, had been the writer's opinion ever since he began to study them in detail, and he was glad to see Professor Pirsson's suggestive communication in Economic Geology,[3] since it indicated that others had the view that igneous activity does not need to manifest itself at the surface as dikes and lava flows to prove its presence.

It is interesting to note that some German investigators look upon the Missouri lead and zinc deposits as genetically connected with igneous rocks. Beck[4] says:

[2]Clowes, F., "Brines from Colliery, Nottingham, England," Proc. Roy. Soc., vol. 46, p. 338. 1889.

[3]Pirsson, L. V., Econ. Geol., vol. 10, pp. 180-186. 1915.

[4]Beck, R., "Nature of Ore Deposits," p. 550.

"The presence of barytes and fluorite, in fact the entire mineral assemblage of the deposits, so closely resembling that of the genuine silver-lead veins of hydrothermal origin, indicates that the hydrothermal theory is the correct one, especially since it will hardly be proved that the zinc and lead contents of the limestone were not themselves introduced by subsequent infiltration."

*Source of the barium in rising solutions.*—Clarke's average analyses of the igneous rocks shows .092 per cent of barium. When this is contrasted with the .00246 per cent, which is the average in the dolomite of southeastern Missouri, it is found that there is about 36 times as much barium available in the igneous rocks as there is in an equivalent mass of sediments. Furthermore, the high temperature and included solvents in the igneous solutions, assuming that they are similar to those found to have existed in other deposits, would greatly facilitate the gathering together of the barium in the igneous rocks before their consolidation. Likewise, the fact that *barium* rarely exists as a simple pyrogenetic silicate would seem to favor the belief that it is concentrated into the magmatic solutions, to be carried upward with them when they are freed from the rock. Nearer the surface its great stability as a sulfate enables it to exist under a wide range of conditions, even at the surface.

The writer believes that the barite veins of Missouri were deposited by waters derived from igneous rocks.

*Barite deposits of the United States.*—As stated at the beginning of the discussion of the origin of barite, the commonly expressed opinion is that the barite in the Appalachian and the Missouri areas owes its origin to cencentration from the surrounding rocks. The writer wishes to present a short account of these various deposits with a statement of their mode of occurrence and a designation of the associated rocks, because there is an interesting similarity in them, aside from the fact that all show about the same type of residual concentration.

There are several important barite deposits in the United States. The states rank as follows in the importance of their production: Missouri, Tennessee, Georgia, North Carolina, Virginia, South Carolina, Alabama, and Kentucky. In general it may be said that most of the production comes from residual deposits, which were formed by the weathering of veins and replacement deposits in the underlying rocks. The deposits are connected with sedimentary, igneous, and metamorphic rocks. Of the first, limestone or dolomite is by far the most commonly associated rock, altho some deposits are found in sandstone and quartzite. Except for those in western Kentucky which are in Mississippian rocks and those in Triassic rocks in Virginia, the deposits are all found in Cambro-Ordovician dolomites or in the residual clay from them. Thruout the Appalachian region they are found in the Knox dolomite; Shanandoah, Beaver Stone River, and Trenton limestones; the Eden shale; or the Weisner quartzite. In Missouri, they are in the Potosi and Proctor dolomites principally, but also in the Ordovician formations immediately above. In the western part of the United States, barite appears commonly associated with igneous rocks.

In Virginia, the deposits in Prince William County are in a series of Triassic sandstones, shales, and limestones. The barite is found as the cement of a breccia of shale and limestone. This breccia is apparently a fault breccia. Diabase dikes are found within four miles of the deposits. In Bedford, Campbell, and Pittsylvania Counties, and also in several other counties in the Piedmont region, barite appears in veins and replacements of highly altered schists and other metamorphic rocks. Near these mines, dikes of basic rocks and granite are found. The barite deposits of southwestern Virginia are in the same region as lead and zinc deposits and are associated mainly with the Knox dolomite.

The deposits in eastern Tennessee are also found in the Knox dolomite. The workable deposits are residual, but possibly the veins have been found along fault zones. They are nearly vertical and are from one to six feet wide. The barite in Cooke County has been followed down for 150 feet. The descriptions of the deposits in the southern Appalachians are so meager that nothing is known of them beyond the fact that the workable deposits are residual. Whether veins exist, or not, is not known.

In North Carolina the deposits are largely a continuation of those in the Piedmont region in Virginia. Here the barite appears entirely as veins in crystalline schists, gneisses, and granites. The veins are strong and range from one to ten feet wide.

They consist of very pure barite. In Madison County, they appear to be near a zone of faulting.

Many minor deposits are found in Pennsylvania, New York, New Jersey, Maryland, and various other eastern states. It is well known that the lead, zinc, and flourite deposits of western Kentucky and southern Illinois contain barite. In some mines it is found in considerable quantities, altho this district produces little barite. These deposits are associated with igneous rocks, but the genetic relation of the deposits to the igneous rocks is not generally conceded. The deposits in central Kentucky are in veins which are inclined to the bedding of the formations. The veins are strong, tho found irregularly in the Ordovician limestone. They are lean in a shaly member. Fluorite, galena, and sphalerite are the associated minerals.

H. S. Poole and C. H. Warren have described important barite deposits at Five Islands, Nova Scotia, and at Lake Ainslie, the latter having been worked since 1890. The Five Islands deposit is along a fault breccia and forms a large well-marked vein. The fault zone lies along the contact of a syenite and some folded Devonian slates and quartzites. The Lake Ainslie deposits are in several parallel veins cutting Pre-Cambrian felsite. They are quite persistent altho irregular along the strike, and they range from 7 to 10 feet in width. Poole suggests that the igneous rocks may have furnished the material.

The western part of the United States has several minor deposits of barite. One of the largest is near Wrangell, Alaska. Others are in California, Arizona, Idaho (10 miles northwest of Hailey), and Clark, Elko, Mineral, and Nye Counties, Nevada. The deposit near Wrangell, Alaska, is described by Burchard.[5] It is essentially an island about 75 feet wide and 250 feet long. The deposit is found in schists of various kinds. According to Hill[6] a deposit of barite and witherite (the latter being in the deeper parts of the mine) has recently been opened near El Portal, Mariposa County, California. It appears as veins in sedimentary rocks for at least a mile east of the main mass of intrusive granitic rock. This suggests a genetic relationship with the

[5]Burchard, E. F., Bull. 592, U. S. G. S., pp. 109-117. 1914.
[6]Hill, J. M., Min. Res. U. S., pt. 2, p. 64. 1914.

granite. E. L. Jones in the same report describes barite veins with a maximum width of three and one-half feet, 10 miles from Parker, Arizona. They are in basalt flows, tuffs and breccias and in some places in sandstones. The veins are not persistent along the strike and are of no prospective value. They are, however, of interest in the general problem of the origin of barite deposits.

This summary of the main features of the barite deposits of this country shows that barite is found in veins, which are more or less persistent and not uncommonly very strong. The vein material is either pure barite, or barite with calcite, fluorite, and various sulfides, chief among which are galena, sphalerite, and pyrite.

These veins are in many cases associated with faults or fault zones, a condition which suggests that the solutions found egress from below. In other cases, there are replacement deposits in limestone. Igneous rocks exist in the neighborhood of some of these deposits.

In the Piedmont region of the Appalachians, the barite is wholly in igneous and metamorphic rocks. In these cases, the conclusion that there is a genetic connection between them seems almost unavoidable. Similar deposits are found in the western United States, in some places wholly within the igneous rocks. Furthermore, many ore deposits of igneous origin contain barite as a gangue mineral.

The important German deposits are wholly in veins which are directly connected with igneous rocks, and are believed by German scientists to have been deposited by magmatic waters.

From the evidence, it seems to the writer that the formation of many of these deposits is readily explained by assuming that they are directly connected with igneous rocks from which the barite and associated minerals were derived.

### *Conclusion as to origin*

Evidence has been presented to show that barium is a widely disseminated element in all kinds of rocks, but that it is far more abundant in igneous than in sedimentary rocks. A discussion of the adequacy of ground water solutions to concentrate and bring about the deposition of the barite in Missouri led to the conclusion that such an origin is improbable. The mode of occurrence is also regarded as unfavorable to the hypothesis.

A similar review of the possibilities of the barite's having been deposited at shallow depths by ascending heated waters of igneous origin seemed to be more favorable as an explanation of the origin for the following reasons:

(a) The mineral association and paragenesis is more characteristic of veins of igneous origin than of those deposited by ground waters.

(b) The confinement of the barite to essentially one horizon is more easily explained by its having been deposited by rising solutions than by descending solutions.

(c) The ability of rising heated solutions to transport barium is much greater than that of descending solutions.

(d) The igneous rocks afford an adequate source of the barium.

(e) Barite is a common mineral in association with shallow vein deposits, especially of lead and zinc.

Furthermore, a review of the deposits of barite in other areas indicates that a large number of them show strong proof of igneous origin, which is merely corroborative evidence of the igneous origin of the Missouri barite deposits.

## ECONOMIC IMPORTANCE OF THE DEPOSITS

Up to 1915, the Missouri deposits furnished more than 65 per cent of the production of barite in the United States. The state's production amounted in 1914 to 33,317 tons, valued at $112,231, being an average value of $3.37 per ton. During 1915, there came a marked stimulation of the barium industry and a consequent rise in price. Consequently, the production of several states was increased materially, while that of the United States increased 100 per cent. Notable among these states were Georgia, Tennessee, and Kentucky. As a result, Missouri produced only about 37 per cent of the total production of the United States in 1915. The total production for the United States in 1915 was 108,547 tons, valued at $381.032. Early in

1916, the price for crude barite reached a maximum of $6.20 a ton at the shipping points. It dropped to about $5.20 in June and is steady at about that price. As a result, Missouri's production will probably be larger than at any time in her history. Old districts are producing much more barite than normally and many new areas are making important productions for the first time. It is generally believed that this new stimulus will be lasting, especially in view of the large demand for crude barite created by the new barium chemical industry.

The barite is prepared either at the Point Milling and Manufacturing Company's plant at Mineral Point, Missouri, in the midst of the producing area, or at the factories of Nielson, Klein and Co., Krausse Mfg. Co., or Finck Mining and Milling Co., all of St. Louis, Missouri.

*Mining.*—The major part of the barite is obtained at an average depth of about four or five feet. Holes more than 10 or 12 feet deep are rare, altho a few go down as far as 18 or 20 feet. According to the miners, artificial ventilation is necessary in these deeper holes.

The predominating method of mining is to sink a small pit, about 3 feet, 6 inches to 4 feet across, until the barite is reached, and then to widen out the bottom until the sides are undercut from 3 to 5 feet (Pl. X.). If the barite is uniformly distributed, this width is carried to the bottom of the clay; if not, only the important parts are mined. As a rule, all the material associated with the barite is thrown out of the pits, altho some miners do not remove more than is absolutely necessary. The miner always tries to remove the barite in the area between the pits, and, thus, he finally succeeds in getting all there is on his lot, which is usually 60 feet square. Occasionally the undercutting or drifting is carried as much as 8 to 10 feet from the pit, especially when the pit is of windlass depth or greater. (Pl. IX, B) In such cases drifting is easier than sinking another shaft. These underground drifts frequently connect with adjacent shafts, thereby making possible the development of a good circulation of air. A fire or some heated stones are sometimes placed in the bottom of one shaft to produce an "up-cast", while the working pit becomes the "down-cast." Where the barite is at the surface, stripping is used. Hydraulic methods of concentration have been tried, but have been unsuccessful because sufficient water has not been available to remove the clay and other materials. It has been reported that a steam shovel has been unsuccessfully tried, but the writer has not learned at what place. In some of the oldest workings, as those near Potosi and Old Mines, the debris thrown back by the early lead miners is now being thoroly searched for barite.

*Preparation of the barite.*—The miner usually spreads the freshly mined barite out on some boards or the ground. Here it is allowed to dry for a few hours to a few days. During this process, the very plastic clay shrinks and cracks to such an extent as to be easily loosened from the barite. The barite is then put in a rattler and given a thoro shaking. This removes the clay and also screens the barite so that the small material, usually that which will pass thru a hole one inch in diameter, is separated from the coarser pieces.

When the barite has quartz or limonite (or rarely pyrite) adhering to it, they are removed by hand with the aid of a small hatchet-like tool. Too much quartz and limonite adhering to the barite renders mining unprofitable.

After cleaning the barite, it is placed in stock piles until it can be hauled away. Since the teams usually belong to farmers, this is when the farmer is relieved of his regular duties, altho some men haul the year around. Thousands of tons accumulate in the summer at the local merchants' places of business, especially at the country stores, where they take the barite in exchange for other commodities. The barite is hauled to the railroad in the slack seasons, as noted above. In winter, the roads are very bad and only small loads can be hauled. In one locality, the writer counted twelve nearly parallel roads, the result of attempts on the part of drivers to avoid the deep mud.

The price for digging and hauling varies according to the distance from the railroads. Near Potosi, the miners were getting $4.00 a ton on company land, while on Hazel Creek, with about a 25-mile haul, the owner received from $1.50 to $1.75 per ton, the remainder going to the hauler. The rate for hauling from Richwoods to De Soto is $3.00 to $3.50 a ton. When the distances were less and two loads a day could be hauled, the rate was $1.50 to $1.75 and then the miner got more per ton as a result. The average price per ton for Missouri barite is estimated at $6.27 by the U. S. Geological Survey.

Royalties run from 50 cents to $1.00 per ton. A considerable amount of "grandmaing" is done in some places. This is the local term applied when the miners work on property for which they are not paying a royalty. The most common practice is to pay so much a ton for mining and cleaning the barite.

At the railroad, the barite is either shoveled into cars or piled on stock platforms. The miners near Mineral Point haul their product to the mill at that town.

*Treatment at the Point Milling and Manufacturing Company's Mill.*—The barite is first crushed to one-inch mesh and is then passed thru an automatic washer (on the plan of a log washer) in which the clay is removed. The material then passes thru screens, the coarser going to the granite grinders and the finer to tube mills. From there the material passes thru a classifier, the oversized pieces going back to the tube mill, and the undersized ones, that pass thru a 200-mesh screen, going to settling tanks where the excess water is removed. The sludge is then placed in lead-lined tanks and treated with sulfuric acid at a temperature of 212° F. to remove the iron stain which is always present on the barite that comes from the clay. The finely ground barite is then washed to remove the acid and then passes to the dryer and on to the packer. It is shipped in barrels and sacks. An ordinary flour barrel full of barite weighs about 700 pounds.

*Uses.*—Barite has a very large variety of uses. In recent years, it has been coming into its own in various fields, as it was first necessary to overcome the belief that it was used as an adulterant. It was formerly thot to have been used not only in paints as a substitute for white lead and zinc oxide, but also as an adulterant in foods of various kinds. This belief has not yet been entirely eradicated. The series of experiments carried out by the scientific section of the Paint Manufacturers' Association of the United States, and the Institute of Industrial Research, proved that mixtures of white lead and zinc oxides with as much as 15 per cent of inert crystalline pigments, such as barite, silica, or calcium carbonate, make a better paint than one consisting of white lead and zinc oxide alone.

The following list of uses is as complete as the writer can make it:

1. In pigments.
2. In lithophone.
3. As a base for colored pigments.
   a. Printers inks.
   b. Aniline dyes, etc., for postage stamps, etc.
4. In putty.
5. In rubber goods (to give weight).
6. In linoleum (weight).
7. In oilcloth.
8. In cloth around hams to keep air and insects out.
9. In enamel, in pottery and porcelain manufacture.
10. In jasper ware (abroad).
11. In producing classic figures on wedgewood ware in North Staffordshire.
12. In making chemical reagents.
13. In enameling iron.
14. In refining sugar especially beet sugar.
15. In tanning leather (to give weight).
16. In manufacture of hydrogen peroxide.
17. In dressing calicoes.
18. As a coating, to prevent aeration in the manufacture of gorgonzola cheese at Valsassina, Italy.
19. In finishing wall paper.
20. In pyrotechnics.
21. In paper collars.
22. In insecticides.
23. In artificial ivory.
24. In sealing wax.
25. In artificial stone.
26. In manufacture of alumina.
27. In asbestos cement.
28. In poker chips.
29. In preparation of fertilizers (for weight).
30. In boiler compounds.

31. In artificial driftwood salts.
32. In loading ropes.
33. In dressing for surface of asphalt pavement.
34. In filler for wood preservatives.
35. In roofing.
36. To give weight to paper. Since Bible paper has been introduced, it is used less.
37. In various glasses, as rolled glass, hollow ware, crystal and table glass. Jena phosphate crown glass contains 28 per cent of BaO and 60 per of $P_2O_5$.
38. In manufacture of commercial chromegreen.
39. Reported as used as an adulterant in flour, sugar and candy, especially certain French candies.

This long list shows the many uses to which this material is put. Many of these uses are merely to give weight to the product sold which is ordinarily light. Such cases are in the manufacture of paper, fabrics, rubber, insecticides, fertilizers, ropes, etc. In other instances, it is used because the mineral takes a color stain uniformly and this makes a small quantity of dye cover a large surface. Its use in the paint industry has been known for fifty years or more. Certain special paints contain large amounts of $BaSO_4$, as the following: Venice white lead has 50 per cent; Hamburg white lead has 66 per cent; Dutch white lead has 75 per cent. Barium salts in glass increase the specific gravity, tenacity, elasticity, and refractive index.

*Future of the barite industry of Missouri.*—A statement as to the probable future production of barite in Missouri is so dependent upon the price of the mineral that these remarks are merely suggestive. If the price is maintained at its present high level, the production will increase in two different ways: (1) the older areas will be carefully searched for barite, and (2) the outlying fields will send a large production to market. The future development of these outlying areas depends entirely on the market, or upon improved transportation facilities. At the present time, they are so far from the railroad that only the very highest prices will lead to their development. Should a railroad reach these fields, they would become very important producers, for many of them are as yet scarcely touched.

Higher prices, whether they come thru a growing scarcity of the mineral, thru its increased use in the chemical industries, or thru the development of unsuspected uses, will cause more and more attention to be paid to deep mining, especially on the veins. This should also result in an improved grade of material. Much could be done to improve the present methods of digging. It is likely that only the larger vein and cave deposits will prove workable, unless the price is high, altho associated metallic sulfides may also aid in making the smaller veins workable. At present, most of the barite produced outside of Missouri comes from veins and not from residual materials.

The Hazel Creek, the Richwoods, and the Wilson Creek areas all contain very valuable deposits awaiting development. In the Central district, there seems to be a probability that barite will be saved as a by-product in the deep mining of zinc. Much good barite will be obtained from the circles and residual material there also.

On the whole it seems that, altho the enormously rich residual deposits which have been accumulating for a great period are only partially exhausted, the best areas are being rapidly worked out and search will go downward to obtain barite from the veins. At the same time, outlying areas may be expected to show an active production. The state, therefore, will probably continue to make a high production of barite for some time to come.

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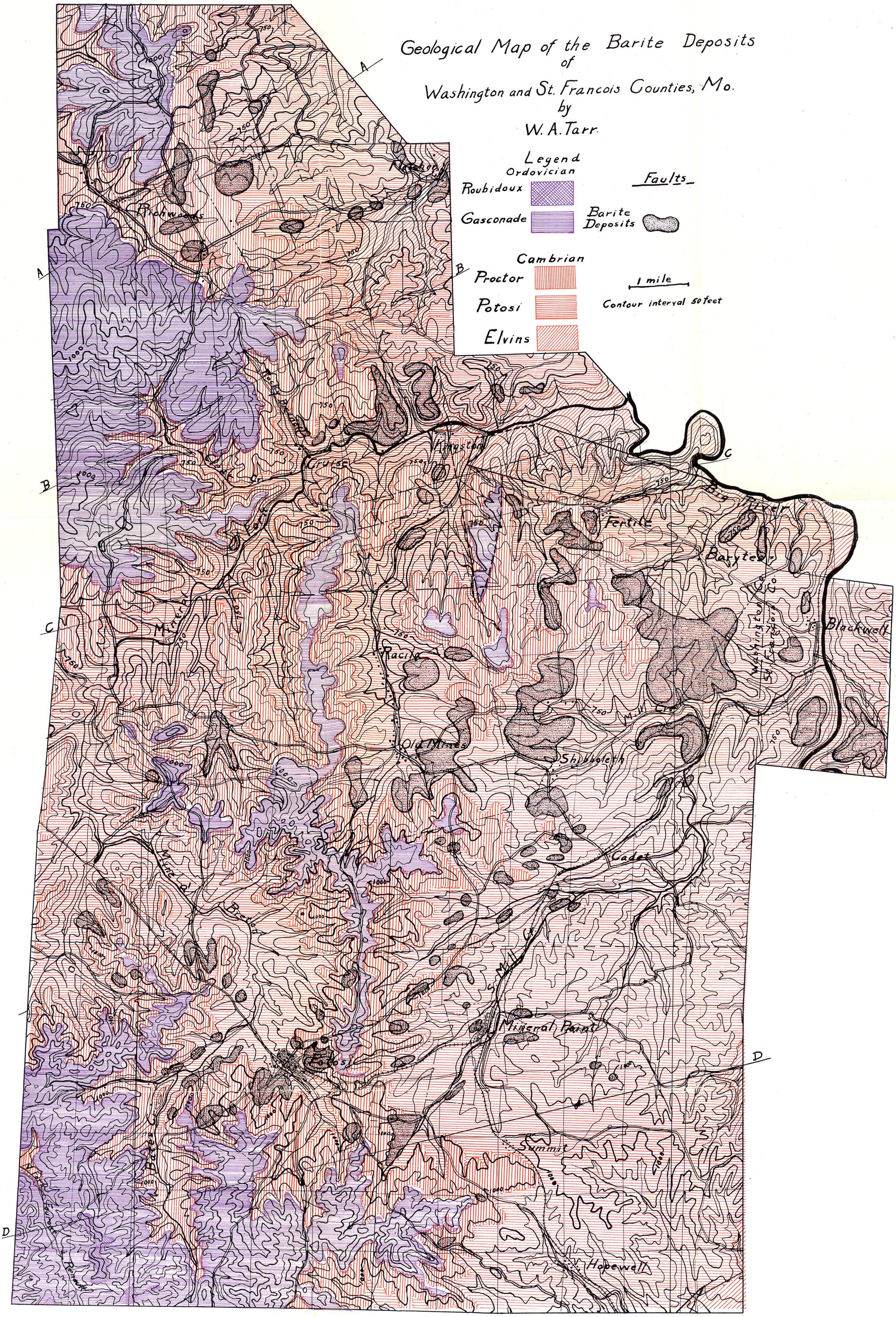
PLATE 1




W. A. TARR

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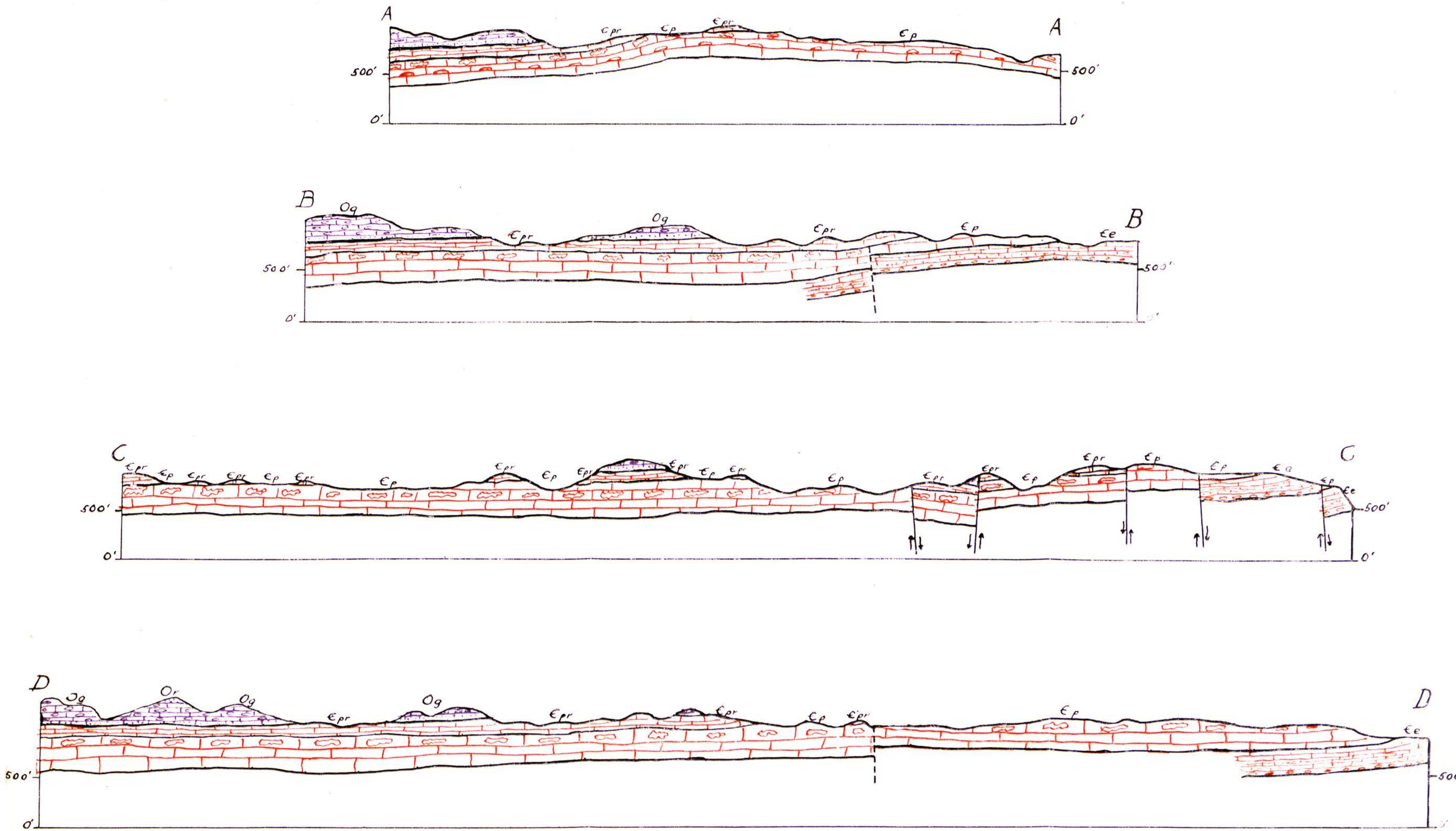


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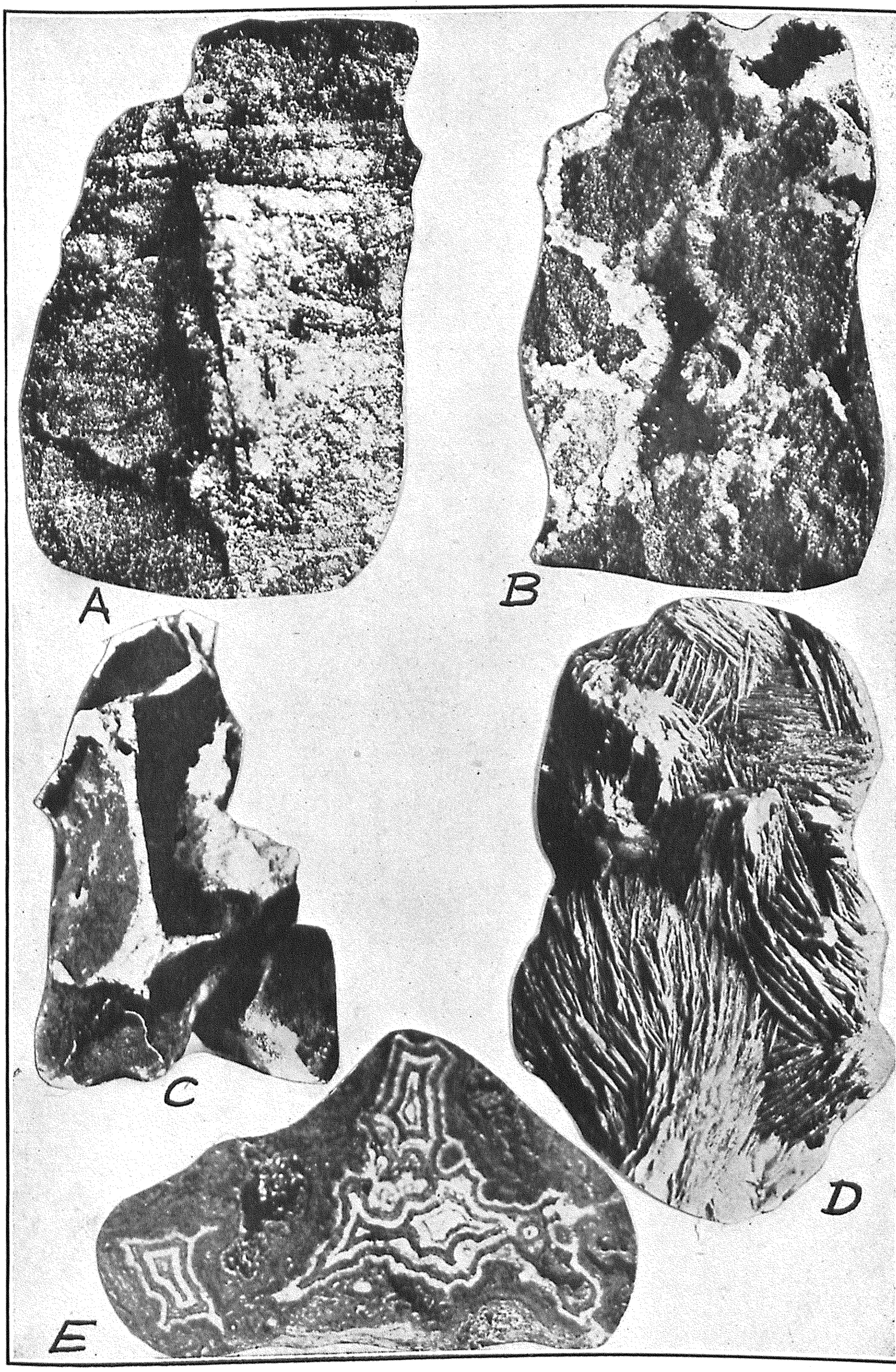


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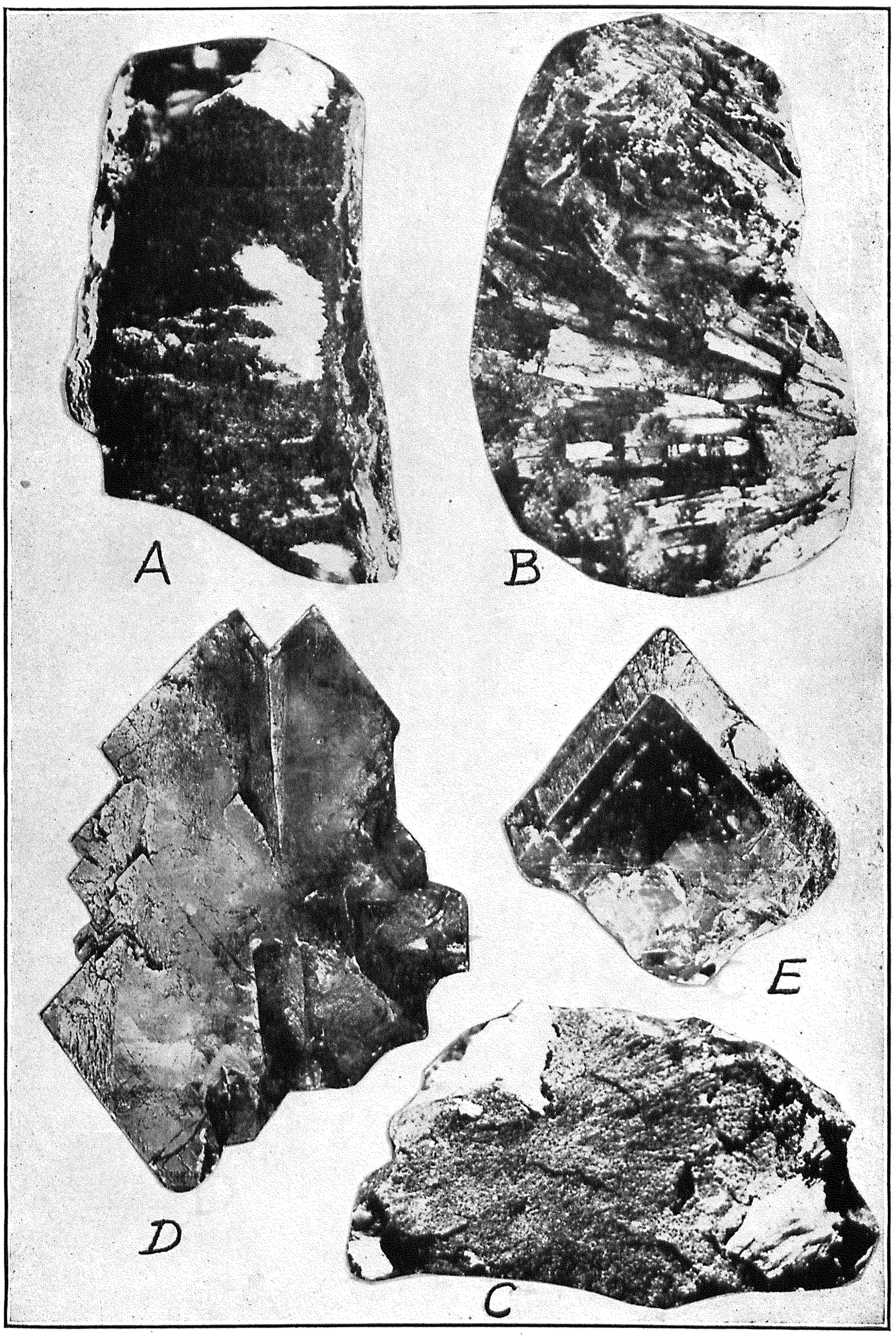


W. A. TARR

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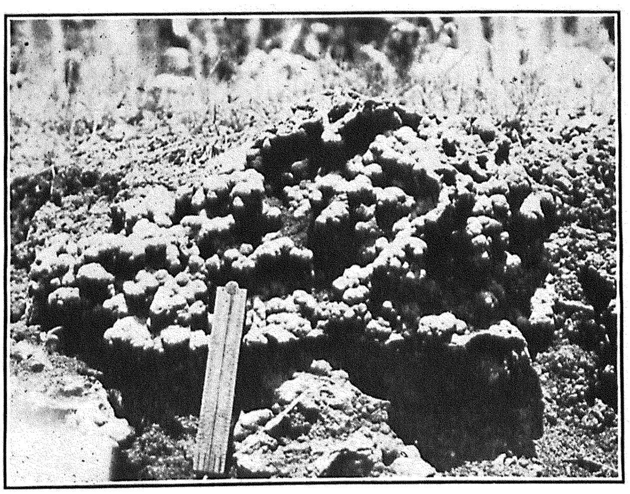

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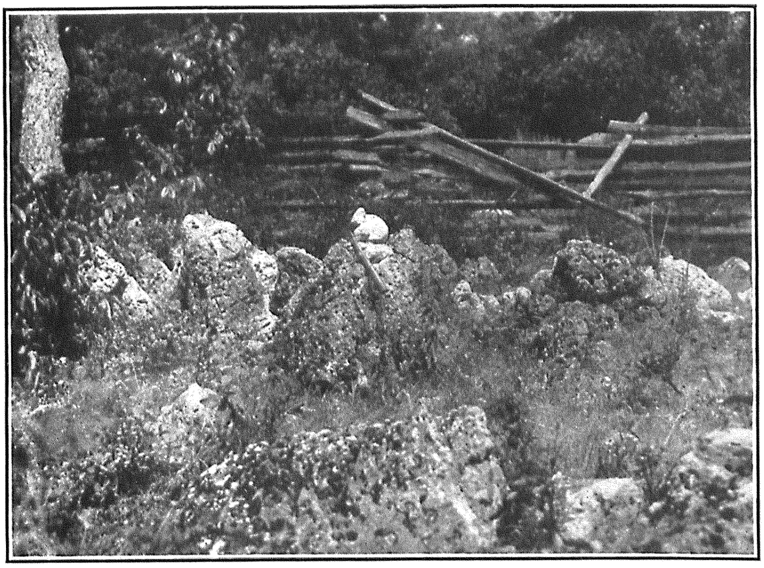

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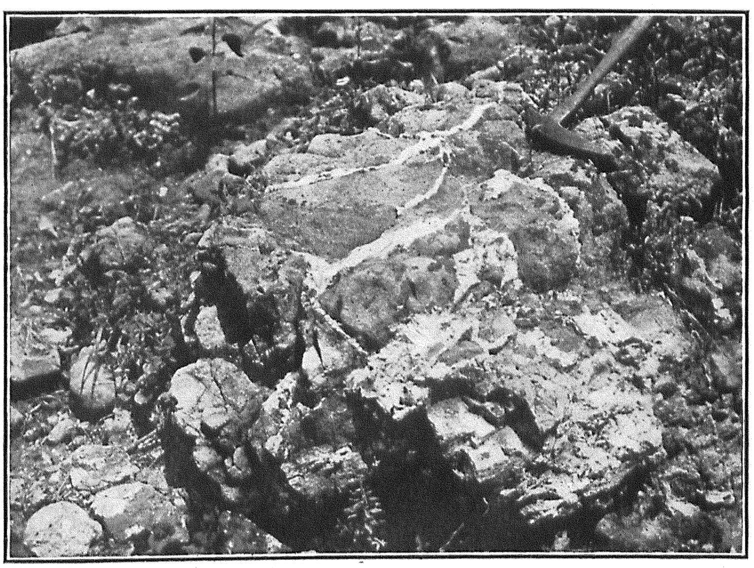

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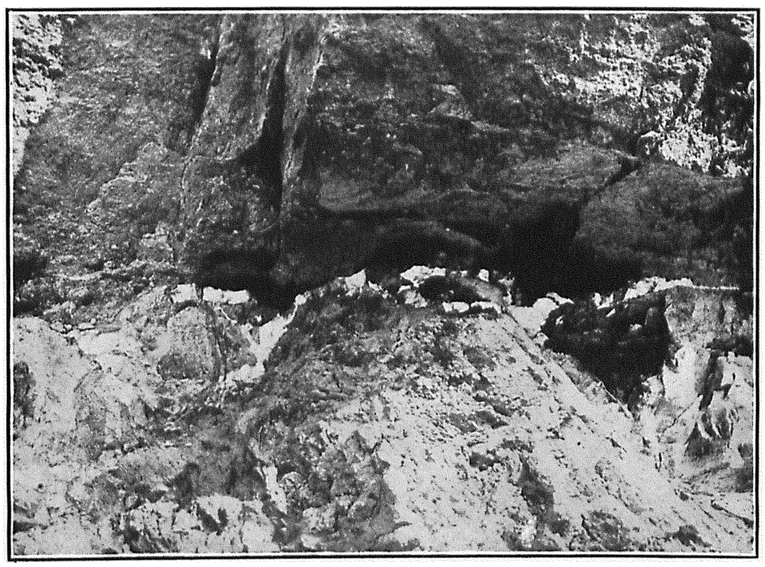

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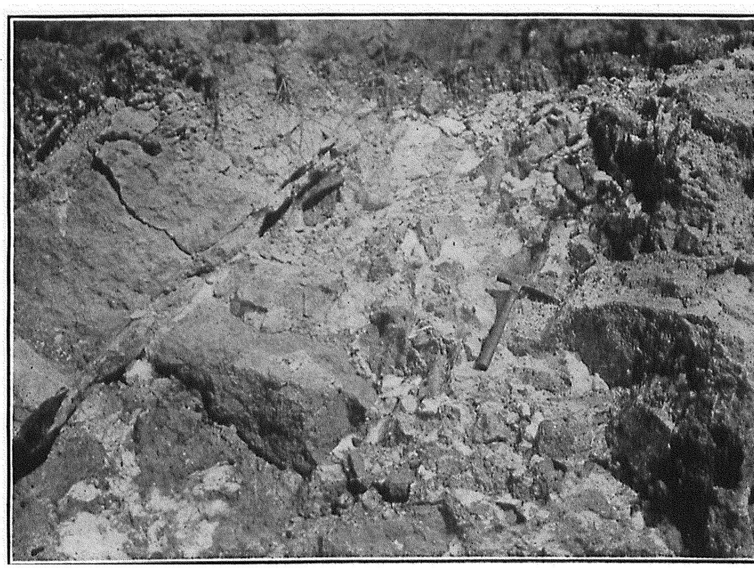

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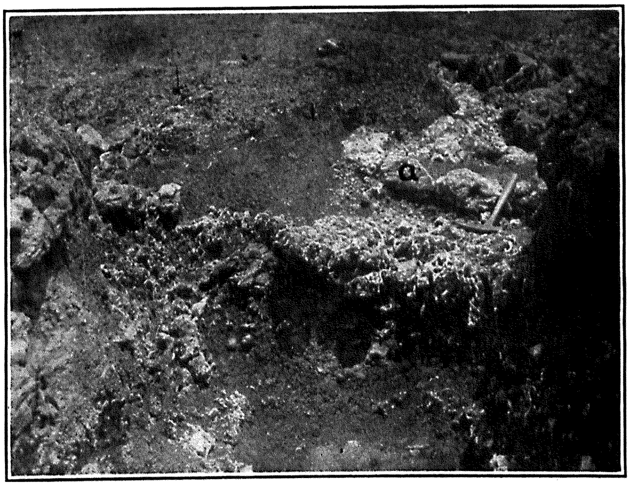


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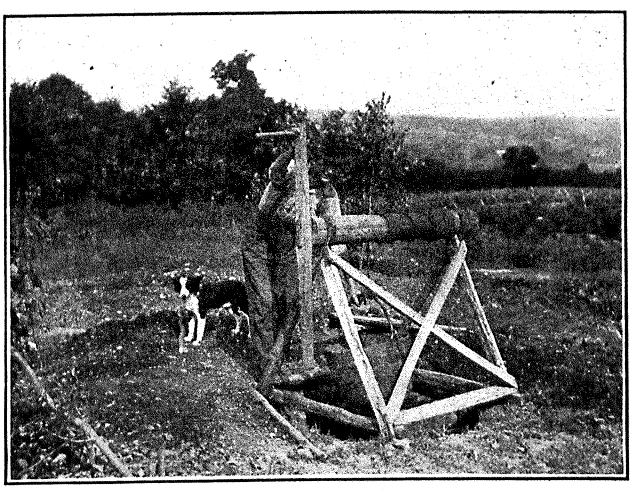

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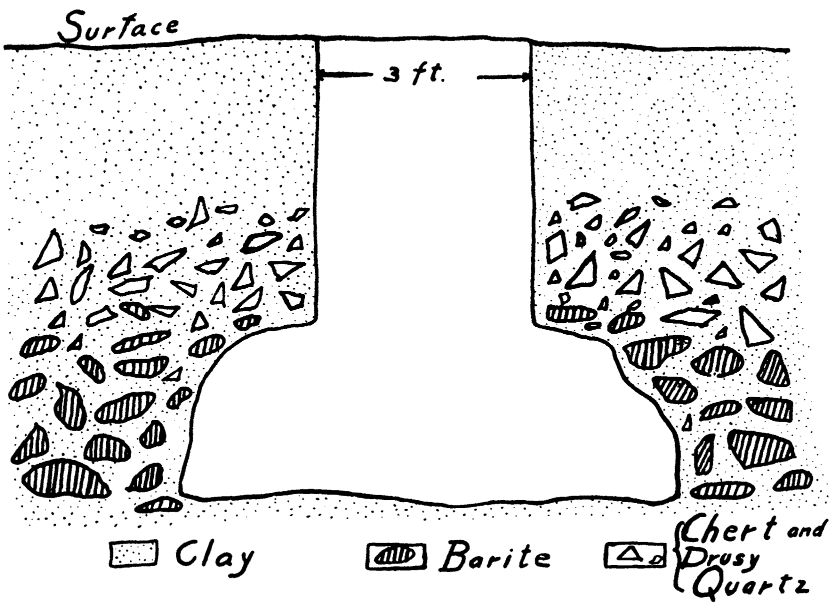


W. A. TARR