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# THE

# Geology of the Granby Area

BY

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AND

H. A. BUEHLER.

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# LETTER OF TRANSMITTAL.

Bureau of Geology and Mines,
Rolla, November 1, 1905.

To the President, Governor Joseph W. Folk, and the Members of the Board of Managers of the Bureau of Geology and Mines:

Gentlemen—I have the honor and pleasure to transmit to you a report on "The Geology of the Granby Area."

This report contains a discussion of the lead and zinc ores of one of the most productive areas in Missouri. The conclusions as to the origin of the ores and the causes for their concentration are somewhat at variance with those in the published reports of other Geological Surveys. However, we believe that they account better for the facts as observed in the field, and therefore I have no hesitancy in submitting them for publication.

Chapter II. is a rather lengthy summary of the more important reports, treating of the lead and zinc deposits of the Southwest Missouri District. An attempt has been made, in this chapter, to point out clearly the differences in opinion which exist as to the genesis of the ores, by quoting somewhat fully from these reports.

Although the ore bodies of the Granby area occur differently, in many respects, from those of the Joplin and other areas of the district, yet they have, in all probability, had a common origin. For this reason the report should have an interest to all who are engaged in mining lead and zinc in Southwestern Missouri.

The greatest care has been exercised to make the descriptions clear and accurate, and it is believed that any theories which are brought forward conform very closely to the facts as observed in the field.

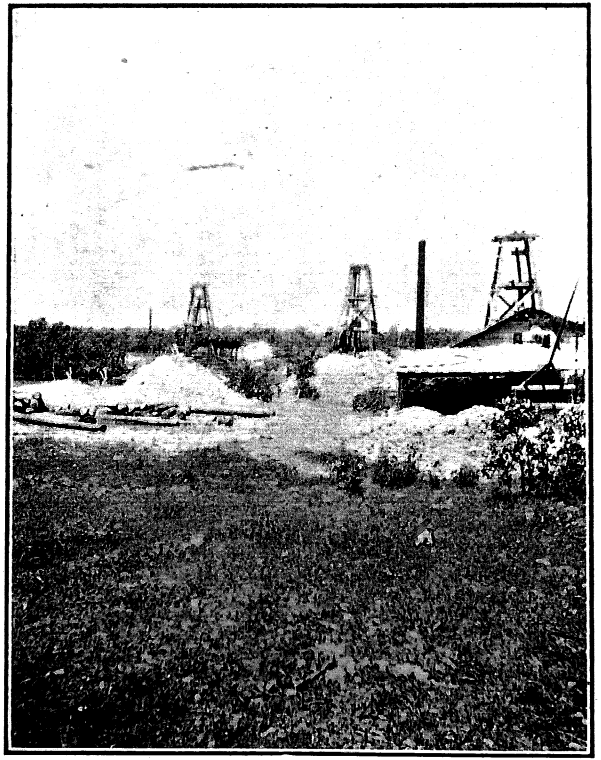
I am, very respectfully, your obedient sir,

E. R. BUCKLEY.

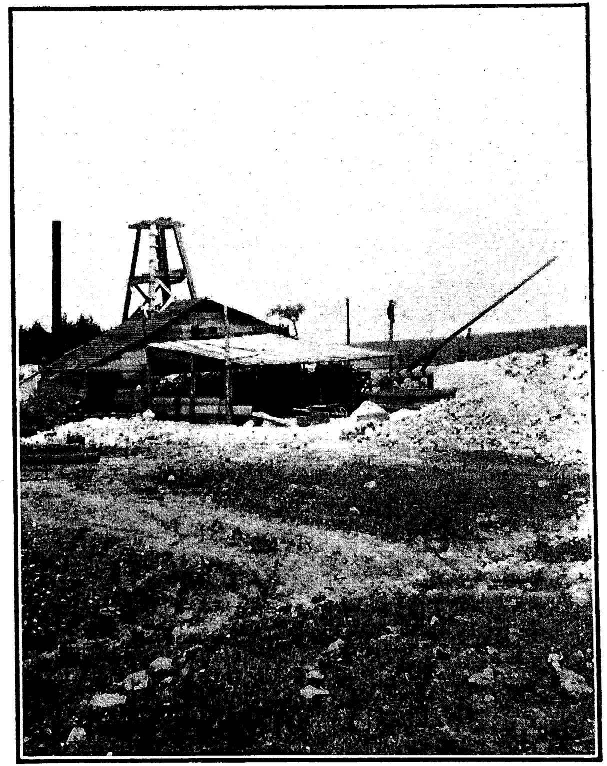
# ACKNOWLEDGMENTS.

The success of these investigations has been due, in a large measure, to President L. C. Burnes and Secretary Elias S. Gatch and the Board of Directors of the Granby Mining and Smelting Company. For assistance in the field, we wish to acknowledge our special indebtedness to Captain John T. Kingston, Superintendent of the Granby Mining and Smelting Company, at Granby, Mr. Ede of the Illinois Zinc Company and Messrs. Perkins, Kinney and Lucas. To all those engaged in mining in this area, we are indebted for many courtesies extended. Without their co-operation, this report would have lost a great part of its value.

We also desire to express our indebtedness to Professor V. H. Gottschalk for many helpful suggestions in working out the chemistry of the ore deposits.



WE-TAK-ER AND RUBY TRUST (1 AND 2) MINES.



WE-TAK-ER MINE, SHOWING HAND JIG AND PICKING SHED.

# INTRODUCTION.

A careful study of the lead and zinc deposits of the Granby area was begun in November, 1904. The mining in this region has been chiefly of a shallow nature, there being only four mines which might be considered deep. The area included in this report, comprises 15 square miles, surrounding the city of Granby, as shown on the accompanying map, Plate III. This area includes most of the land around Granby, which has produced, or is producing, commercial quantities of lead and zinc ores. Granby is one of the oldest lead and zinc producing camps in the southwestern part of the State, mining at this place having been actively engaged in for over half a century. The area is renowned for its great variety of lead and zinc minerals and for the great quantity of calamine which it has produced. Over some portions of the area, the abandoned shafts are as close together as they could easily have been dug. A conservative estimate would place the number of shafts dug since the district was opened, at over 5,000. Most of these shafts have a depth of less than 75 feet. Information as to what was obtained from many of them is very meager, records having been kept of only the most productive.

The first step in the preparation of this report was the making of a topographic map, on a scale of four inches to the mile, and a contour interval of ten feet. Lines of level were run along the more important roads, the elevations of the intermediate points being obtained by use of an aneroid barometer. Great care was exercised in making this map, the aneroid being frequently checked on known points, elevations of which had previously been determined by the level. The roads, streams and most of the valleys were traversed, their location and direction being determined with a fair degree of accuracy.

The sides of many of the sections are of different lengths, and in some instances it was necessary to measure these in order that any locations made upon the map might be reasonably accurate.

All of the active mines were accurately located, and wherever it was possible, maps of the underground workings were made. In addition to the active mines, a great many of the abandoned shafts were also located. In some cases it was possible to obtain approximately the size, shape and direction of the underground workings connected with the abandoned shafts, from men who were in charge of these mines when they were in operation. All of this information has been recorded on the maps accompanying this report.

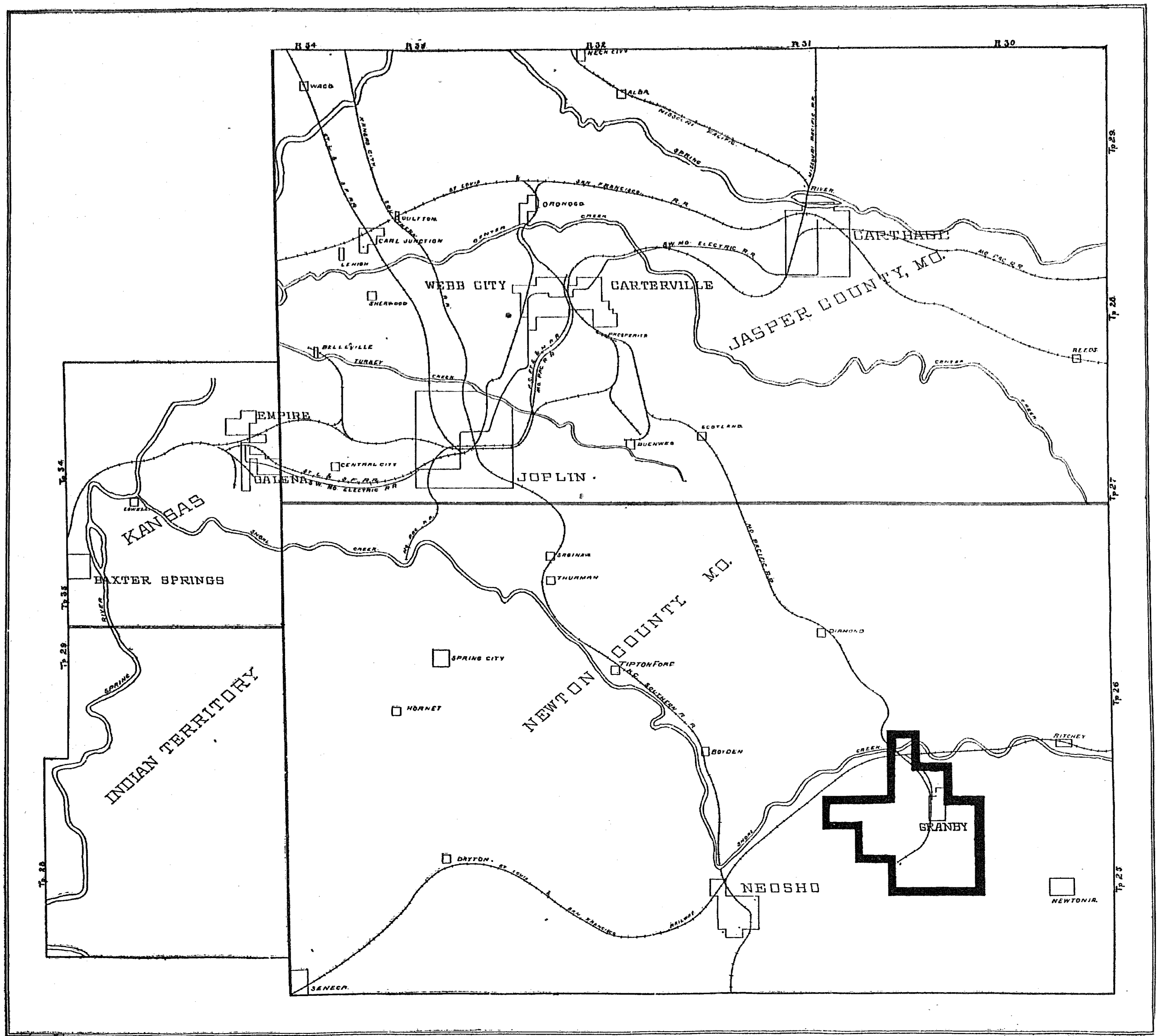
A careful study was made of all the outcrops of rock exposed at the surface. These outcrops have been located in colors on the topographic map, showing the elevation at which they occur. The different colors indicate whether the outcrop is limestone, flint (chert) or sandstone and shale. The relative abundance of the flint, or other fragments of rock on the surface, is indicated by colored dots.

Finally, a careful examination was made of all the active mines, the ores were studied with relation to the rocks, and a careful examination was made of all drill records. Owing to the extremely muddy or clayey condition of the mines, their examination was attended with more or less difficulty. The information embodied in the drill records was not sufficiently detailed to be of much assistance in working out the structure of the area.

The study of this area was undertaken for the purpose of, first, determining the age and origin of the lead and zinc ores; second, the conditions which determine the location of the ore bodies as a whole; third, the conditions which resulted in the local enrichment of the ore bodies. It is thought that the results obtained through this investigation ought to be of service in the development of the lead and zinc deposits of the entire southwestern district, as well as the Granby area. The facts which we have gathered lead to conclusions which differ from those advanced by the Geologists of the United States Geological Survey and others who have previously published reports covering this area. We find that the observations recorded have not always been correct, and that the theories based thereon are correspondingly inaccurate.

It is thought that any theory of the deposition of the ores which is applicable to this area must, in general, be applicable to the entire southwestern lead and zinc district. Observations made in the Joplin, Webb City, Oronogo and other areas in Jasper county verify the conclusions reached relative to the ores of the Granby area, although the manner of occurrence and association of the minerals are in some particulars different. These will be pointed out in their proper place.

All of our efforts have been directed toward a solution of the three problems concerning the origin and concentration of the ores referred to above. Any information which this report may contain, outside of that required in the discussion of these problems, has been gathered incidentally. It is not intended in this report to discuss in detail the methods of mining and smelting carried on in the area, although some mention is made of these in the last chapter.




GENERAL MAP SHOWING THE LOCATION OF THE GRANBY AREA.

# CHAPTER I.

## LOCATION, HISTORY AND PRODUCTION OF THE AREA.

The Granby area lies in the southern part of the lead and zinc district of Southwestern Missouri. It is in the east central part of Newton county, and for the purposes of this report has been made to include parts of township 26 N., range 31 W., and township 25 N., range 31 W. and township 25 N., range 30 W .(see map Plate III). In a direct line, it is about 16 miles southeast of Joplin, and about the same distance almost due south of Carthage. It is also about 20 miles due west of Aurora. It can be reached by the Missouri Pacific and St. Louis & San Francisco railroads. Granby is the only city in the area, and is located in section 6, township 25 N., range 31 W.

The area is surrounded by land which has been but little prospected, and is as yet almost wholly undeveloped. Mining is being carried on to a limited extent, at a number of localities in the county outside of the Granby area. The most important of these are Neosho, Spurgeon, Diamond and Newtonia.

### HISTORY OF MINING IN THE GRANBY AREA.

Capt. John Kingston, who first visited Granby in 1856, says that Wm. Foster first discovered lead at Granby in 1850. While passing through Granby on his way to St. Louis, Mr. Foster stopped at the home of Mr. Madison Vickery, who was digging a well on the hillside at the site of the present lime-house. Mr. Vickery had picked up an unusually heavy mineral and carried it to the house. He showed the specimen to Mr. Foster, who recognized it as galena. Instead of continuing his journey to St. Louis, Mr. Foster started at once to sink a shaft, the first in the area. No mining of any consequence was done at Granby until 1853, when Mr. Foster got out a considerable quantity of mineral.

A furnace of three Scotch eyes was erected soon after by a Mr. Fitzgerald, on Shoal Creek, near where the St. Louis & San Francisco railway depot now stands. This furnace was operated successfully for several years, stimulating mining and attracting men from all parts of the country. Two other small furnaces were soon after erected, one by Mr. John Plummer and one by a Mr. Long. The lead smelted during these years was disposed of in various ways; it was hauled in wagons to Fort Smith, Arkansas, and then boated down the river to New Orleans, to be shipped from thence to New York and Boston; some was taken to the Grand river, and from thence, on flat boats, to New Orleans, and some was hauled to Boonville and shipped by boat to St. Louis.

In 1856, Blow and Kennett obtained from the Atlantic and Pacific Railroad Company a lease of the Granby section, and immediately erected large furnaces on the land. Following the erection of these furnaces, the output increased rapidly, until from 1858-1861, inclusive, the output reached from ten to twelve million pounds per year. During the war of the Rebellion the mines are said to have been worked alternately by the Confederate and Federal soldiers.

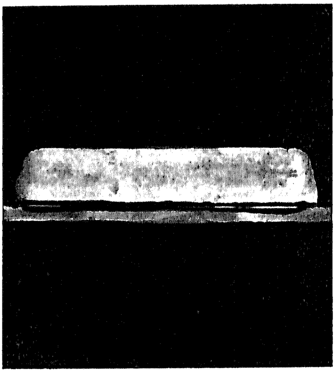
In 1865, the Granby Mining and Smelting Company was organized by Henry T. Blow, absorbing the interests of Blow & Kennett. The furnaces were repaired, a new lease was obtained, and mining resumed with increased vigor and more success than ever.

When this camp was first opened up, cerussite and galena were the only minerals exploited. Mr. A. V. Weis, who was superintendent of the furnace at an early day, was the first person to recognize the value of the calamine. He was ridiculed, until, upon sending samples to Washington University for analysis, his statements were confirmed. The first zinc ore was sold at this camp in 1869, when $3.00 to $5.00 per ton was paid for the highest grade of calamine, known as silicate.

In the "Newton County Tribune" of September 30, 1868, Mr. W. S. Mesplay wrote an article calling the attention of the miners to the so-called "black-jack," stating that it was zinc ore, and advising them to save it, as it must some day be valuable. After reading this article Mr. Blow and others had the ore tested in St. Louis, proving the correctness of Mr. Mesplay's statements. Nothing was done in the way of mining or smelting this ore until the railroad was completed to Granby, in 1870. The ore was then shipped quite extensively to Carondelet, Missouri; LaSalle, Illinois; and into Pennsylvania.

For many years galena was the chief product of this area. Later calamine became most important. With the opening of the Mascot (1897) and Homestake mines, sphalerite, or zinc blende, took the lead, while calamine became second and galena third.

For forty years the Granby Mining and Smelting Company has been engaged in smelting galena at Granby. In the early days some galena was smelted by the company at Lone Elm, near Joplin. This part of



One of the oldest pigs of lead in Missouri. Made in 1860 by the Granby Mining and Smelting Company.

the business is now centralized at Granby, and the furnaces located there have an annual capacity of 5,000 tons of pig lead.

The zinc ores are shipped to a smelter, belonging to the company, at Neodosha, Kansas.

The average number of miners, mill men and laborers employed at the mines, mills and smelter on the Granby Mining and Smelting Company's land, during 1904, was 425. During the same period there were 65 pumps, 65 steam hoists and 15 horse hoists in operation. There were seventy-five producing shafts and 35 being put down.

In 1869, when Judge B. K. Hersey was general superintendent at Granby, Capt. John T. Kingston became superintendent of the furnace and mines. Upon the death of Mr. Hersey, in 1877, Mr. Kingston became general superintendent, occupying that position continuously up to the present time.

The Mascot mine was opened in 1897, the ore being concentrated in hand jigs. In 1898 a modern concentrating plant was erected, the first in the area. At present there are six concentrating plants, besides the one at the furnace, all in active operation.

The original Granby area included only one section of land, commonly known as "Section Six." This section of land has probably produced more lead and zinc ore than any other section in Southwest Missouri. The productive area surrounding Granby has been gradually extended until now it may be said to cover from 12-15 sections. At the present time there are several companies actively engaged in mining in this area, where formerly there was only one. The mines are all operated on a lease system, which is described in a subsequent chapter.

Profesor G. C. Broadhead,* in the report of the Geological Survey for 1873 and 1874, gives the following brief history of this area: "In 1850 the Prairie Diggings, one mile south of Granby, were opened, and in 1851 mining began in Brock Hollow on the Granby section."

"The Granby mines were the first which actually began to flourish. In 1856 Blow & Kennett obtained a lease on the Granby section from the Atlantic and Pacific Railroad Company, which owned the land. They erected six Scotch hearths with blast produced by fans and steam power. Six other hearths were erected and worked by other parties. Miners from all parts of the world flocked to Granby, and the town grew rapidly. The production rose to over 8,000,000 pounds per year. The principal work was done at Brock Hollow, the Dutch, the Frazier, and at some parts of the Crab Tree and Hard Shaft Diggings."

"The beginning of the war in 1861 stopped the mining operations

*Report of the Geol. Sur. 1873-74, pp. 488-489, by G. C. Broadhead.

of the whole region until in 1865. Henry T. Blow then obtained a lease of the Granby section and vigorously started and pushed the work * * * finally the discovery of zinc ore, and its value, secured the success of these mines for a lengthy future."

## OUTPUT OF THE AREA.

In the report of the Geological Survey for 1873, page 501, G. C. Broadhead estimates "The total production of Granby, from the beginning of mining to the end of the year 1873, at about 80,000,000 pounds of galena, equal to about 27,100 tons of lead, worth, at 7 cents per pound, $3,920,000.00." In volume VII of the reports of the Missouri Geological Survey, Mr. Arthur Winslow estimates the total production of Newton county from 1850-1893 at 77,285 tons of lead ore, valued at $3,-560,400.00, and 183,000 tons of zinc ore, valued at $2,096,000.00. This makes a total value of ore mined in Newton county, up to 1893, most of which comes from the Granby area, of $5,656,400.00. The output from 1893 to 1904, inclusive, amounted to 22,983,014 pounds of lead ore, valued at $523,562 90, and 170,347,659 pounds of zinc ore, valued at $1,726,597.70. This makes the total value of lead and zinc ores produced in the Granby area from 1850 to December 31, 1904, approximately $7,-906,560.60.

The following statement of the lead and zinc ores produced at Granby, Missouri, from January 1, 1893, to December 31, 1904, was furnished by the secretary of the Granby Mining and Smelting Company:

STATEMENT OF ZINC AND LEAD ORES PRODUCED AT GRANBY, MO., FROM JANUARY 1ST, 1893, TO JANUARY 1ST, 1905.

| Year. | Lead ores, pounds. | Value. | Zinc ore, Company lands, pounds. | Zinc ore, Outside lands, pounds. | Zinc ore, total pounds. | Value. |
|---|---|---|---|---|---|---|
| 1893 | 2,345,675 | $46,913 50 | 10,662,282 | ........ | 10,662,282 | $60,972 00 |
| 1894 | 3,170,621 | 53,900 59 | 13,236,193 | ........ | 13,236,193 | 59,562 00 |
| 1895 | 2,532,996 | 50,659 92 | 11,670,599 | ........ | 11,670,599 | 55,432 50 |
| 1896 | 2,266,041 | 46,586 86 | 11,098,615 | ........ | 11,098,615 | 76,298 75 |
| 1897 | 1,308,515 | 27,478 81 | 11,676,550 | ........ | 11,676,550 | 90,780 90 |
| 1898 | 1,547,091 | 38,677 28 | 10,442,601 | 120,355 | 10,562,956 | 93,368 08 |
| 1899 | 735,375 | 18,384 38 | 14,445,456 | 269,298 | 14,714,754 | 163,325 40 |
| 1900 | 977,843 | 24,446 08 | 15,093,691 | 991,137 | 16,084,828 | 213,113 00 |
| 1901 | 2,084,960 | 52,124 00 | 15,276,470 | 742,199 | 16,018,669 | 172,193 50 |
| 1902 | 2,189,230 | 54,730 75 | 15,846,566 | 321,893 | 16,168,459 | 191,186 60 |
| 1903 | 1,682,954 | 47,122 71 | 13,392,310 | 1,159,621 | 14,551,931 | 207,729 80 |
| 1904 | 2,141,713 | 62,538 02 | 22,038,871 | 1,862,952 | 23,901,823 | 342,635 17 |
| Totals | 22,983,014 | $523,562 90 | 164,880,204 | 5,467,455 | 170,347,659 | $1,726,597 70 |

Zinc ore produced, 170,347,659 pounds; value ........ $1,726,597.70
Lead ore produced, 22,983,014 pounds; value ........ 523,562.90

Total value ........ $2,250,160.60

# CHAPTER II.

## PREVIOUS WORK BEARING UPON THE GEOLOGY OF THE AREA, WITH COMMENTS.

The Granby area has been investigated and reported upon by Swallow,* Schmidt and Leonhard,** Winslow,*** and Bain.**** Swallow describes briefly the Granby mining camp and gives an estimate of the output in his report for the Pacific railway in 1859. He does not attempt a discussion of the ore deposits. The report of Schmidt and Leonhard is contained in a chapter published in Broadhead's report for 1873 and 1874. The note books in the possession of the Bureau, as well as the published report, indicate that a careful examination was made of all the mines in the Granby area; that sketches of the underground workings were made; and that the ore deposits and geology of the area were carefully studied. This is the first and only detailed examination which has been made of the Granby area up to the present time. In the preparation of Volumes VI and VII of the reports of this Bureau, on lead and zinc, Winslow and Robertson both visited Granby, making hurried examinations of the mines being worked at that time (1890-91). Volume VII of these reports contains a short description of the mines of this area, which were being worked at that time, but evidently very little attention was given to a study of either the ore deposits or the geology.

In the preparation of the report of the U. S. Geological Survey on the lead and zinc deposits of the Ozark region, Bain made a preliminary study of the Granby area. In that report he discusses the stratigraphy, structure and ore deposits of the area. He has mapped and described several faults, which are very important factors in his theory of the origin of the lead and zinc ores of the district.

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*Geological Rept. of the Southwestern Branch of the Pacific Railway, 1859, page 92 and pages 36-37, by G. C. Swallow.

**Report of the Mo. Geol. Survey, 1873-74, pp. 415-436, by G. C. Broadhead.

***Mo. Geol. Survey, 1894, Vol. VII, pp. 602-606, by Arthur Winslow.

****Lead and Zinc Deposits of the Ozark Region, Pt. II, 22nd An. Rept. U. S. Geol. Survey, pp. 187-191, by H. Foster Bain.

In addition to the above reports, there have been numerous references to this area in the miscellaneous publications upon the lead and zinc deposits of the Mississippi Valley. Among these are papers by James D. Robertson,* Charles P. Williams, ** W. P. Jenney,*** Rossiter W. Raymond**** and Erasmus Haworth.***** The origin of the lead and zinc ores of the Mississippi Valley has been discussed in the reports of the United States Geological Survey; in the reports of the Geological Surveys of Wisconsin, Iowa, Missouri, Arkansas, Kentucky, Virginia and Kansas; in the proceedings of the American Institute of Mining Engineers; in the proceedings of other scientific societies; and in the various mining and geological journals. The opinions of Whitney, Owen, Percival, Chamberlin, VanHise, Bain, Haworth, Schmidt, Blake, Swallow, Broadhead, Branner, Adams, Watson, Leonard and others, as to the origin of the lead and zinc ores in the various districts, are contained in these reports, journals and proceedings. These articles are too widely scattered, too numerous, and most of them do not apply directly enough to the ores of the Granby area or the Southwestern Missouri district to justify us in making abstracts from them.

There are, however, two somewhat divergent theories as to the origin****** of the lead and zinc ores of the Mississippi Valley, represented on the one hand by Whitney, Chamberlin, Blake, Robertson and Winslow, and on the other hand by Jenney, VanHise and Bain. In most of the late reports on the Lead and Zinc Deposits of Wisconsin, Virginia and Arkansas, the different authors have applied the theory of VanHise and Bain with no essential modifications.

In the following pages the reader will find extracts from the publications of different authors, some of whom are ascensionists and others descentionists.*******

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*"The Missouri Lead and Zinc Deposits," by James D. Robertson. Am. Geol. Vol. XV, 1895.

**"Industrial Report on Lead, Zinc and Iron," by Charles P. Williams. Missouri Geological Survey, 1877.

***"Lead and Zinc Deposits of the Mississippi Valley," by W. P. Jenney. Transactions of the American Institute of Mining Engineers. Vol. XXII, 1894.

****"Note on the Zinc Deposits of Southern Missouri," by Rossiter W. Raymond, Transactions of the American Institute of Mining Engineers, 1879.

*****"Geology of the Lead and Zinc Mining District of Cherokee County, Kansas," 1884; Also "Relations Between the Ozark Uplift and Ore Deposits," Bulletin, G. S. A., Vol. II, by Erasmus Haworth.

******By origin we mean the first or primary concentration by ground water.

*******We believe that lateral secretion must accompany both descension and ascension as applied to the movement of ground water, and for that reason it is not considered separately.

Adolph Schmidt, in his report on "The Lead and Zinc Regions of Southwest Missouri,"* says:

"The whole region belongs geologically to the Subcarboniferous System. The formation consists of a series of Limestone and Chert beds belonging to the upper part of the so-called Archimedes or Keokuk Limestone."

"In some places they are overlaid by disturbed layers of Sandstone, perhaps in part the 'Ferruginous Sandstone' of Swallow, and in part a Coal Measure Sandstone; in other places by pockets of Slate and Coal belonging to the Lower Coal Measures. The ore deposits in this region lie more often horizontally than vertically. They are connected with certain more or less altered strata of the Archimedes Limestone, and are covered by broken masses of Chert and Limetone."

The succession in deposition, as given by him, is shown in the following four series, the oldest mineral always being given first:

"1—Galena, blende, dolomite, bitumen.

2—Galena, blende, dolomite, calcite, calamine, smithsonite, zinc bloom.

3—Galena, cerussite, pyromorphite.

4—Galena, pyrite, limonite."

The relation of the ore to the white chert is explained as follows:

"The chert is mostly white, gray or yellow, occasionally rose or flesh colored. The chert is one of the principal ore-bearing rocks in the mines of Southwest Missouri. It contains galena in numerous sheets or seams either deposited between layers of chert or filling small cracks in the chert. It is evident in all places that the galena has formed after the chert had been formed and hardened, as crystals of galena and blende are never found entiredy enclosed in the body of the chert, but always in cracks or cavities—chert is also found in intimate connection with blende, both forming a conglomerate in which sharp-edged pieces of chert are surmounted by crystalline blende."

The change in the white chert he noted as follows:

"In many places the solid chert undergoes a change and passes into a soft porous variety - - - The change always begins from the outside of the piece or from small crevices or cavities - - - The absence of ore in the altered chert goes far towards proving that the alteration of the chert must have taken place after the deposition of the ores."

The geological history of Southwest Missouri is given in the following five periods:

**Period of Deposition.**

"*First Period*—Original deposition of the various stratified rocks, namely: The Bed Rock, the alternative layers of Limestone and Chert, the Silico-calcite, the Slates and Coal, and of the Sandstone.

"These several strata, after their depositions, probably remained unaltered for a very long time and became dry, hard and dense before the second period began."

*"The Lead and Zinc Regions of Southwest Missouri," by Adolph Schmidt, in Vol. I, Geological Survey of Missouri, 1873-1874, by G. C. Broadhead.

**Period of Dolomization.**

"*Second Period*—Local dolomization of certain strata .of Limestone. Disturbances and ruptures in the Chert in consequence of the contraction of the Limestone during the metamorphic action. Principal deposition of the ores from watery solutions."

"This metamorphic action was confined to a part of the alternate layers of Limestone and Chert, and very limited in its vertical extent—rarely exceeding 20 feet."

"The dolomization of the Limestone, and the simultaneous deposition of the ores, began either from horizontal crevices and then extended through the whole mass of one stratum of Limestone and was limited by the layers of Chert above and below, or it began from vertical crevices in the Limestone and formed a mass of Dolomized Limestone, with ore extending along the crevice between the Chert layers, and generally from 3 to 10 feet wide. In the first case the openings of Granby were formed, in the second the runs of Joplin."

**Period of Dissolution.**

"*Third Period*—Dissolution and removal of a part of the Limestone from the Silico-calcite and from the alternate layers of Limestone and Chert. Gradual breaking down of the remaining concretions and of the layers of Chert, and of the strata above. Continued deposition of ores in diminished measure."

"In this period the immense accumulations of broken Chert were formed, which in so many places overlie or accompany the ore deposits. The ore (nearly always Galena) was deposited, in many places, in the fissures and little cracks of the broken Chert beds, in sheets between these layers and in crystals ahhering to pieces of broken Chert, sometimes on all sides of the fragments, showing plainly that the Galena was formed after the Chert had been broken."

**Period of Regeneration.**

"*Fourth Period*—Local regeneration of the partially dissolved and softened Limestone by renewed deposition of Carbonate of Lime. Local infiltrations of Quartzite. Continued deposition of ores."

"All the conglomerates which consist of Chert-fragments, cemented either by a silicious or by a calcareous mass, the cementing mass inclosing crystals of Blende or Galena, were formed in this period."

**Period of Oxidation.**

"*Fifth Period*—Oxidation of the metallic Sulphurets, and alteration of these Sulphurets into Silicates and into Carbonates."

"During this period the Galena, in many deposits, was more or less completely altered into Cerussite and Pyromorphite, the Blende into Calamine and Smithsonite, and the Pyrites into Limonite. Some of these materials also, while in solution, were carried over larger or smaller distances and re-deposited as seams or impregnations in Sands, in Clays or in Chert Breccia."

With regard to the formation of sinks, Schmidt says the following of Oronogo:

"The present circular form, which is peculiar to these Diggings, may have been caused by the erosion of a large cavity in the underlying Limestone, and by the breaking down of the upper strata. The condition and relative position of the various rocks, especially the fact that all the layers, irregular as they are, yet invariably dipping towards the centre of the circle, decidedly support this view. The boulders lie about 70 feet deeper in the centre than at the circumference of the circle."

"The existence of numerous large and small sink holes all over the Lime stone region of Southern Missouri shows that such local subterraneous erosions, causing circular, funnel-shaped depressions on the surface, are nothing unusual."

Broadhead, Potter and other geologists, who worked in this State in the early days, recognized the unconformity between the Mississippian and Pennsylvanian series. Later these unconformable relations were pointed out by Haworth in a paper published in 1884,* in which he follows certain conclusions reached by Mr. O. St. John in the report of the Kansas State Board of Agriculture for 1881-82.

Haworth's observations showed that:

"No specimen has yet been seen in which the mineral of any kind was imbedded in the primary chert or limestone. Apparently the first mineral that was formed was galena. Crystals of this are frequently found entirely covered by blende, or by pyrite or marcasite, or by calcite. Blende is often covered by pyrite, but no specimen has been seen in which blende covered the pyrite. Calcite also sometimes covers the blende. A portion, at least, of the secondary chert was deposited after some of the galena, sphalerite and pyrite were crystallized, as is proved by the many specimens in which these three minerals are completely and snugly surrounded by secondary chert." * * * "The evidence, then, is that after the chert and limestone were greatly fractured and dislocated, the galena began depositing. Next in order came the zinc blende, and afterwards pyrite and marcasite, associated with calcite. Before very large quantities of these minerals were deposited the secondary chert began forming. The production of these minerals with the secondary chert was continued simultaneously, sometimes the chert being deposited on the minerals, sometimes the minerals on the chert."

"The general proposition that the metallic ores were originally deposited with the rock masses, here the same as in other localities, cannot well be doubted. Its subsequent segregation has unquestionably been effected by water percolating through the rocks, which slowly but surely derived these very small, but infinitely numerous particles of the ore and carried them into the fissures and openings where conditions were favorable for their precipitation."

Haworth recognized, at this early date, the following facts: 1st, That the lead and zinc minerals do not occur in the primary flint or in the limestone; 2nd, That blende is often covered with pyrite, but that pyrite is never covered with blende; 3rd, That the secondary chert began forming before any great quantity of the lead and zinc minerals were deposited; and 4th, That the ores are due to segregation by ground water, the minerals being derived from infinitely numerous particles in the country rock.

In 1894 Mr. Arthur Winslow, formerly State Geologist of Missouri, contributed a paper to the American Institute of Mining Engineers on the "Lead and Zinc Deposits of Missouri." This paper con-

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*A contribution to the Geology of the Lead and Zinc Mining District of Cherokee County, Kansas," by Erasmus Haworth, 1884, pp. 14, 15.

tains a summary of Volumes VI and VII of the reports of the Bureau of Geology and Mines, on "Lead and Zinc Deposits." Referring to the Coal Measures in the southwestern lead and zinc district, he says:

"They generally occupy what were originally depressions or "pockets" of approximately circular outline, which were probably great sink-holes, in the Lower Carboniferous limestones. * * * In Lawrence, Greene and Dade counties are other pockets of Coal Measure rocks, consisting of conglomerates, sandstones and shales, and a little coal in places. * * * They occupy depressions like the latter, but also spread out over the surface and over the underlying Lower Carboniferous. The conglomerates are composed of pebbles of Lower Carboniferous chert. This and the facts of their distribution prove the unconformity between the two formations. A long period of vigorous erosion evidently intervened."

Referring to the gangues of the ore bodies, Winslow says:

"The chert occurs in large slabs or blocks as in the original rock; or, it may be very much shattered and comminuted. The fragments are angular and not water-worn. They are sometimes corroded and contain blende or galena in the crevices or cavities; but these minerals are never diffused through this rock. * * * Secondary cherts constitute extremely interesting gangues, composed principally of amorphous, chalcedonic silica. * * * They vary in color, being black, brown, drab and even white. * * * Fragments of the original white chert are held so firmly by this secondary chert that when a block is broken the fracture passes through the enclosed fragments without even loosening them from the matrix. * * * Sometimes the solutions of silica have partially redissolved the original chert and the two grade into each other. The silicification and consolidation of this matrix were evidently later than the formation of the blende, galena and dolomite, as well-formed crystals of these minerals are held enclosed; often, perfect exterior casts of such crystals are left by their dissolving out from the matrix. * * * Where silicification was only partial the material is less indurated and grades into a shale."

With regard to the limestones, he says:

"Limestones are found in some deposits, particularly in Jasper county, where galena and blende crystals appear to be held in that rock. This is a secondary rock, formed in the ore bodies, and cements the chert and other fragments."

Referring to the dolomitic rock in the Mississippian limestone, he says:

"Dolomites are abundant in Southwestern Missouri, particularly in Jasper and Newton counties, as irregular bodies immediately associated with the ore deposits. * * * Blocks of limestone are often found covered with a shell of such dolomite, evidently formed by the action of the solutions containing magnesia upon the limestone."

Referring to the brecciated condition of the flint, he says:

"All the phenomena of these deposits yield evidence of great decomposition, alteration and local disturbance of the country rock."

Referring to the relation of the Coal Measure pockets to the brecciated flint in the case of a circular deposit near Alba, he says:

"A consideration of all these facts plainly shows that we have here an instance of a coal pocket, around the margin of which the ores occur in the breccia of residuary materials derived from the Lower Carboniferous rock. This zone of brecciated material, although irregular, appears to be in the neighborhood of 100 feet wide, and beyond this the solid limestone is encountered."

Referring to the method of formation of the brecciated deposits, he says:

"The breccia deposits of the southwest are the products of the action, on a larger scale, of the same agents as have formed the deposits filling crevices and caverns."

With regard to the formation of crevices and caverns, he says:

"From what has already been said concerning the geologic history and structure of Southern Missouri, it is plain that this has been an area of frequent crustal movements; several uplifts and depressions have succeeded each other. * * * Faults necessarily produced vertical openings in the rock, but in addition the rocks have been fractured without faulting along many lines, forming joint planes. Further, they are massive sediments which, covered since their original deposition, have probably shrunk and suffered various chemical changes, resulting in similar fractures and openings. In the intervals between different submergences, and especially since the last great Carboniferous uplift, the rocks have been exposed at the surface, and have been subjected to prolonged action of atmospheric waters and other surface agents of decay. These waters, sinking into the ground, naturally chose the openings along faults and joints for their lines of flow. Charged with carbonic acid, and probably with organic acids also, they exerted a corroding action on the limestone wall rocks, and soon widened the space between the planes of fracture. Where the rocks were most soluble, or the agents most aggressive, the action was quickest, and hence arose such irregularities as chambers or caverns."

Referring to the clays which frequently fill the cavities, he says:

"The clays, which sometimes fill these cavities almost completely, cannot be explained in precisely the same way (by the decay of the wall rocks). The wall rocks contain such materials, it is true, but not in anything like a sufficient quantity for the filling to be merely residuary clay in place. The great bulk of these clays must have been transported. These we refer largely to surface origin, and the transporting agent was water flowing in from the surface." * * * "In some cases, chemical deposition doubtless supplemented this process. The very pure, plastic, tallow-like clays have doubtless originated in this way."

Referring to the origin of the ores, he says:

"According to our theory, the concentration is entirely subsequent to the formation of the rocks. It is primarily the result of great and long-continued surface decay of the rocks, and secondarily, the result of locally favorable physical and chemical conditions."

"Taking, first, the Southwestern Missouri district, we have there great bodies of breccia impregnated with ore. These breccias fill large spaces or caverns in the country rock which have resulted from surface decay. The breccias are composed of residuary materials, associated with metalliferous and other minerals. They are in Lower Carboniferous limestone, and must hence have been formed later. We have already emphasized the fact that, immediately after this epoch, before or during the early Coal Measures, there was a time of vigorous erosion. This doubtless affected not only the marginal Lower Carboniferous rocks, but the Silurian magnesian limestones of the interior also. With the emergence, after the deposition of the Lower Carboniferous limestones, the rainfall was probably great and drainage abundant. The geological map shows a tongue of Lower Carboniferous extending from Southwestern Missouri eastward into the Ozark area. This probably marks the site of a former estuary towards which drainage converged. Thus a great volume of water probably flowed into this basin, bringing with it the products of decomposition of the magnesian limestones and other rocks to the east. To this source we attribute the magnesia which dolomized the Carboniferous limestones in the earlier stages of the erosion of the Jasper county area. After this, as the Coal Measure epoch developed, vegetation became dense, swamps were formed, vegetable matter began to decompose, and coal beds to accumulate. Here, then, were furnished almost perfect conditions for the reduction of the ores in solution. Already great quantities of residuary materials had accumulated from the decay of the Lower Carboniferous rocks in situ. In addition, the drainage was constantly supplying new solutions and matter in suspension from a distance; and upon all of these the organic matter acted.* Ideal physical conditions were furnished by sink-holes, caverns, etc., filled with breccia, as have been described. Under these circumstances, the deposition of the ore must have been rapid and abundant. The silicification which gave rise to the secondary cherts of the ore bodies must have taken place at the same time or shortly after. To the post-Lower Carboniferous or early Coal Measure epoch, we therefore assign the formation of the principal deposits of Southwestern Missouri. Others were doubtless formed at other times, and later additions may have been made to these, but that was the time of greatest activity. These were the special conditions of time and place which supplemented the general conditions of surface decay in producing the deposits of the southwestern district."

"The origin of those deposits of the southwestern, and also of the central and southeastern districts, which occur in vertical crevices or cavities of other shapes and attitudes, we ascribe to the convergent flow of waters which had leached surface residues and had passed through decomposing rocks. The cavities furnished the requisite physical conditions, and the chemical condition necessary was the presence of organic matter. This probably existed in all epochs, but was most abundant during the Coal Measures; and this was doubtless the time of maximum enrichment of these deposits also.

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*As bearing upon the chemistry of the process, we quote the following from Bischoff's Chemical Geology: "Water saturated with carbonic acid dissolves 1/4103 of its weight of artificial carbonate of zinc. Sulphuret of potassium precipitates from this solution white sulphuret of zinc. If, therefore, water contains alkaline or earthy sulphate, organic matter and carbonate of zinc, the conditions for the formation of zinc blende are complete."

The finding of galena and blende within the very coal beds of outlying marginal coal pockets shows the influence of carbon in their deposition."*

In most particulars our observations are in perfect accord with those of Winslow and Robertson. They made accurate observations and, in the main, interpreted the facts, as we believe, correctly. They did not make the mistake of mapping unconformity as faulting, and neither did they make the mistake of attributing all discordances in bedding to unconformity. They recognized the modifying effects of solution, and have, in several instances, pointed out minor faulting.

We do not agree with Winslow as to the age of the secondary chert. His reason for believing this to be last, is the inclusion within the chert of blende individuals having perfect crystal outlines. As will be shown in another part of this report, we believe that the black flint and included blende were mainly formed contemporaneously with the dolomite, although there is evidence that some of the black flint is younger and some is older than some of the dolomitic spar.

Winslow's theory of the origin of the breccias is clear and sound, conforming to the facts in the field.

We cannot agree with Winslow in his conclusions as to the origin of the tallow clays from chemical deposition. The silicate of alumina is very stable under all conditions within the zone of weathering, and it is difficult to conceive of any conditions under which this clay could be dissolved and re-precipitate in the position where it is now found.

The explanation which Winslow gives to account for the occurrence of the ore bodies, although not exactly in accord with our own, comes the nearest to fulfilling the conditions of any which has thus far been published. We believe, with Winslow, that the ore deposition was subsequent to the deposition of the Mississippian limestone, and that it was the result of downward circulating water. We believe that the lead and zinc was originally deposited in the marginal sediments of the Pennsylvanian sea, and that the localization of the ore bodies is due to the character and distribution of the drainage from the land area which existed during Lower Coal Measures time.

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*"The question may suggest itself here, why, if the Coal Measure epoch was so favorable for the deposition of ores, such are not found in bodies within the coal area proper. Our answer to this is, that as the metalliferous contents and products of decomposition of the rocks were reduced and precipitated in the interior of the Ozark uplift or along the margin, little remained to be carried far from the shore line, and that little became diffused in the Coal Measure seas. Instances of the occurrence of both lead and zinc compounds in small quantities are, however, common in the Coal Measures; those of Miami and Linn counties in Kansas are the most noteworthy."

Thus far we are in accord with Winslow. We do not believe that the lead and zinc minerals were concentrated in the breccias at the time the shales were being deposited, but that the deposition of lead and zinc was in minute quantities through portions of the Coal Measure shales. We believe that the present position of the ores is the result of a concentration by circulating ground water. This is explained more fully in a subsequent chapter.

Winslow recognized the possibility of having deposits formed by the convergent flow of waters from the surface, but did not apply this to the entire southwestern district as we have done. He ascribes to the Coal Measure period the maximum enrichment of the ore bodies. In this we cannot agree, believing that the concentration only came about after there were established conditions by which we could have both oxidizing and reducing solutions coming in from the surface.

The ideas of VanHise and Bain upon the origin of the Lead and Zinc Ores of the Southwestern District are expressed in the report on "The Lead and Zinc Deposits of the Ozark Region," published in the 22nd annual report of the U. S. G. S., and in a paper on "The Lead and Zinc Deposits of the Mississippi Valley," presented at a meeting of the Institute of Mining Engineers, in London, in 1902.

From the latter paper we quote the following as expressing their latest views upon the structural features and ore deposition of the district of which the Granby area is a part.

On page 20 they say:

"In every case the ore bodies are found where there is the clearest evidence of the movement and mingling of considerable bodies of solutions. * * * No ore bodies have been found except in areas where there was opportunity for a mingling of the ground-waters of the Carboniferous and the Cambro-Silurian limestones. * * * Only when opportunity was afforded, by deep fault planes cutting the intervening shale, for the waters of the Cambro-Silurian to rise and mingle with the waters above, was there any considerable ore-deposition; and it is an interesting conformation of the correctness of this view that dolomite is a constant accompaniment of the ore. Wells penetrating the Carboniferous rocks, away from the ore bodies, yield water practically free from magnesia. Those penetrating the Cambro-Silurian show that the water is notably charged with magnesia. This indicates that both the magnesia and the metals now found in the ore bodies were brought into the Carboniferous rocks from or through the Cambro-Silurian below. * * * The overlying impervious Eureka-Kinderhook shale prevented the actual upward flow, until the faulted area near Joplin was reached, where the water passed upward along the fault planes."

Further on in the discussion, page 23, the statement is made:

"Opportunity is afforded for the water to deposit its metallic load as soon as reducing agents find it. This is when the water leaves that formation, as is shown by the ores at Granby and elsewhere in the Kinderhook. * * * We can conclude, therefore, that the Cambro-Silurian limestone was the main original reservoir from which the underground solutions derived their metallic contents."

It is further stated that:

"The ores of the first concentration were deposited in the presence of an excess of precipitating agents. There was more than a sufficient amount of organic material and of hydrogen sulphide to throw down all the metallic compounds; and hence all the sulphides precipitated were intimately mingled. The sulphides thus precipitated were not deposited to an unusual degree contiguous to the black shales of the Eureka-Kinderhook and of the Coal Measures. The probable reason for this is that the precipitation was mainly caused by the solutions, and not by the solid organic matter of the shales. * * * The time of the deposition of the ores of the first concentration is not well fixed. It began after the deformation, which fractured and faulted the limestone and which cut the Eureka-Kinderhook. It seems reasonable to correlate this event with the uplift of the Ozark dome, (at the beginning of the Tertiary). The deposition continued from that time onward, and since the general movement of the underground water in the district is today substantially the same as indicated, it is probable that the ores of the first concentration are still being deposited."

Referring on page 25 to the iron sulphides present in the district, they say:

"Such dominance has, however, been noted in the deep drilling at Granby, Missouri, and an increase in the amount of iron sulphide present is noticeable at many points."

Referring on page 26 to the occurrence of the oxidized ores, they say:

"The formation of the oxidized ores has taken place mainly above the level of underground-water; since below that level there is usually an excess of organic matter, and hence the medium is reducing. The changes due to oxidation, carbonation, hydration and solution are coincident with the elevation of the ground-water, in consequence of progressive denudation."

The general conclusions reached by VanHise and Bain, page 57, are that there are three stages of concentration of lead and zinc, as follows:

"First, a concentration of a minute fraction of one per cent in the Cambro-Silurian limestone at the time of its deposition; second, a concentration by an artesian circulation early in the erosion-history of the region; and, third, a reconcentration by a shallow circulation in the later stages of the erosion-history."

On page 50 of the paper on "The Lead and Zinc Deposits of the Ozark Region," published as part II., of the XXII Annual Report of the U. S. G. S., VanHise says:

"In the Missouri district chert is very abundant indeed. In the areas in which oxidized ores occur the chert has largely changed to a soft rock—which can be cut with a knife—called 'tallow' rock by the miners. Evidently this is residual material from which considerable quantities of chert have been dissolved."

It is uncertain whether Dr. VanHise refers to "Tallow Clay" or "Cotton Rock." Probably the latter, because it is the only recognized decomposition product of the chert.

On page 51 VanHise says:

"While some geologists may still hold that there was only a single concentration in Wisconsin, I believe that no one who examines the Southwestern district of Missouri will be inclined to hold that view."

On page 59 VanHise says:

"In all the districts the Cambro-Silurian limestone is regarded as the immediate source of the ores."

On page 60 VanHise says:

"Finally, these deposits illustrate beautifully the facts that comparatively shallow circulations may, at the point of precipitation, first deposit ores by ascending waters, and that these ores may have been concentrated by descending waters."

On pages 106-107 Bain says:

"One of the most common cementing materials found in the ore breccias of that district (Southwestern Missouri) is a black cherty material, evidently deposited after the brecciation and the main deposition of the ore. * * * Examination shows that the blende found in this chert has commonly a well-developed crystal outline. There is, however, no evidence of the blende having been formed in cavities. Neither are there those laminations in the matrix which usually surround crystals that have grown in soft material, and in growing have crowded the latter aside. * * * It is suggested that at the time the blende was formed the siliceous matrix was in colloid condition, and so interposed no hindrance to the movement of the metal through it and the growth of the sulphide crystals."

Further on, page 108, he says:

"In such material the sulphides, by simple diffusion, would be segregated and crystallized freely as from solution."

On page 119, he makes the following observations:

"In the Carboniferous limestones of the Joplin district there is a very intimate association between the ores and the process of dolomitization of the country rock. The dolomitization is clearly secondary, so far as the recrystallization of the country rock is concerned, though it in part antedates the ores and is not known except in the ore regions."

On page 121, he says:

"The most important gangue material, especially in the breccias, is chert. This occurs in the region in two forms, which are easily distinguished in the field and which have very different relations to the ores. The two sorts of chert are spoken of in this report as older and later chert. The latter is also referred to as secondary chert. * * * As a rule, the earlier chert may be distinguished from the later by the color, the former being white or bluish, and the latter black."

In his discussion of the ores of the first concentration, Bain says:

"Neglecting the recent changes and considering the ores only in their unmodified form, the three dominant processes concerned in the formation of the ore bodies seem to have been (1) dolomitization, (2) deposition of the metal sulphides, and (3) silicification. To some extent these processes were contemporaneous or recurrent, but as a whole, they occur successively in the order named."

Further on he says:

"The main period of dolomitization was followed by the principal deposition of the metal sulphides, the ores proper. These seem not to have been originally deposited in any regular sequence, either vertical or horizontal. Blende rests on galena and galena on blende indiscriminately, and both cover and are in turn covered by iron sulphide. * * * A very common order is, first, blende, with a subordinate amount of galena and occasionally pyrite; second, crystals of calcite and pink dolomite in druses and channels running through the ore body; and, third, in these channels, and on the dolomite especially, chalcopyrite."

Referring to the formation of the black flint, he says:

"The process of silicification, which in the southwestern district took the form of deposition of secondary chert, was dominant later than the principal deposition of the ores. The chert forms a common matrix for the entire mass of material, and blende, galena, pyrite and dolomite all maintain their form when in contact with it. This is possibly due in part to processes connected with the diffusion of material through solutions, which have already been discussed, but the field relations make clear that the main silicification took place relatively late in the general process."

Referring, on page 154, to the characteristics of the ores of the first concentration, he says:

"First, they show characteristically thorough cementation; second, they are associated with considerable quantities of dolomite, though in a nondolomitic country rock; third, while the bulk of the ore is blende, there is a subordinate but notable amount of galena in intimate admixture of blende. * * * It seems to be characteristic of the unaltered ore that it is in hard, thoroughly cemented ground. It usually occurs under a good roof, by which it has been protected from descending waters, and in mines having ores of this class the water pumped bears no relation to the amount of rainfall and evidently is derived from a deep-seated and widely connected circulation. It is also to be noted that in these ores the different sulphides occur together, and this without any evidence of rearrangement or bringing in of one or the other. This intimate mixture of the sulphides is believed to be an especially characteristic and significant point. * * * When the sulphides are found separately, either vertically or in areal distribution, and particularly in regions where several of them occur in definite order, their separation is a reason for looking for secondary changes in the ore bodies."

Referring to the ores of the second concentration, Bain says:

"So far as these changes lead to the enrichment of ore bodies already present or to the formation of ore bodies in new situations, they may be spoken of as (a) oxide enrichment and (b) sulphide enrichment."

In a further discussion of this subject, he says:

"Large bodies of blende at and for some distance below the ground-water level are very common throughout the region, and are especially characteristic of the southwestern district. * * * This is due to several causes. Organic material is common in the limestone, the selvage and the slate or shale bars. The widespread presence of bitumen has been already emphasized. The ground-water is one great reducing solution. It accordingly protects the ores from oxidation and the consequent change to the carbonates and silicates which characterize ores in the belt of weathering. It also serves to reduce any oxides or sulphates brought down to it by waters passing from the surface through the belt of weathering. There is thus an actual enrichment of the ore bodies beginning at the water level, and in this region extending as far below it in each case as the influence of surface waters can penetrate against the general upward movement of water due to hydrostatic pressure."

On page 168 Bain says:

"The best reason for believing that the ground water is fed mainly from distant sources lies in the fact that the amount of water pumped from the mines is independent of seasonal changes. Except in the case of unprotected openings or very open ground, severe storms and rainy weather do not increase the amount of water that must be handled."

Bain cites, as an illustration of secondary enrichment, the ore body on which are located the Boston Get There mines. He says:

"The mines are in typical sheet ground. The ores occur along bedding planes between the flint layers, below the heavy and here undisturbed limestone and flint * * * to the south and west small open cavities are found in the earlier ore, and in these, as well as in minor cracks, are clear, usual ruby-color blende crystals, associated with cubes of galena and small rounded rhombohedrons of siderite, the iron carbonate. On both the galena and blende are small crystals of marcasite, and on the blende are little sphenoids of chalcopyrite, usually with uniform orientation. Greenokite also occurs as a greenish-yellow material dusted over the other minerals * * * *".

"A consideration of the relations of these ores makes it clear that there has been here solution of the ores in the northeastern portion of the ground and redeposition of them farther down the slope. It also seems clear that the waters active in this process were downward flowing surface waters, * * * * *"

Referring to the faulting in the southwest district, Bain says:

"The presence of deep fractures in the Joplin regions is shown by faults of 100 to 150 feet or more. * * * In this district the faulting is made clear by the relations of the overlying Coal Measures shales and sandstones to the limestones and cherts of the Boone formation. These relations are, however, obscure by unconformity between these beds and by the influence of downward settling as a result of solution."

Further on Bain says, with reference to the Granby area:

"There is, however, important faulting. The fault running along the north edge of the camp through sections 31, 6 and 5, traced by Mr. Willis, has a throw to the north of at least 80 feet. * * * In the Mascot mine, and again in the Little Four and the big open pit between, there are unmistakable evidences of faulting and brecciation along a course almost due north. The downthrow, which is to the east, does not seem to be important. A second fault runs northwest past the Future, Clara Barton and Jack Sprout mines, intersecting the Mascot fault a little north of the center of section 12. * * * The well-recognized presence of bars of various sorts of material in other parts of the camp indicates that detailed studies will show numerous faults and zones of fracture."

Referring to brecciation, Bain says:

"One of the most important and most significant features of the southwestern district is the amount of brecciation which has taken place. * * * Something of their extent may be inferred from the fact that the John Jackson mine has been worked for a distance of 830 feet, with a general height of stope of 40 to 60 feet, and the usual width of 50 to 60 feet. In places the ore body is 125 feet wide. * * * This ore body is in hard, thoroughly cemented ground. It is impossible to refer the origin of the breccia to any secondary settling or to the action of surface waters in softening the rock. The mine is covered by a thick bed of undisturbed rock. * * * Brecciation was evidently accomplished by a series of movements extending over some little time, with intervals during which the process of cementation was active."

On page 174 he says:

"Such thoroughly shattered material (referring to the breccia in the B and C mine) is not uncommon, and there is everywhere evidence that the chert and limestone have been squeezed and broken."

"Brecciation and faulting are closely associated throughout the district, they occur together along zones of fracturing. The same stress has been relieved at one point by brecciation and at another by definite fracturing or faulting. Brecciation is far the more common, and this seems an expression of the general law that stresses are relieved more frequently by many small fractures than by a few large ones."

Referring to the usual phenomenon of the strata dipping toward the valley from the ridges on either side, Bain says, on page 190:

"Across the valley from the Sunset mines are those of the Wyoming group, in which the dip is also approximately toward the valley, and accordingly the reverse of that observed in the Sunset. This dip or pitch of the rocks with the surface and toward the valley is said to be a common phenomenon of the Camp, and affords strong ground for believing that the streams in general are located over the main lines of disturbance in the underlying rock."

It is evident from the above abstracts from VanHise and Bain, that they consider the southwestern lead and zinc district, of which the Granby area is a part, the clearest exposition of the theory of a first concentration by an upward circulation, and a second concentration by a descending circulation, of any of the districts in the Mississippi Valley. This being the case, it is of the utmost importance that the attention of the reader should be directed to certain structural features of the district which, we believe, have been misinterpreted.

A short time after the publication of the report on "The Lead and Zinc Deposits of the Ozark Region," a week or so was spent in an examination of the Aurora area. Later, this area was visited a second time. We were unable to identify the faults indicated on Bain's map, and from their position concluded that the unconformity between the Coal Measures and the Mississippian limestone had been mistaken for faulting. Since that time most of the localities in the district where faulting has been mapped have been examined, and we are unable, in any instance, to find any major faulting. Minor normal faults, such as may have resulted from the settling of the beds due to leaching, are exhibited in many of the mines. There has been some settling of the Pennsylvanian shales along the plane of contact with the Mississippian limestone and flint, which movement has naturally resulted in the production of slickensides. Frequently, as a result, the dipping of the shale beds has been intensified or the beds themselves have been broken.

Bain states very clearly that the faults, which he recognized, are normal faults, and yet the statement is made that these were produced by the same compressive stresses which formed the breccia. In our experience we have not known of any case where compressive stresses forming breccias have also resulted in normal faulting.

The statement is also made that these normal faults have throws sufficient to carry them through the Devono-Carboniferous shale into the Cambro-Ordovician below. We have always believed that normal faults, as a rule, have their greatest throw at the foci from which they originate. In other words, that normal faults increase with depth to the place of origin, and that reverse or thrust faults, decrease with depth. One cannot estimate the depth to which a normal fault may continue from a knowledge of the amount of displacement at or near the surface. He must be acquainted with the cause of such faulting before he can estimate the probable throw of the faults. The normal faults in this district are an accompaniment of the breccias, and there is no doubt in our minds as to their probable origin. We believe that they have resulted chiefly from unequal settling as a result of solution. We have been unable to follow any of them into the unaltered horizontally bedded rocks below, and this being the case, they must be altogether superficial phenomena.

Upon the belief in deep-seated and extensive faulting, is based the theory that the lead and zinc had their source in the Cambro-Ordovician formations. To bring them near the surface an artesian circulation is necessary, and, in order to supply an artesian circulation, we must have deep-seated faulting or brecciation. Without these the theory is apparently untenable.

Another proof which Bain cites as a reason for believing that the ground-water is derived mainly from the Cambro-Ordovician, is given in his statement that the amount of water pumped from the mines is independent of seasonal changes. We do not know from what source this information was obtained, but it is contrary to all that we have been able to learn in the district. In the Granby area, even in the Mascot mine, which has a depth of 215 feet, from 25 to 30 per cent more water is pumped during the rainy seasons than at other times. Late in the summer, when rains are infrequent, very little pumping is required. The mines on the Continental tract, 170-190 feet deep; the mines on the Missouri Lead and Zinc Fields, 150-170 feet deep; those on the lands of the Granby Mining and Smelting Company at Oronogo, 180-220 feet deep; those in Chitwood having a depth of about 170 feet; those on Smelter Hill, having a depth of about 190 feet; and those north of Webb City, the Goldenrod and others, 175 feet deep, pump from 25 to 50 per cent more water during the rainy than during the dry seasons. It is also a matter of observation that when these mines have been once drained, very little water comes in from the bottom. There is scarcely any inflow of water which might be attributed to an upward circulation.

Another reason given by Bain for the ores having a deep-seated origin, is the occurrence of large quantities of dolomite. He states that there is no other adequate source from which the magnesia could have been derived. W. P. Jenney believed that the Mississippian limestone was the source of the magnesia. We believe that the Pennsylvanian strata, which have been practically removed from this area, contained an abundance of magnesia to provide all the dolomite associated with the ore bodies in the district. We believe that the shales and thin beds of limestone of the Pennsylvanian series were the source of the magnesia required to form the dolomite. The Pennsylvanian strata were, in part at least, derived from the disintegration of the magnesian limestones of the Cambro-Ordovician series. Therefore, the ultimate source of the magnesia may have been, in part, the Cambro-Ordovician; but before reaching its present posiiton, it probably first became a part of the Pennsylvanian strata.

Bain states that, in the case of the ores of the first concentration, the sulphides are intimately mingled. In this, our observations do not wholly agree. The galena and blende are associated, chiefly, in such deposits as are clearly later than the first concentration, although some of the dolomitic spar contains both.

We do not agree, altogether, with Bain's theory of the origin of the black flint, as shown by the discussion of chert and flint in chapter IV.

Bain believes that the ground-water is all "one great reducing solution." The reason for this belief is embodied in the general observation that "organic material is common in the limestone, the selvage, and the slate or shale bars." The organic material is certainly common in all the rocks associated with the ore deposits. There are, however, certain areas within the mines where oxidizing conditions are present, as evidenced by the occurrence of lead and zinc carbonates to a depth of more than one hundred feet. Outside of the ore bodies, and often to some depth within the ore body, the ground-water, which passes directly into the flint or limestones, is probably oxidizing instead of reducing, as explained in our discussion of the ore deposits of the Granby area.

If one will read, carefully, Bain's characterization of the ores of the first and second concentration, he will find the descriptions to be somewhat confusing. The fact that the ore is unaltered, that it occurs in hard thoroughly cemented ground, that it occurs under a good roof, and that it is associated with dolomite are insufficient evidences that the ore belongs to the first and not the second period or stage of concentration. Neither is the occurrence of the different sulphides together an indication that they were formed during the early stage of concentration.

We believe that the ruby-colored blende crystals, referred to, are a late deposition. But the fact that the galena and blende are covered with crystals of marcasite and greenokite, and that they occur along bedding planes between the flint layers below the undisturbed limestone and flint, are not in themselves evidence that the ore is a secondary or late enrichment. Much of this ore is probably a late concentration, but the description given does not serve to distinguish it from the ores which are classified as those of the first concentration.

To make ourselves clear, let me say that, from our investigations, we are unable to distinguish any well defined first and second concentrations. The concentration has been practically continuous, subject to interruptions occasioned by the physical changes accompanying periods of elevation and subsidence.

We do, however, recognize an early and late deposition of the ores and a succession in the formation of the so-called gangue minerals. These are discussed in a subsequent chapter.

The views held by Walter P. Jenney on the physical features of this district and the origin of the ores are clearly set forth in a paper read before a meeting of the American Institute of Mining Engineers in 1893. The main conclusions reached by Mr. Jenney are given in the following quotations from that paper.

On page 14, Mr. Jenney says:

"The result of this investigation of the deposits of lead and zinc in the Mississippi valley has made it possible to announce the general law that all workable deposits of ore occur in direct association with faulting fissures traversing the strata, and with zones or beds of crushed and brecciated rock, produced by movements of disturbance. The undisturbed rocks are everywhere barren of ore."

Further on he says:

"For the occurrence of ore deposits, it is requisite not only that the strata should be disturbed and faulted, but that the fissures should penetrate to and form open channels connecting with the zone of supply of the ore-forming solutions, which may be located at a considerable depth in the earth; also that the pressure should be sufficient to force the mineralizing solutions to the surface; that the solutions should contain metallic substances in adequate quantity, and that the physical and chemical conditions should be such as to permit ore deposition. Through the absence of any of these conditions, districts otherwise favorable for ore may remain unmineralized."

Mr. Jenney's conception of the importance of the faulting in this district is summed up in the following paragraph:

"In conclusion, it may be said of the fissures, which occur in direct association with the deposits of lead and zinc ores in the Ozark and Wisconsin uplifts, that they are not the result of local causes, and are not confined to a narrow vertical range, or to rocks of a similar lithological character, but, on the contrary, that these fissures are the result of forces connected with widespread dynamic disturbances, affecting the North American continent, and that the fissures are faulting-planes of indefinite vertical extent, traversing all the geological formations from the crystalline rocks to the Coal Measures."

Mr. Jenney's belief that the ore bodies of this district are modified fissures is brought out everywhere in this paper. In one place he says:

"All the deposits of lead and zinc ores in the Ozark uplift belong to the great class of fissure-fed impregnations, and may be designated as runs, a term by which this form of deposits is known to the miners."

That Mr. Jenney recognized the extreme irregularity in the location and distribution of the ore bodies is shown by the following paragraph:

"It is probably futile to attempt to reduce to a general law, or to define in belts, the location of the ore-districts in this region. From the complex nature of the movements of disturbance that must have taken place, which alone appear to have influenced the special mineralization of certain areas, such attempts at broad generalization must be imperfect and liable to error."

Mr. Jenney applies the term "cherokite" to the black flint. Referring to its origin, he says:

"Analyses and microscopic examinations of samples of cherokite show that this rock has been formed by the silicification of the residual sandy mud resulting from the dissolution of the Cherokee limestone by waters charged with carbonic acid. The formation of the cherokite seems to have closed the ore-depositing period, the silicification of the gangue having taken place subsequent to the formation of the ore."

With reference to the black flint, he says:

"Under the microscope, thin sections of cherokite show a highly crystalline structure, with imperfect interlocking crystals of quartz as the predominant mineral, and spots of dark bitumen, or carbon, and scattered oölitic grains, probably derived from the limestone. Cherokite is frequently impregnated with blende and galena. * * * By the oxidation and removal in solution of the minerals included in the mass of the cherokite, the rock is converted into a skeleton. * * * The minerals thus decomposed and removed were in all cases minerals of primary origin, blende and galena, and rarely pyrite; calcite, barite and other minerals of recent deposition have not been observed included in cherokite."

Referring to the dolomite, he says:

"Dolomite results from alteration of the Cherokee limestone, and is connected directly with the formation of the ore deposits.* * * The effect of this dolomitization is to change the fine grain structure of the limestone to that of coarsely crystalline dolomite, and to obliterate all fossils and evidences of organic origin."

Referring to the distribution of the minerals in the ore deposits, Mr. Jenney says:

"Where blende and galena occur in the same ore body, the blende usually predominates in depth, often to the total exclusion of the lead ore in the lower portions of the deposits, while galena is commonly found in formations near the surface. There is no sharp line of demarkation between the blende and galena in the deposits, and in the zone of transition the two minerals are intermingled. * * * In certain localities in the Southwest, the ore deposits are not confined to a single geological formation, but, following the fissures, channels and openings in the strata, extend vertically from one horizon to another. Deposits of this character occur near Webb City, Missouri, where the Cherokee limestone is overlain locally by shales of the Coal Measures, and show a more strongly defined separation of the ores of the two metals; the Cherokee carrying deposits of blende with scarcely a trace of galena, while the galena is concentrated in the superficial formation."

The following is quoted from Dr. Jenney's paper in order that the reader may understand more clearly his position with regard to the cause of the concentration of the ores in this area:

"The extreme purity of the limestone of the Cherokee renders it readily soluble in waters containing carbonic acid. Not only are the limestone strata thus dissolved and removed by the action of sub-äerial waters, but in the subsequent deposition of the ores, the limestone fragments that remain in these brecciated beds are metasomatically replaced by the ores. The limestone itself acts as a chemical precipitant and neutralizes any free acid or acid salts present in the ore-forming solutions, and the organic matter and bitumen originally contained in the calcareous rocks, but set free by their dissolution, constitute powerful reducing agents in the ore-deposition."

"Physical conditions antecedent to the formation of the ore have influenced the localization of the deposits and greatly increased the extent of the brecciated zones. Prior to the formation of the mineral deposits, the Cherokee limestone, where it occurs near the surface, was subjected to the prolonged action of surface waters; in the districts where the beds were faulted and disturbed, an extensive subterranean erosion of the calcareous strata has taken place. This removal of the limestone, interbedded with the chert in the shattered and fissured belts, caused a settling of the formation and of the superincumbent rocks, resulting in the more complete brecciation of the chert and in the formation, ultimately, of broad zones, consisting almost entirely of angular fragments of chert intermixed in the most confused manner, and mingled with residual clay of the eroded limestone."

"The action of these combined physical and chemical forces began with the elevation of the Ozark uplift above the ocean at the close of the Subcarboniferous period, and continued with attendant faulting and disturbance of the strata for a vast period of time, during which the Ozark area remained dry land—an interval when the climatic and atmospheric conditions are believed to have been, at least during the Coal-period, singularly favorable for the production of surface-waters charged with carbonic acid and the organic acids resulting from the decay of vegetation. At a much later age, when other dynamic disturbances produced a more profound and widely extended fissuring of the formations and inaugurated the period of ore-deposition, these zones of brecciated rock directly connected with the fissures and containing the chemical elements requisite to effect the reduction and precipitation of the metals, afforded free escape and circulation for the ore-depositing solutions and formed a matrix admirably fitted to receive the minerals."

Mr. Jenney was evidently very firmly imbued with the idea that the southwestern lead and zinc district is traversed by numerous faults extending to great depths, and even penetrating the pre-Cambrian formations. He believed that the ore deposits were the result of solutions rising along these fault planes; and in this connection, he says that "the strongest argument in favor of the mode of deposition from solutions rising from unknown sources in the crust of the earth is that the ore bodies are associated with faulting fissures of indefinite extension in depth, and that all the evidences of the occurrence of the ores and minerals in the deposits point to these fissures as the channels through which the mineralizing solutions were introduced." He explains the differences in the mineralogical composition of different ore bodies within the same horizon as being the results of successive upflows of solutions of different chemical composition.

A careful study of this district has not yet revealed the presence of extensive faults. No one knows to what extent the ground-waters penetrate the pre-Cambrian rocks, and whether or not the underlying crystalline rocks contain the necessary metals. Analyses of the water obtained from deep wells show the presence of practically no lead or zinc. Mr. Jenney's theory of the deposition of the ores is based upon the same facts as is the VanHise-Bain theory, and, therefore, is open to the same objections.

# CHAPTER III.

## PHYSIOGRAPHY.

### DRAINAGE AND RIVERS.

With the exception of the north half of Sec. 25, T. 26 N., R. 31 W., this area lies on the south side of Shoal creek, the tributaries of which drain the entire area. Shoal creek is a moderate sized stream which flows through Sec. 25 in a general direction a little south of west. Most of the streams tributary to Shoal creek, in this area, are of an intermittent character. In several instances they are fed by large springs issuing from caves in the prevailing Mississippian limestone.

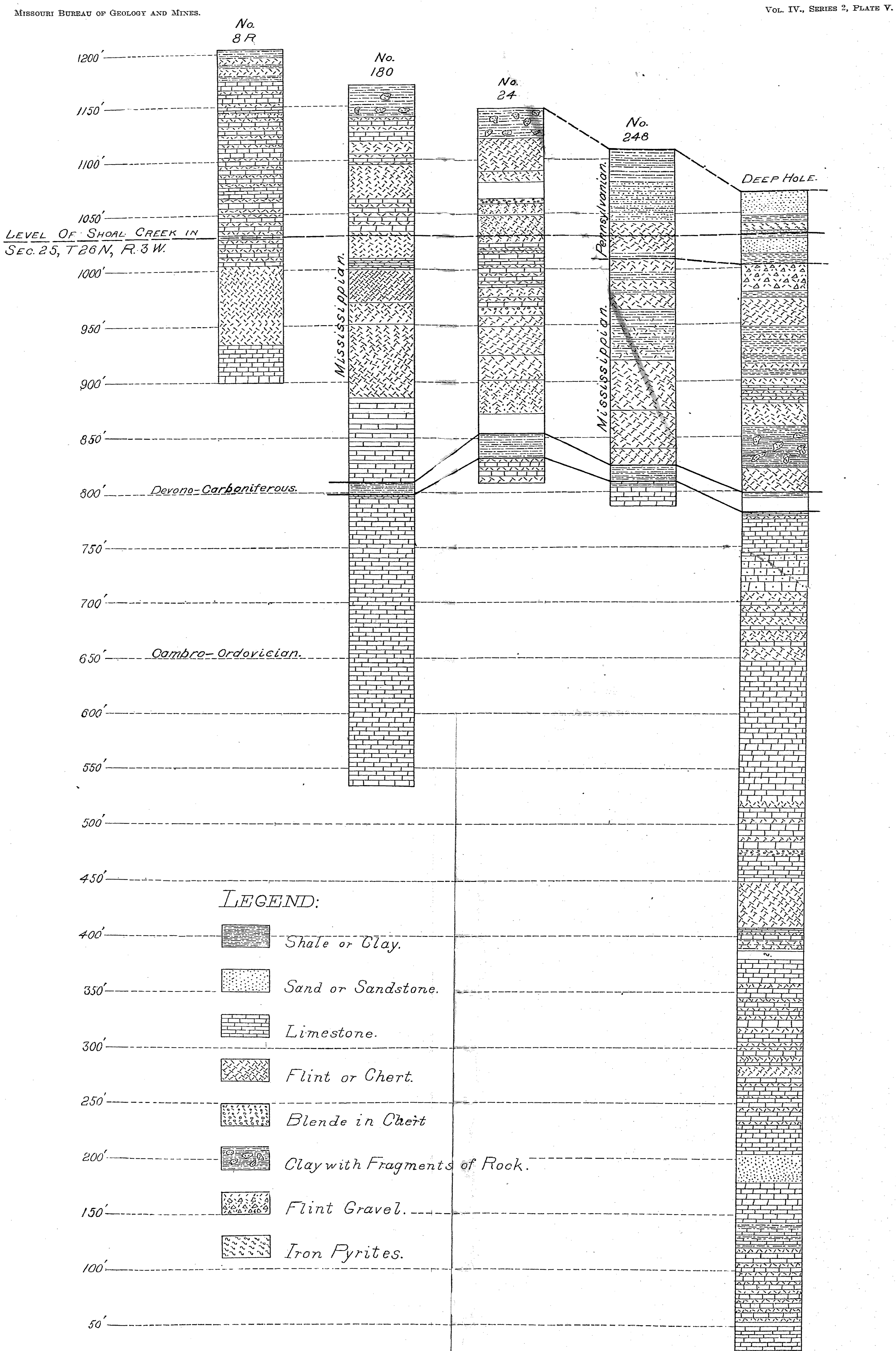
For a distance of from 2 1-2 to 3 1-2 miles south of the river the land is broken and hilly. However, as one passes away from the river, a level or rolling country, commonly known as the prairie, is reached. As a rule the ridges and hills have gentle slopes leading upward to the prairie land. The only precipitous slopes occur along Shoal creek, where the water impinges against the bank. These cliffs are in Secs. 25 and 31, and are indicated on the topographic map by the closeness of the contours. The turns in some of the valleys are very abrupt, as shown by the topography in the N. 1/2 of Sec. 11, T. 25 N., R. 31 W., and in the N. 1/2 of Sec. 36, T. 26 N., R. 31 W. The first of these valleys contains a spring-fed stream, one of the few perennial streams in the area. The latter valley provides a channel for the water drained from the surrounding hills during each storm. At present there is a well defined stream channel in the valley. These windings in the valley are probably due to the meanderings of streams, which existed during one of the base level periods through which this area is thought to have passed. Perhaps the best defined valley in the area is the one which extends from the center of Sec. 25, through Secs. 36, 31, 6, 5, 7 and 8, having its source in the prairie land of Secs. 17 and 18. There is a stream flowing through this valley during the greater part of the year, being fed by springs and water which is pumped from the mines tributary to the valley. The water which comes from the springs is, during certain seasons, entirely absorbed by the bed of the stream before it reaches Shoal creek.

The lowest elevation in the area is along Shoal creek, which, in the N. W. corner of Sec. 3, T. 25 N., R. 31 W., has an elevation of about 1,000 feet above the sea level. From the east side of Sec. 25 to this point Shoal creek has a fall of about 30 feet. The highest point in the area, 1,260 feet above sea level, is in the S. E. corner of Sec. 17, T. 25 N., R. 30 W. This makes a maximum difference in the elevation of different parts of the area of 260 feet.

As will be shown later, the drainage of this area is in a large measure superimposed upon the drainage of pre-Pennsylvanian times. It is not altogether controlled by this ancient drainage, but has been modified by the structures in the formations, and by the different kinds of rocks at or near the surface. Altogether it is an area which is well drained, and over which there has been established a comparatively simple drainage system.

The direction and depth of many of the valleys and stream channels have been greatly influenced by solution of the limestone by the underground water. Sink holes occur mainly near the valley tracts, although they occur also in what is known as the prairie. We have evidence that sink-holes were abundant during the pre-Pennsylvanian erosion interval, and these, in a measure, have had a modifying influence on the present topography.

Prior to the Pennsylvanian period the hillsides were covered with flint as today. These were deeply buried and later silicified into a compact mass known as a breccia. With the removal of the shales, sandstone and limestone of the Pennsylvanian, these breccias have, in many places, become exposed at the surface. These hard masses have a tendency in many places to deflect the streams at the surface, thereby protecting areas of shale and sandstone lying in side valleys or ravines. On the other hand, the soft, easily erodable shale invites the streams, and, as a result, they have a tendency to meander into the pre-Pennsylvanian channels.




SECTIONS DRAWN FROM RECORDS OF DRILL HOLES.

No. 8 R. {Lot 17, S. W. ¼, S. E. ¼, Sec. 13.

No. 180. {Lot 48, S. E. ¼, S. W. ¼, Sec. 12.

No. 24. {Lot 9, S. W. ¼, N. W. ¼, Sec. 6

No. 248. {200 feet N. E. of lot 87, S. W. ¼, S. E. ¼, Sec. 31.

Deephole.—Near Pleasant Mill in N. E. ¼, S. W. ¼, Sec. 31.

# CHAPTER IV.

## GENERAL GEOLOGY. (See Geologic Map, Plate I.)

The geologic history of this area is the geologic history of Southwest Missouri, and perhaps that of the entire Ozark Region. The oldest rocks which outcrop over this area, are of Mississippian age, and the youngest belong to the succeeding Pennsylvanian period. Deep drilling indicates that the Mississippian limestone is from 260-380 feet in thickness, depending upon the elevation of the surface. This limestone is underlain with from 10-20 feet of shale, thought to be of Devonian age. Underneath this thin horizon of shale, there occurs an unknown thickness of alternating sandstone and dolomite, belonging to the formations of the Cambro-Ordovician period. Plate V. shows four columnar sections compiled from the records of drill holes bored in different parts of the area under discussion. These sections show a fairly well defined flint horizon at a depth of 200-250 feet below the surface. This flint horizon varies greatly in thickness, being in some places only 10 feet, and in others 150 feet thick.

Above the Mississippian limestone there occur small irregular, isolated areas of shale and sandstone, belonging to the Pennsylvanian period. In one place the shale is reported to contain a thin seam of coal. The remnants of the Pennsylvanian rocks occur in the valleys, on the tops of the ridges and along the hillsides. The Pennsylvanian strata originally covered this area to an unknown depth, probably hundreds of feet, having been almost completely removed by subsequent erosion.

Since the Pennsylvanian strata were deposited over this area, there have been changes in the level of the land as a result of alternate subsidence and elevation. C. F. Marbut believes that the Ozark Region, of which the Granby area forms a part, was almost, if not quite, base leveled during Cretaceous times, and that this region was subsequently elevated, and again reduced to nearly base level during the latter part of the Tertiary period. It is possible that this area was covered with sediments of later age than the Pennsylvanian, but if it were, these have been long since removed.

In this report we need give very little consideration to those formations which are older than the Mississippian, although the changes in level due to elevation and subsidence may have had an important bearing upon the occurrence of the ore bodies. It is in the Mississippian limestone that the ore bodies occur, and their formation must be due to agencies which are of later origin. However, in order to understand the location and method of formation of these ore bodies, one should fully understand the geologic history of the area since the Mississippian period.

## THE MISSISSIPPIAN.

That portion of the Mississippian, which outcrops over this area, is variously known as the Burlington, Keokuk or Boone formation. Dr. Gierty of the U. S. Geological Survey believes that it belongs to the Keokuk, which is directly above the Burlington. This formation has a wide distribution over the State, and is easily recognized by the abundance of fossil remains of crinoids which it contains. The upper portion is also characterized by an abundance of flint, which occurs either as nodules or layers throughout the formation. The fossiliferous character of this limestone is nicely shown in the accompanying illustration. (See Plate VI.) The most abundant fossils are crinoids, the stems of which have been remarkably well preserved in the limestone, and especially in those beds which have been silicified. Remains of corals and brachiopods are also abundant in the limestone. The secondary chert also contains many beautifully preserved fossils. The flint occurs in the limestone of this area very much as it does in this formation in other sections of the State. The nodular variety is well illustrated by the accompanying photograph taken from the report on the "Quarrying Industry." (See Plate VII.) The following section illustrates the character of this formation as it is found in this area at this time. As a rule, the limestone is removed from the upper beds, and there remains nothing but broken fragments of flint imbedded in a soft, plastic red clay. As the formation is penetrated deeper, the flint beds are less broken, until, finally, unaltered limestone, with imbedded flint, is reached.

The flint is probably, in part, original, but such evidence as we have been able to collect, indicates that a greater part was either precipitated from a solution or was a metasomatic replacement of the limestone. There are at least three generations of flint associated with the limestone and the ore bodies. The first is a white variety, which is thought to be original, since it does not contain fossils common to the limestone; the second is a white, gray or blue variety, containing fossils, and thought to be a replacement of the limestone; the third is a black flint, which has

FOSSILIFEROUS KEOKUK LIMESTONE, SHOWING CHARACTERISTIC WEATHERING.

NODULAR FLINT IN UNDECOMPOSED LIMESTONE.

evidently resulted from either the silicification of arenaceous mud or the precipitation of silica from the underground waters, perhaps both. This flint contains no fossils and serves as a matrix, in which are imbedded fragments of the white flint, forming what is commonly known as a breccia. This breccia is well shown in Plate VIII. In places both the white and black flints have been decomposed. When decomposed, the white flint is known to the miners as "cotton rock," on account of its white, soft character, while the decomposed black flint is called "cod rock."

At several places over this area a bed of oölitic limestone, about four feet in thickness, was observed occupying about the same horizon in the formation. It was passed through in the shafts on the hillsides near the furnace, in the shafts near the middle of the west line of Section 5, T. 25, R. 30 W., and on the prairie west of the "prairie run." It also outcrops on the hillsides north of Shoal creek in the N. W. ¼ of S. E. ¼ of Sec. 25, T. 26, R. 13 W. The formation has a gentle dip to the north or northwest of about 25 feet to the mile, on account of which this bed occurs about 40 feet lower at the last-named locality than on the hillsides west of the furnace.

## EROSION INTERVAL.

At the close of the Mississippian, there was an erosion interval of considerable duration. During this period the upper beds were removed and the land deeply trenched by running water. The underground waters flowing along joints took the limestone into solution, producing caves, caverns and sink-holes.

During this period there was also a process of concentration recrystallization and silicification, in progress. The beds of limestone became more completely crystalline; the original flint nodules were enlarged through the replacement of the limestone by silica; and the limestone beds were silicified. Perhaps, near the surface, during the latter part of this erosion interval, the flint may have been partly decomposed forming cellular chert (flint).

Just the order in which these changes occurred and the position of the altered beds with respect to the surface, are not known. We only know that the limestone was saturated with mineraling solutions, carrying chiefly calcium carbonate and silica; and that zinc and lead salts were not deposited, and therefore probably not carried in solution.

The great thickness of the limestone deposits of the Mississippian, and the enormous deposits of coal formed during the Pennsylvanian, have lead some to believe that the atmosphere during the post-Mississippian erosion interval was heavily charged with carbon dioxide. If this be true, the water falling upon the land must have been more heavily charged with carbon dioxide than at present. Such a condition provides an easy explanation for the extensive solution of the limestone to depths beyond the present zone of cementation. Solution and silicification appear to have been much greater prior to the Pennsylvanian than since, although the recent silicification represented by the black flint is very prominent.

The Mississippian limestone was probably subjected to a longer period of erosion, prior to Pennsylvanian times, than it has been since erosion has removed the Pennsylvanian.

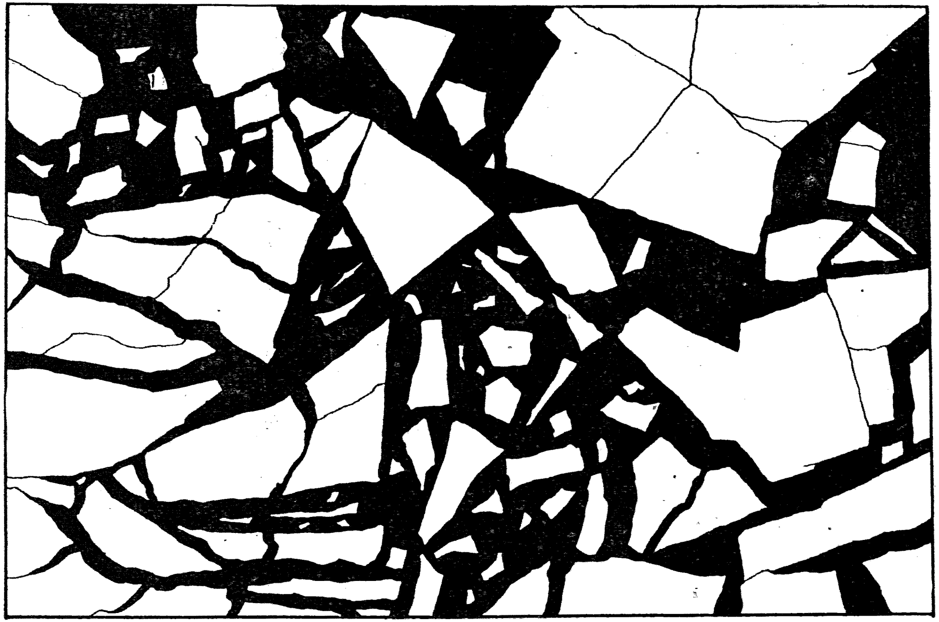
It may be well to repeat that there is no evidence that either lead, zinc or dolomite in any form, were deposited during the Mississippian period or the post-Mississippian erosion interval; that there is evidence of deposition and solution of silica; and that the limestone was very generally re-crystallized and removed in solution where it came within the belt of weathering.

The close of this period left the land rough and hilly, very much as it is today. The upper beds of limestone had either been removed or altered into a rough, porous or dense, nodular chert. The hillsides were covered to an unknown depth with broken fragments of flint forming a talus. Within the hills, back from and beneath the talus, the limestone was dissolved for some distance, causing the beds of flint to drop down and dip toward the valleys, as shown in the accompanying illustration. See Plate IX. The thin beds of flint were broken into small fragments, while the heavier beds were tilted from the limestone toward the valley. This is the condition in which we suppose the land to have been at the time the Pennsylvanian period was inaugurated.

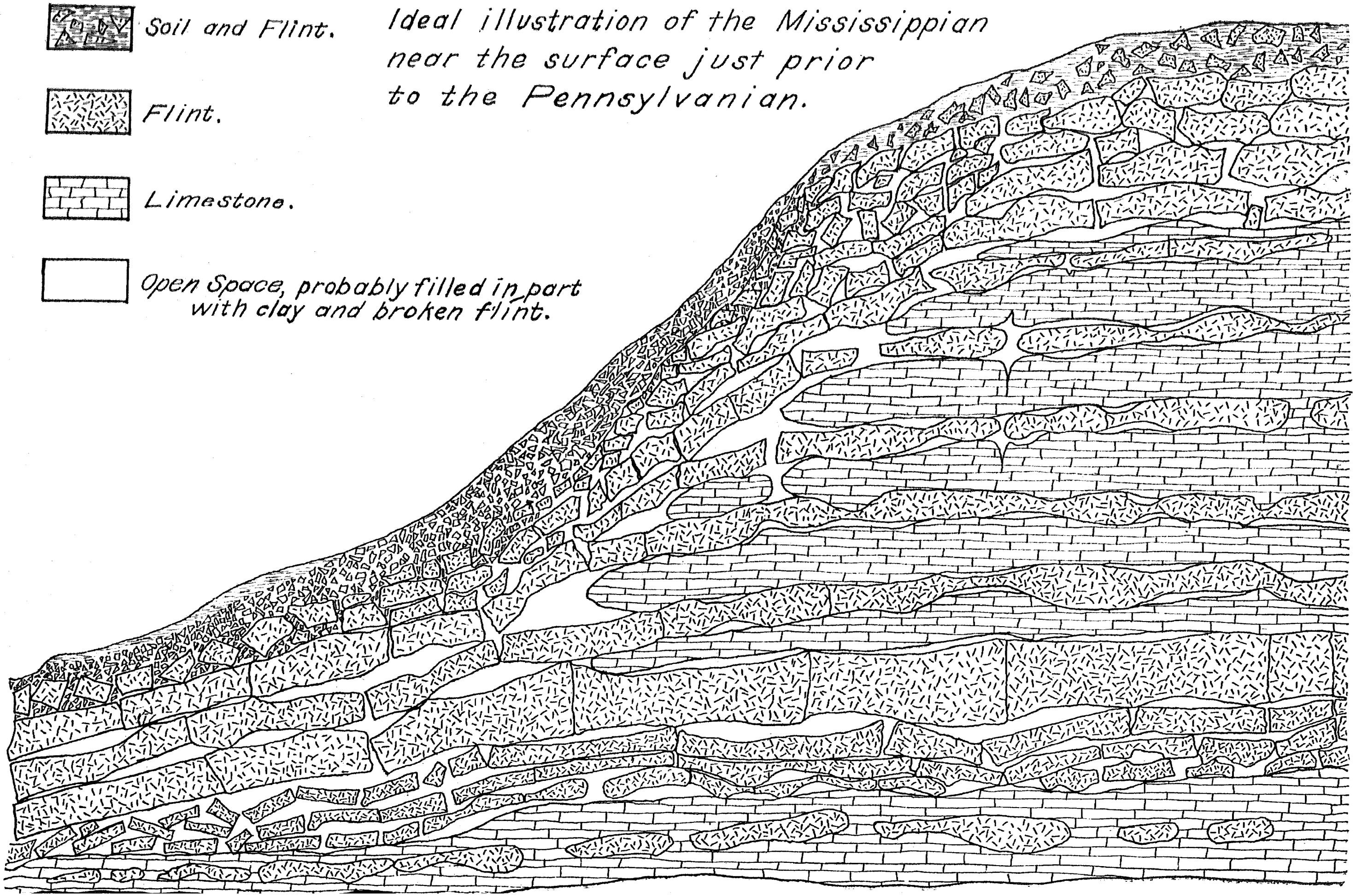
## THE PENNSYLVANIAN.

Everywhere south and southwest of the main area of Pennsylvanian rocks, in this State, there are isolated outcrops of sandstone, shale and coal belonging to this period. The detached areas are larger and more numerous as the main area is approached. They become less frequent as the summit or table-land area of the Ozarks is reached. However, they are found scattered over the entire region, usually occupying depressed or protected areas in the underlying formations.

Along the principal valleys and on the prairie land of the Granby area, there are irregular areas of sandstone and shale of Pennsylvanian age. In some instances, in sinking shafts, shale is passed through at a depth below what is supposed to have been the level of the pre-Pennsylvanian land surface. The occurrence of shale and sandstone in these irregular depressions has led to the belief that the deposits were laid



FLINT BRECCIA.
Drawn from a specimen collected on one of the Mine Dumps.


Soil and Flint.
Flint.
Limestone.
Open Space, probably filled in part with clay and broken flint.
Ideal illustration of the Mississippian near the surface just prior to the Pennsylvanian.

down in sink holes of pre-Pennsylvanina age. The sink hole depressions may, in some cases, be of post-Pennsylvanian age, the shale having been let down into depressions formed by subsequent solution. The occurrence of rounded boulders at the base of the shale, for example, in the Gold Dollar shaft in the N. W. Corner of Sec. 8, T. 25, R. 30 W., leads one to suppose that, in some cases, the former has been the cause of the present depressed position of the shale. On the other hand, the slickensided character of the shale and the broken and often jumbled character of the beds point to later solution as the cause. In some instance both may be required to explain their position. The relation between the Mississippian and Pennsylvanian series is well shown by the accompanying cross sections. See Plate X.

A part of the broken flint, which formed the talus slopes on the hillsides prior to this period, now constitutes what may be termed the Pennsylvanian basal conglomerate. The fragments of flint are usually angular, evidently having been little disturbed by the waters of the Pennsylvanian sea. For this reason it resembles very much a mechanical breccia, for which it has been persistently mistaken. The fragments are not assorted and there are no foreign boulders. In a number of localities rounded boulders have been found near the base of the shale, but these are an exception and not the rule.

In many instances the conglomerate at the base of the Pennsylvanian has all the appearance of a fault breccia. Indeed, as stated above, many of those who have previously studied the area, seem to have considered it as such. It has, however, as already pointed out, had an entirely different origin.

It is not intended to imply that all the so-called breccia is a conglomerate. This would hardly be true, since much of the broken flint occurs at depths which are only reached by ground water. The breccia also occurs beneath little disturbed beds of flint and limestone, and here it constitutes a simple solution breccia in which the cementation by silica has been brought about entirely by ground-water.

Plate XI is a photograph of one of the hillsides in the Granby area, which is covered with residual flint.. It is easy to understand how these talus slopes might be buried as they are by the encroachment of the sea, especially if it were shallow and of an estuarine character, as the Pennsylvanian sea was supposed to have been in its early history. These hillside conglomerates are not everywhere preserved, but they are especially conspicuous in the neighborhood of the sandstone areas where there are excellent gradational phases. This conglomerate we have called the Granby.

The shale and sandstone areas occur not only in the valleys, but also on the upland surface, where they frequently occupy depressions, thought to be either sink holes or the broad heads of ancient valleys. Drill holes and shafts, which have been sunk in the valleys and on the prairie, show that the pre-Pennsylvanian topography has not been entirely uncovered. In some places, at least, the stream channels were deeper, at that time, than they are today. In other places the drainage evidently followed different courses than the present. The relations existing at the surface between the flint conglomerate, sandstone and limestone outcrops are well illustrated in Plate XII.

Had there been time at our disposal, it would have been extremely interesting to have worked out the ancient drainage system. As it is, we must content ourselves for the present with a knowledge that it is here.

The shale is usually very carbonaceous, and in one place a drill hole passed through a small seam of coal. The beds are usually badly disturbed and broken, as though there had been settling since Pennsylvanian times. In places the shale grades into or is interbedded with sandstone. The sandstone is medium-grained, and fossiliferous. It is usually distinctly, though thinly, bedded, and frequently overlies directly the pre-Pennsylvanian flint talus. In a number of instances it was observed attached to and filling the interstices between the angular fragments of flint. In such places the flint fragments were actually imbedded in the sandstone forming the conglomerate referred to above. In a number of instances the sandstone was found to be very hard and quartzitic, but still preserving beautifully the fossil remains.

The shale contains numerous crystals of pyrite, and frequently crystals of zinc blende are found within and near the bottom of the deposit. The sandstone contains no minerals of special importance. The shale contains boulders of limestone, around which a coating of acicular gypsum, about one inch in thickness, has evidently formed. This shell, which encloses the limestone boulders, has altered to aragonite, the sulphate having been changed into the carbonate. This structure is nicely illustrated in the accompanying photograph. (See Plate XIII.)

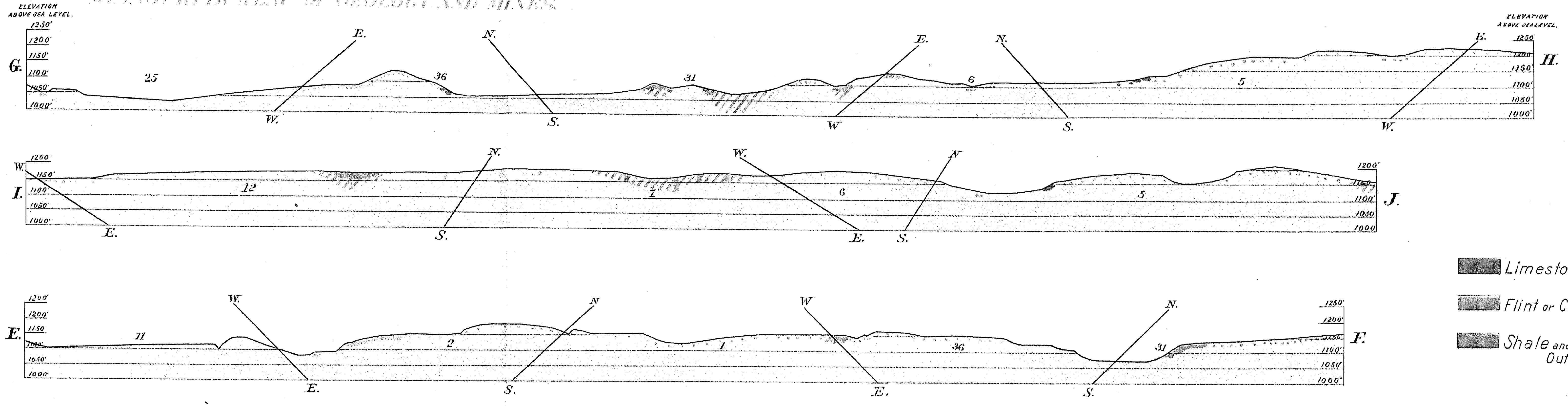
## STRUCTURES.

*Bedding*—The limestone, sandstone and shale each have well-defined bedding and stratification planes. The position of many of the bedding planes in the limestone has been determined by the layers of flint, which offer easy planes of parting. As a whole, the bedding planes are approximately horizontal. There are local dips everywhere, the direction, as far as observed, being from the hills toward the valleys.

# CROSS SECTIONS
## ACCOMPANYING GEOLOGICAL MAP

BY

E. R. BUCKLEY




### LEGEND

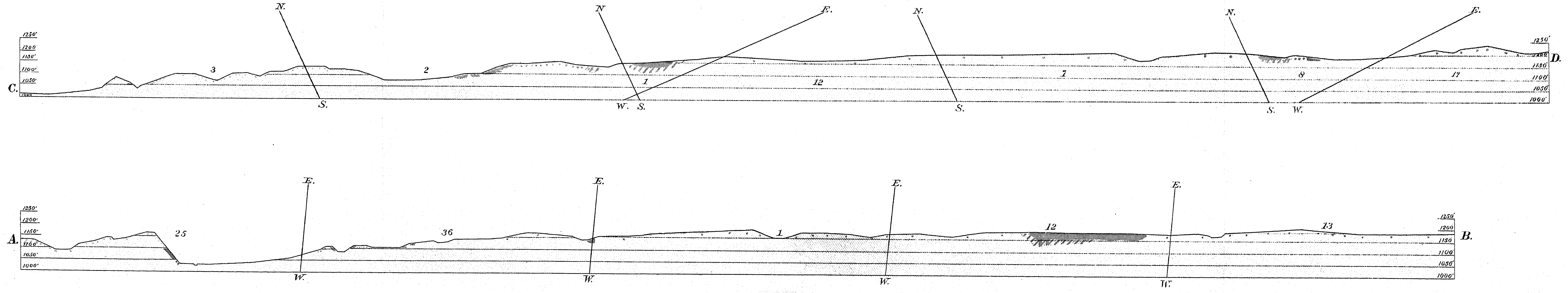
- Limestone Outcrops.
- Flint or Chert Outcrops.
- Shale and Sandstone Outcrops.
- Limestone Fragments.
- Flint Fragments.
- Sandstone Fragments.
- Mississippian. (Probably Keokuk)
- Pennsylvanian.

*Horizontal Scale* ........ 1" = 1320'.

*Vertical Scale* ........ 1" = 300'.

*Straight Lines crossing the profiles are Section Lines.*

AUG. GAST BANK NOTE CO. ST. LOUIS.



HILLSIDE, NEAR GRANBY, COVERED WITH RESIDUAL FLINT.

This dipping of the strata toward the stream channels has been due to the greater activity of solutions along the hillsides. The greater zone of solution by circulating ground-waters follows the water level, which in general follows the contour of the surface. Near the furnace of the Granby Mining and Smelting Company the strata dip quite sharply into the hill, as the result of a cave which is known to exist at that place.

Ignoring the local dips, and considering only the position of the well-defined horizons in the Mississippian, we are led to believe that there is a general northerly dip of about twenty-five feet to the mile. This dip is shown by the position of the oölitic bed in different localities over the area.

*Jointing*—Evidently there is no well-defined system of jointing in this area. The observations taken at important outcrops over the area show that the following directions are most prominent:

N. 30° W.
N. 45-50° W.
N. 60-70° W.
N. - S.
N. 40-50° E.
N. 65-70° E.

In the mines, underground, the beds are badly disturbed as a result of settling through the solution of the limestone. For this reason it is difficult to make out the joints.

*Folding.*—The beds in this area are not folded except where the strata are depressed as a result of unequal settling due to solution. In each case the folds are due to differential settling of the blocks comprising the beds and not to a bending of the strata. Some of these folds are described in connection with the discussion of the ore deposits in a subsequent chapter.

*Faulting.*—Dr. H. Foster Bain, in his report on "The Lead and Zinc Deposits of the Ozark Region," published in 1902 by the United States Geological Survey, says, in discussing the Granby Area:

"There is, however, important faulting. The fault running along the north edge of the camp through sections 31, 6 and 5, traced by Mr. Willis, has a throw to the north of at least 80 feet. Other faults are known to occur," - - - "The amount of Coal Measure material depends mainly on the extent and distribution of the faults." - - - "In the Granby area there is evidence not only of brecciation, but of general deformation and faulting. Along the north fault already referred to, there is a throw of more than 80 feet, as is shown by the presence of Coal Measure shales and sandstone to that depth in drill holes along it, with the underlying cherts and limestones rising in the hills to the south." - - - "Near the fault on the hill west of the Mt. Pleasant Mill, Coal Measures sandstone has a dip of 35° N. The strike here is N. 80° E., but the general course of the fault is shown by the contact of the shale and the chert to be approximately S. 70° E. To the southeast, in section 5, the displacement disappears and the fault is marked by brecciation of the chert and limestone and development of ore bodies." - - - "In the Mascott mine, and again in the Little Four and the big open pit between, there are unmistakable evidences of faulting and brecciation along a course almost due north. The down throw, which is to the east, does not seem to be important. A second fault runs northwest past the Future, Clara Barton and Jack Sprout mines, intersecting the Mascott fault a little north of the center of section 12. This fault has a downthrow to the west, and the result is that a V-shaped block has been faulted down, with the maximum throw at the apex."

"The well-recognized presence of bars of various sorts of material in other parts of the camp indicates that detailed studies will show numerous faults and zones of fracture. In part deformation has bent the strata, and phenomena of this character are clearer here than in any of the mines elsewhere observed in the district."

"The main brecciation has occurred along the bedding planes as a result of the strata slipping over each other, but brecciation across the bedding also occurs."*

In none of the earlier reports upon this district, including those by Schmidt, Swallow, Broadhead and Winslow, is there any reference to faulting in this area. The detailed examinations, which we made during the winter and spring of 1905, likewise did not reveal the presence of faulting or brecciation resulting from mechanical deformation, as described by Bain in the report quoted above.

The breccias described by Bain are in part Pennsylvanian basal conglomerates, formed from the flint fragments of the pre-Pennsylvanian talus slopes, as described above. The faults described are discordances in bedding due to the unconformity between the Mississippian and the Pennsylvanian series. There is, in places, minor faulting between the formations along their contact, but it is unimportant. The different elevations at which the sandstone and shale occur may be in part due to solution of the underlying limestone and consequent settling of the sandstone or shale. This, however, has probably not been so important as the differences in the elevation of the floor upon which the Pennsylvanian sediments were deposited.

*"The Lead and Zinc Deposits of the Ozark Region," by H. F. Bain, 22nd Annual Report of the U. S. G. S., 1900-1901, pp. 187-190.

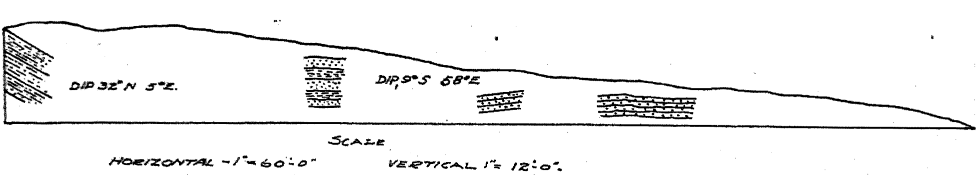
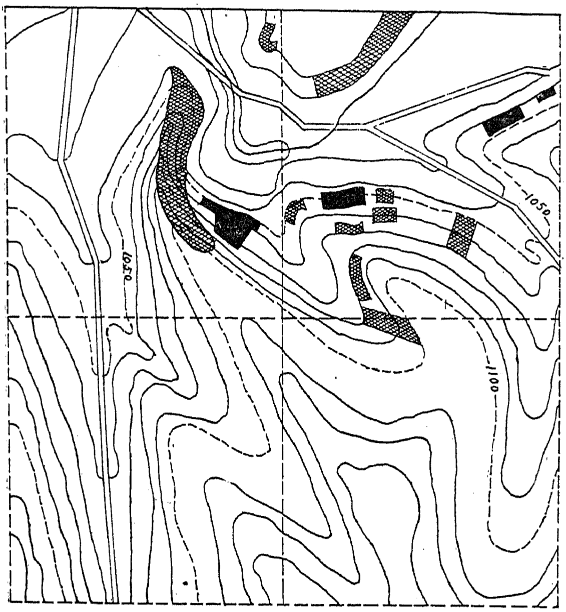
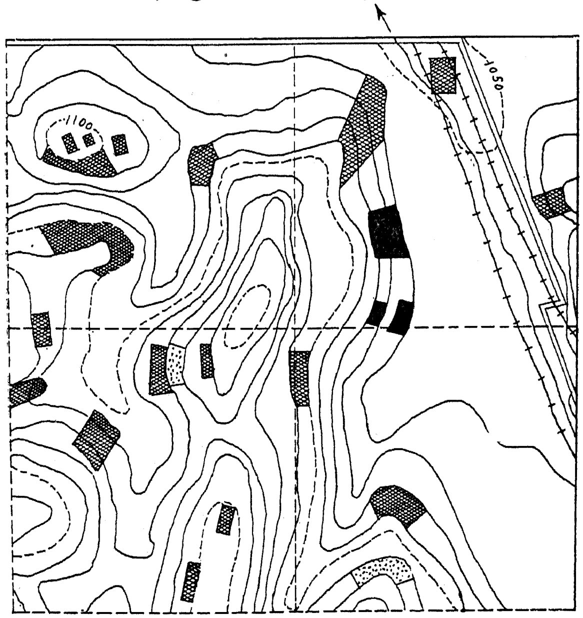



Figure 1. Outcrops of sandstone and shale along the Missouri Pacific Railroad near contact of the Mississippian and Pennsylvanian Series.

E½, N.W.¼ AND W.½ N.E.¼.
Sec. 3,-T.25,-R.31.W.

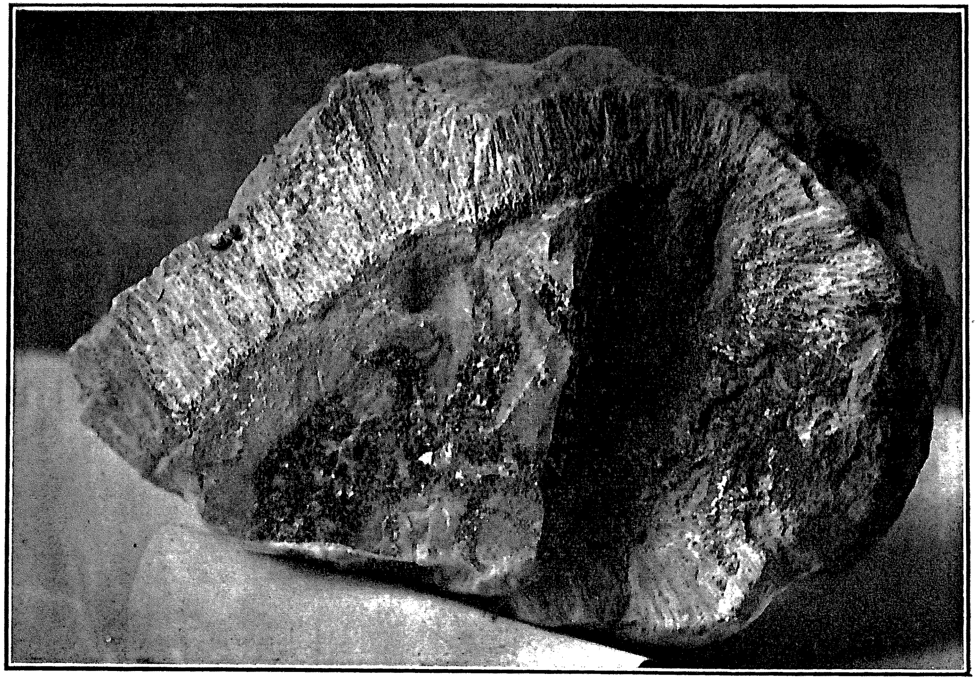



N.E.¼. Sec. 36-T26-R.31 W.




Limestone. Chert. Sandstone.

Flint, sandstone and limestone outcrops, illustrating the unconformity between the Mississippian and Pennsylvanian series.



ARAGONITE ENCLOSING A BOULDER OF LIMESTONE.
From the Granby conglomerate.

Referring to the fault mapped by Bain as occurring north of the town of Granby and near the Mt. Pleasant Mill, detailed observations show, that were we to consider the apparent contact of the chert with the sandstone and shale as the direction of the strike of the fault, this would be N. 50° W. at the railroad cut and about S. 50° E. about two hundred paces southeast of this outcrop. As these directions are followed either way, they soon pass into hills composed of chert of the usual kind found in this area. If one should attempt to follow the contact between the sandstone and the limestone, he would be led in a very irregular winding course along the hillsides to the heads of the valleys, as shown by the distribution of the shale and sandstone on the accompanying Geologic map, Plate I. The relations existing between the limestone and the sandstone and shale are those of unconformity and not faulting. The dipping sandstone beds referred to by Bain as occurring on the hill west of the Mt. Pleasant Mill are shown in the accompanying drawing, figure 1, which is drawn to scale. In the vicinity of the Mt. Pleasant Mill, which is near the fault mapped by Dr. Bain, four holes have been drilled. These show the presence of a considerable thickness of sandstone, shale and conglomerate, but in themselves they give absolutely no evidence of faulting. Throughout the Ozark region it is not uncommon to find the shale and sandstone belonging to the Pennsylvanian filling irregular depressions in the underlying formations, frequently fifty to sixty feet deep.

The flint breccias mentioned by Dr. Bain in his report, as quoted above, do not occur along zones of mechanical deformation, but chiefly at or near the base of the Pennsylvanian, where, during the pre-Pennsylvanian erosion interval, solution was very active. This breccia, which is in part a conglomerate and in part a solution breccia, was formed from a chert talus which, as pointed out above, was formed on the sides of the hills and ridges as at the present time. During the Pennsylvanian period, the conglomerate and breccia were deeply buried beneath sandstone, limestone and shale and the interstices were later filled with materials deposited chiefly from solution.

## THE CHERTS OF THE GRANBY AREA.

As stated on a previous page, there are three generations of chert easily recognizable in this area. The first has a white color and is devoid of fossils common in the limestone; the second is white, gray or blue and contains fossils; while the third is chiefly black and brownish black and contains no fossils.

Nodules and thin layers of white or grayish colored chert are especially characteristic of the Burlington and Keokuk limestones. As a rule, these nodules and layers occur along the bedding planes, although it is not unusual to find isolated nodules within the beds and evidently completely removed from the circulation of underground waters. These nodules and layers vary greatly in size, frequently being two feet long by six inches thick. They are usually very dense and compact, and when fresh, they break with a sharp splintery and often conchoidal fracture. Frequently the exterior portion of the nodules contains fossils, and it is thought that this, at least, must be a secondary product, resulting from deposition from underground water. Some of the beds of flint contain fossils throughout, and this is thought to be secondary. Wherever these nodules occur above the level of ground water, they are usually sharply separated from the limestone. Frequently when the limestone is broken they fall away from it, almost in the same manner as a pebble does from a loosely compacted conglomerate. This condition is due to the decomposition of the chert along its contact surface with the limestone.

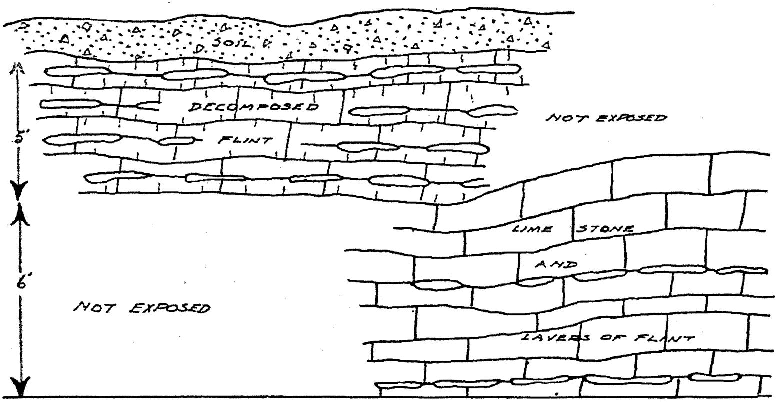



Figure 2. Limestone overlain with decomposed flint.

As a result of weathering, the chert is frequently altered into a porous, soft, yet solid mass, commonly known as "tripoli." In the secondary white chert there are often myriads of fossils, such as one finds in the original limestone. Due to various causes, as explained elsewhere, the limestone in which the white chert was originally embedded has been in some places removed. Through further weathering this chert has been broken into fragments and later it has been deeply buried under the Pennsylvanian. Since Pennsylvanian time the fragments of white flint have been cemented, in some places, with black flint, forming a rock having all the appearance of a "breccia." In other places the white flint or chert fragments have been, at some period of their history, cemented with calcite or dolomite. Wherever denudation has brought the limestone and chert near the surface, solution and disintegration have removed the former and softened the latter, forming a porous chert. (See figure 2.)

In many places the removal of the limestone, through the agency of underground water, has been more rapid than the removal of the residual chert from the surface by the ordinary means of transportation by water and gravity. Naturally this has resulted in the accumulation of chert near the surface, and we now find many of the hillsides covered to an often unknown and varying depth with chert or flint fragments. (See figure 3.) These fragments of chert, as found today,

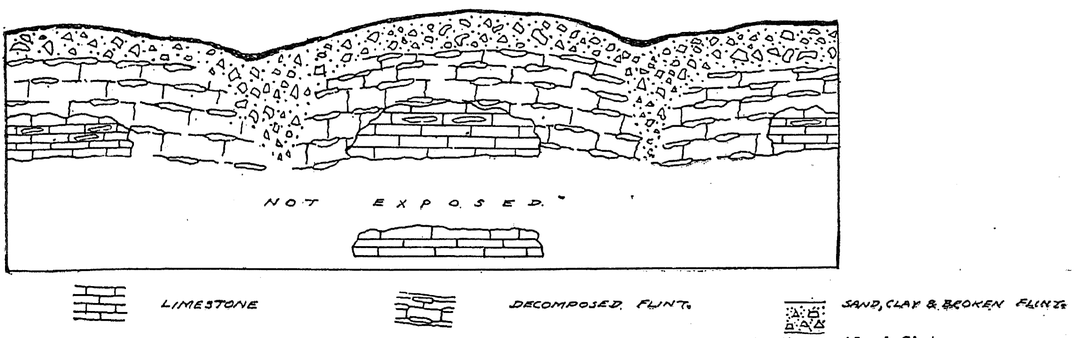



Figure 3. Ideal section showing the relation of the limestone to the residual flint.

consist of, (1) the white variety occurring originally in thin layers or nodules within the limestone, (2) the porous variety which has resulted from the silicification of limestone beds near the surface and later decomposition, and (3) the chert or flint conglomerate or breccia, in which the white chert is cemented with dark colored silica.

An understanding of the geological history of the area is necessary to an understanding of the origin and distribution of the flint as it occurs today.

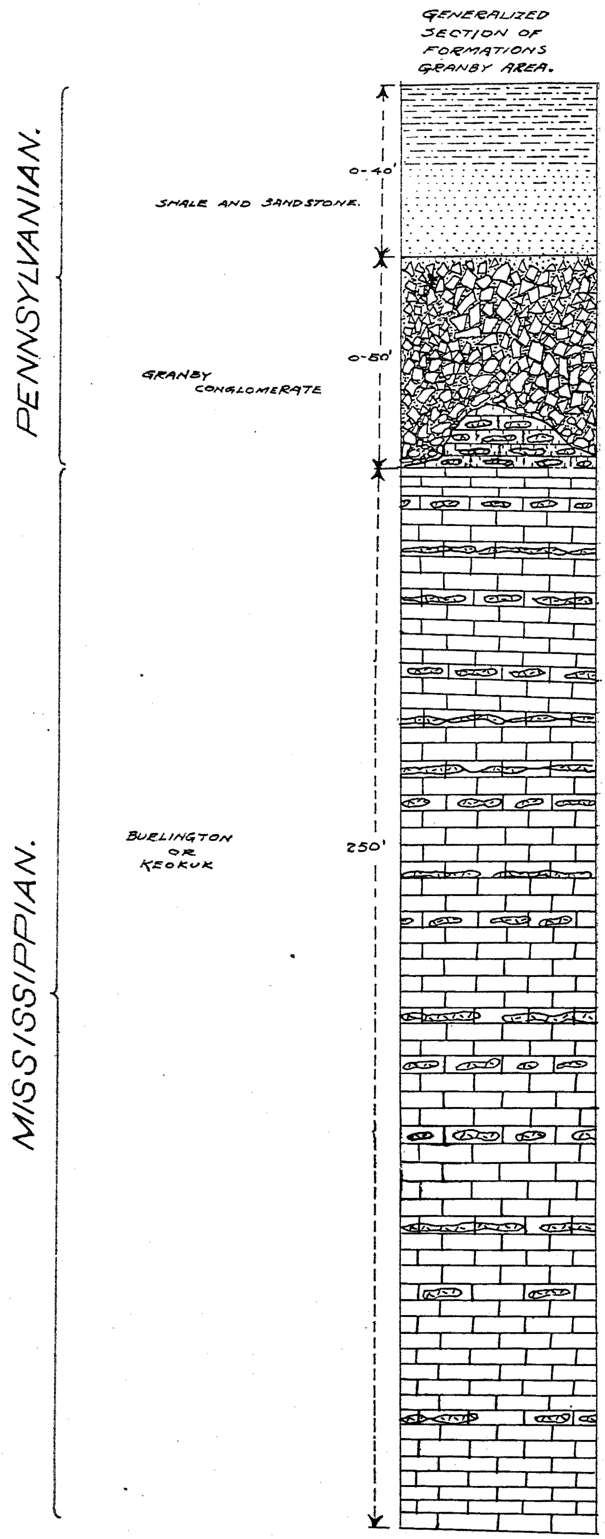
Some of it was probably formed at the time the limestone was laid down, through the accumulation of the siliceous skeletons of marine animals.* It is quite certain, at least, that the nodules and thin layers were formed around siliceous nuclei, which were deposited with the limestone. It is possible in some instances that these nuclei were nothing more than grains, or thin disconnected laminae of sand. These nuclei evidently occurred along fairly well defined planes and may, in themselves, have assisted in determining the position of the bedding planes.

*The remains of sponges have been recognized in the flint at Grand Falls by the geologists of the U. S. G. S.

The bedding planes, having been once established, became the channels along which the ground-water circulated most readily. Although the siliceous nuclei may have determined the position of the bedding planes, the position of the nuclei along the path traveled by the ground-water has been the direct cause for their growth. The absence of limestone fossils in many of the flint nodules and in the cores of many others has led us to believe that they were in part an original deposition. The presence of fossils within many of the flint nodules is evidence that, in part, at least, they have been formed by the abstraction of silica from the circulating ground-water.

After the Mississippian limestone was laid down, and prior to the deposition of the Pennsylvanian or Coal Measure strata, the white nodules and layers of flint and also the porous flint, which formed chiefly through the decomposition of secondary flint near the surface, were well developed. This is shown by the fact that porous and white nodular flints occur as fragments within the conglomerate at the base of the Pennsylvanian formation.

We find very little evidence that the black flint is all later than the major deposits of lead and zinc and the associated dolomite. As explained elsewhere, we believe that the black flint and the blende, which is disseminated through it, are contemporaneous. We also believe that these are among the earliest ores deposited. We are also convinced that a greater part of the black flint and gray dolomitic spar were deposited contemporaneously, although there is unmistakable evidence that some of the black flint is both earlier and later than the dolomitic spar. In order to explain the presence of isolated crystals of blende in the black flint, Bain states that the flint may have been in a colloid condition. We agree that some of the silica may have been in a colloid condition when deposited, but we do not believe that there were any masses of silica in colloidal form, filling the spaces between the flint fragments. The black flint, which was deposited from solution, probably formed very slowly, and if so, it is reasonable to suppose that the process of hardening kept pace, almost, with the growth of the flint. As explained elsewhere, we believe that the black flint was, in part, formed by precipitation from solutions, and, probably, in part, from carbonaceous, arenaceous material, carried into the flint breccia mechanically. Evidence that some of the black flint may have been, at one time, a siliceous mud is found in certain cracks, resembling ordinary mud cracks, found in a thin sheet of black flint in the Goldenrod mine north of Webb City.




GEOLOGIC SECTION OF THE FORMATIONS OF THE GRANBY AREA.

## RÉSUMÉ.

As stated elsewhere, there was established in pre-Pennsylvanian times a system of drainage, which, in many places, practically coincides with the present. Prior to Pennsylvanian time, the beds of Mississippian limestone were decomposed and disintegrated, and the hillsides were strewn with chert fragments in a manner very similar to that in which they are today. Not only were the systems of drainage well established, but there were produced sink holes, of large and small dimensions, forming circular and often irregular depressions at the surface. There are very few within the area included in this report, but elsewhere in the Southwestern Lead and Zinc District they are abundant. The encroachment of the Pennsylvanian sea resulted in covering the uneven land surface with an unknown thickness of sandstone and shale. The old stream channels and the circular depressions resulting from sink holes were filled with these sediments. The residual flint, which covered, in places, the flanks of the hills and tops of the ridges, was deeply buried. The open, porous zones, formed by this mantle of chert along the hillsides, became channels through which the ground-water circulated freely and abundantly. Once, twice or perhaps more times these conglomerate beds have been under conditions of silicification. One of these times may have been during the depression of the land surface, when the Pennsylvanian strata were being laid down. Other times may have been long after the Pennsylvanian period, when through denudation or subsidence these beds were again brought near the surface.

There is no evidence that since Pennsylvanian time this part of the continent was ever again submerged beneath the ocean, although it seems scarcely probable that the agents of denudation have not removed from the surface of this area more than the Pennsylvanian strata during the great length of time represented by the Permian, Triassic, Jurassic, Cretaceous, Tertiary and Quaternary.

In many cases the present streams are flowing through valleys which were developed in pre-Pennsylvanian time. There still remain, however, small areas of sandstone and shale, nestled back in the hills and sunk into depressions on the prairie land, where they have been protected by the surrounding more elevated beds from the active agents of erosion. The residual flint formed prior to the Pennsylvanian period has in some places been completely removed, but there still remain numerous outcrops of rugged flint conglomerate which give evidence of the ancient chert covered hillsides and ridges of the pre-Pennsylvanian erosion interval.

# CHAPTER V.

## MINERALS, ROCKS, SOIL AND CLAYS.*

Many of the minerals of this area, both metallic and nonmetallic, are of common occurrence throughout the lead and zinc district of southwestern Missouri. However, there is probably no single locality in the state so rich in beautiful specimens of the oxidized minerals, either crystalized or as pseudomorphs after other minerals, as Granby. This locality has long been noted for beautiful specimens of calamine, smithsonite, hydrozincite, leadhillite, cerussite and pyromorphite.

The following is a short description** of the minerals that were recognized during the examination of the mines of this area.

### METALLIC MINERALS.

*Galena* ($PbS$). The sulphide of lead, commonly called "mineral" by the miners. Crystallizes in the isometric system, is frequently twinned and has a highly perfect cubic cleavage. It has a metallic lustre and a pure, lead gray color. Hardness=2.5 to 2.75. Specific Gravity=7.4 to 7.6. When pure it contains 86.6% lead and 13.4% sulphur.

In this area it occurs chiefly in cubic crystals, usually in aggregates weighing up to several hundred pounds. Where the crystals have been protected from oxidation, the faces are bright and glistening. Where the crystals have been etched, the faces are irregular the corners frequently rounded and the whole is usually encased in a grayish colored layer of cerussite. There are all stages of oxidation of the galena from that which is covered with a thin film of carbonate to that of which there remains only a cast of carbonate showing the original size and shape of the galena crystal. When the limestone, flint, clay and zinc minerals have been removed from the ore the concentrate is a very high grade galena containing about 84% of lead.

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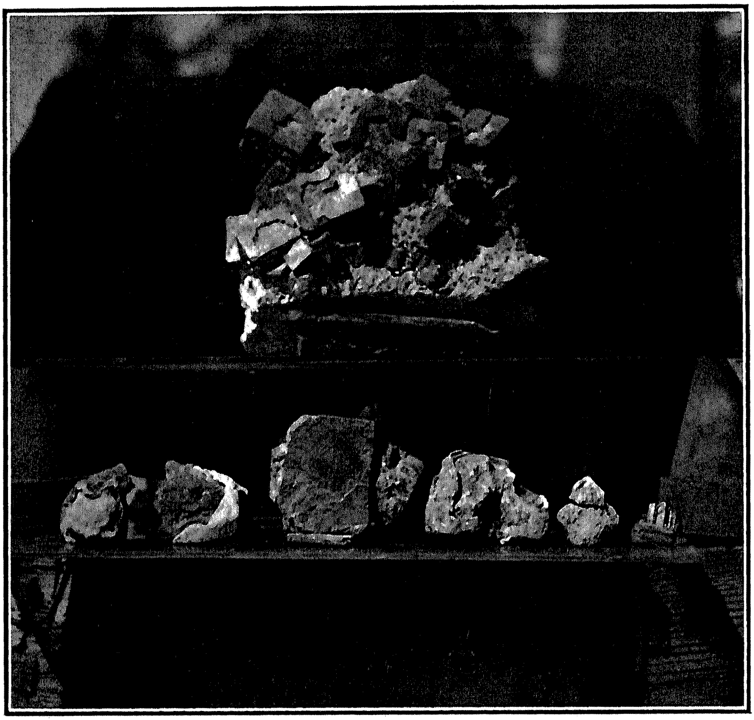
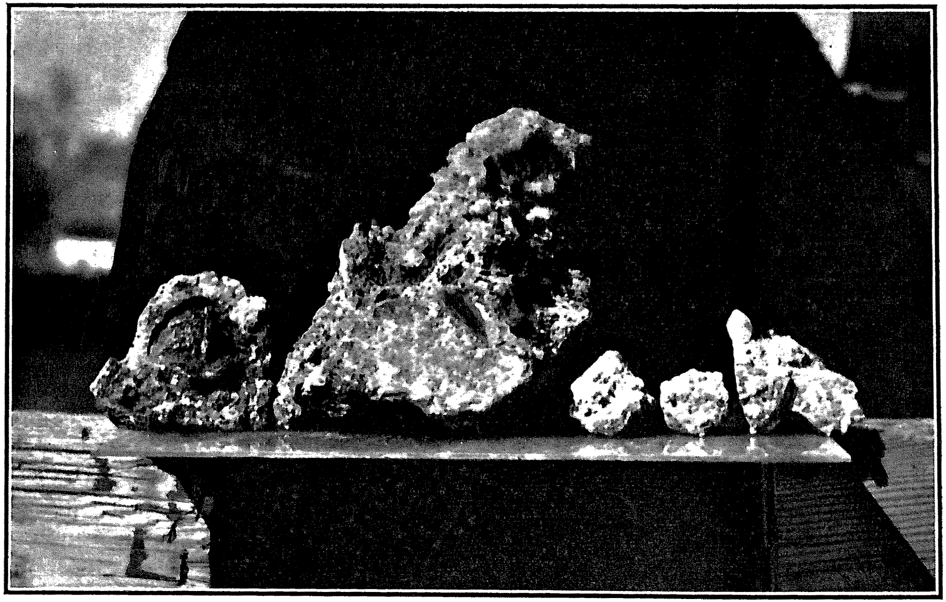
*The descriptions of minerals, rocks, etc., are not arranged alphabetically. Reference should be made to index.

**The general description of each mineral is taken from Dana's "System of Mineralogy."



SPECIMENS OF GALENA

Several are altered, in part, to cerussite.
(Specimens in John T. Kingston's collection.)



Large specimens are sphalerite altering to calamine. Three small specimens contain crystals of Leadhillite.
(Specimens in John T. Kingston's collection.)

*Sphalerite or Blende* ($ZnS$). The Sulphide of Zinc, commonly known as "Resin," "Resin Jack" or "Black Jack." Crystallizes in the Isometric system, having tetrahedral forms. Twinning is common and cleavage very perfect. Hardness 3.5-4. Specific Gravity 3.9-4.1. When pure it contains 67% zinc and 33% sulphur.

In this area it occurs in resin colored crystals; in irregular shaped particles disseminated through the flint and dolomite; or in low conical shaped individuals, commonly known as "pebble jack," in shale. This mineral occurs associated with dolomite, galena, calamine, greenockite, flint, limestone and clay.

*Greenockite* ($CdS$). Cadmium Sulphide. When pure it contains 77.7% cadmium and 22.3% sulphur. It crystallizes in the hexagonal system and has a honey to bronze yellow color.

In this area it occurs as a bright yellow coating on the surface and along some of the cleavage planes of the sphalerite. It has not been found in sufficient quantity to be of commercial value.

*Pyrite and Marcasite* ($FeS_2$). Iron disulphide, commonly known to the miners as "mundic," "sulphur" or "iron." These minerals have the same chemical composition, but the former crystallizes in the isometric system and the latter in the orthorhombic. The former has an indistinct cleavage and a conchoidal fracture, while in the latter, the cleavage is rather distinct and uneven. Pyrite has a nearly uniform, pale, brass-yellow color and a metallic lustre. Marcasite has a pale yellow, bronze color and a metallic lustre. The hardness is the same for both minerals, 6.-6.5. Pyrite has a specific gravity of 4.9-5.1, while the specific gravity of Marcasite is 4.85-4.90. When pure they contain 53.4% of sulphur and 46.6% of iron.

In this area, these minerals occur chiefly in the Pennsylvanian shales, although to a lesser degree they are associated with the sphalerite in the deep mines. Pyrite has also been reported from the deep drill holes of the area. It does not occur in sufficient quantity to be of commercial value.

*Chalcopyrite* ($CuFeS_2$). Sulphide of Copper and Iron. It crystallizes in the tetragonal system, has sometimes a distinct cleavage and uneven fracture and is brittle. The lustre is metallic and the color brass yellow, often irridescent. Hardness=3.5-4. Specific gravity, 4.1-4.3. When pure it contains 34.5% copper, 30.5% iron and 35% sulphur.

In this area it occurs chiefly in the form of small tetrahedral crystals sprinkled over a surface of pink dolomite crystals. It is frequently altered, in part, to malacite, one of the carbonates of copper. Chalcopyrite is not a common mineral in this area and has no commercial value.

*Calamine* ($Zn\ SiO_4H_2O$) or ($Zn\ (OH)_2\ SiO_2$). The hydrosilicate of zinc, commonly known to the miners of this area either as "Jack" or "Silicate," At an early day this mineral was known in this area as "gray jack," in distinction from the sphalerite or blende, which was called "black jack." Calamine being the predominant mineral in this area, it took the name "jack." In other parts of the state where sphalerite is the predominant mineral it has also taken the name "jack." The explanatory words "gray" and "black" have been in each case dropped.

Calamine crystallizes in the orthorhombic system. It has a perfect cleavage, a vitreous to subpearly lustre and a white, sometimes delicate bluish or yellowish color. It is transparent to translucent. Hardness=4.5-5; specific gravity=3.40-3.50. When pure it contains 67.5% of zinc oxide, 25% of silica and 7.5% of water.

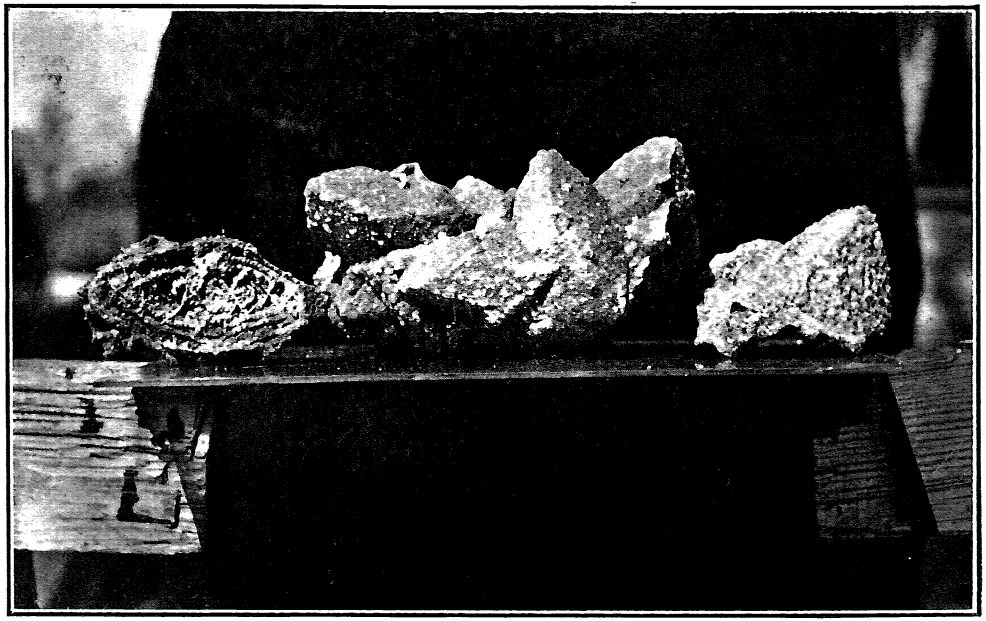
In this area it occurs in thin, translucent to colorless, tabular crystals; in irregular mammilliary aggregates; in sheaf-like forms; also massive and granular. In the massive form it constitutes one of the chief zinc ores of this area. In a finely pulverulent or granular form, it constitutes about 20 to 30% of the so-called tallow clay of this area. The calamine ore contains, besides calamine, one or more of the following minerals—galena, sphalerite, dolomite crystals and smithsonite. With these are usually associated flint and clay.

*Smithsonite* ($ZnCO_3$). Anhydrous Carbonate of Zinc, commonly known to the miners as "Carbonate." This mineral crystallizes in the rhombohedral system. It has a perfect cleavage, is translucent to substransparent and varies in color from white to grayish blue or brown. The hardness=5; specific gravity=4.30-4.45. When pure it contains 64.8% zinc protoxide and 35.2% carbon dioxide.

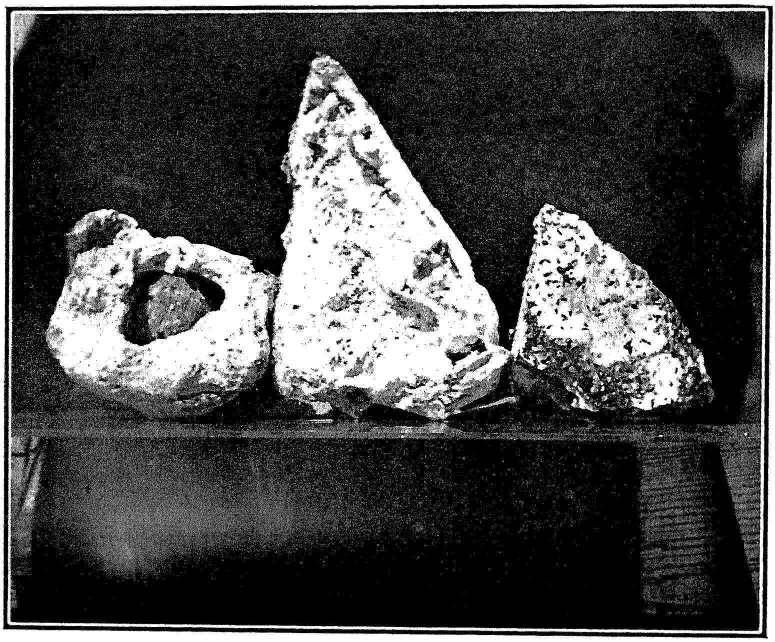
In this area it occurs chiefly associated with calamine, from which it is seldom separated. A considerable quantity of this mineral was found in the Sunset group of mines, but elsewhere the quantity has been very small. Occasionally excellent pseudomorphs after calcite are found.

*Hydrozincite* ($ZnCO_32Zn\ (OH)_2$). This is the basic carbonate of zinc and occurs chiefly in a massive, fibrous or earthy form. Its color is usually pure white, grayish or yellowish. Hardness=2-2.5, specific gravity=3.58-3.80. In its pure state, it contains 75.3% of zinc oxide, 30.6% carbon dioxide and 11.1% of water.

In this area it chiefly occurs associated with calamine. It is



PSEUDOMORPHS OF CALAMINE AFTER CALCITE.
(Specimens in John T. Kingston's collection.)



PSEUDOMORPHS OF SMITHSONITE AFTER CALCITE. THE CRYSTAL ON THE LEFT CONTAINS A CORE OF UNALTERED CALCITE.

(Specimens in John T. Kingston's collection.)

usually very white and has a soft earthy texture. It does not occur in sufficient quantity to warrant a separation from the other zinc minerals.

*Cerussite* ($PbCO_3$). Carbonate of lead, commonly known to the miners of this area as "dry bone." In the Wisconsin-Illinois zinc district, the term "dry bone" is applied to the mineral smithsonite. In that district smithsonite is more abundant than cerussite, while in the Granby area, the latter is the predominant mineral. Cerussite crystallizes in the orthorhombic system. It is commonly twinned, has a distinct cleavage, has an adamantine sometimes submetallic lustre, has a white to grayish black color and is transparent to subtranslucent. Hardness=3-3.5; specific gravity=6.46-6.574. When pure it contains 83.5% of lead oxide and 16.5% of carbon dioxide.

During the early period of mining in this area when the mines were shallow, considerable cerussite was produced. At the present time it occurs chiefly in layers coating the galena, or as casts of galena crystals in small openings in the rock. This mineral, as well as smithsonite and calamine, has been found in the form of stalactites lining caverns in the limestone.

*Leadhillite* ($4PbO. SO_3.2CO_2.H_2O$). This is a sulphatic carbonate of lead. It crystallizes in the monoclinic system. It has a very perfect cleavage, a pearly, somewhat adamantine lustre, a white, yellow or sometimes grayish color and is transparent to translucent. When pure it contains 82.7% of lead oxide, 7.4% of sulphur trioxide, 8.2% of carbon dioxide and 1.7% of water.

In this area it has been found in one shaft, where it occurs in transparent, tabular crystals and as pseudomorphs after calcite. This may be said to be one of the rare minerals of the area and has no importance from a commercial standpoint.

*Anglesite* ($PbSO_4$). Lead Sulphate. This mineral crystallizes in the orthorhombic system. It has a distinct cleavage, is very brittle, has a resinous to adamantine lustre, a white, yellowish gray and sometimes blue color, and is transparent to opaque. When pure it consists of 73.6% of lead oxide and 26.4% of sulphur trioxide.

In this area small crystals of anglesite occur associated with galena. It is not an abundant mineral and of itself is not of commercial importance.

*Pyromorphite* ($(PbCl)(Pb_4P_3O_{12})$). Phosphate of lead. Crystallizes in the hexagonal system. It has a sub-conchoidal, uneven fracture, a resinous lustre, a green, yellow or brown color and is subtransparent to subtranslucent.

This mineral has been found in different shallow mines in this area. It is not abundant and has been classed as one of the rare minerals of the area.

*Malachite* ($CuCO_3$). Cu ($OH_2$). Copper carbonate. This mineral crystallizes in the monoclinic system. It is commonly twinned and has a perfect cleavage. The lustre is adamantine and more or less silky in the fibrous varieties. It is translucent to opaque and the color is bright green. Hardness=3.5-4; specific gravity=3.9-4.03. When pure it consists of 71.9% cupric oxide, 19.9% carbon dioxide and 8.2% water.

It is of infrequent occurrence in this area, but is occasionally found as small nodules resulting from the oxidation of chalcopyrite. In such instances it is of the earthy variety. The blue carbonate known as Azurite probably occurs in the area, but none was observed while making the examinations for this report.

*Limonite* ($Fe_2O_3.3H_2O$). Hydrous ferric oxide. Not crystallized. It has a silky and often submetallic lustre. Sometimes dull and earthy, Hardness=5-5.10; specific gravity=3.6-4.0. Color is various shades of brown and yellow, with sometimes nearly a black exterior. When pure it contains 59.8% of iron, 25.7% of oxygen and 14.5% of water.

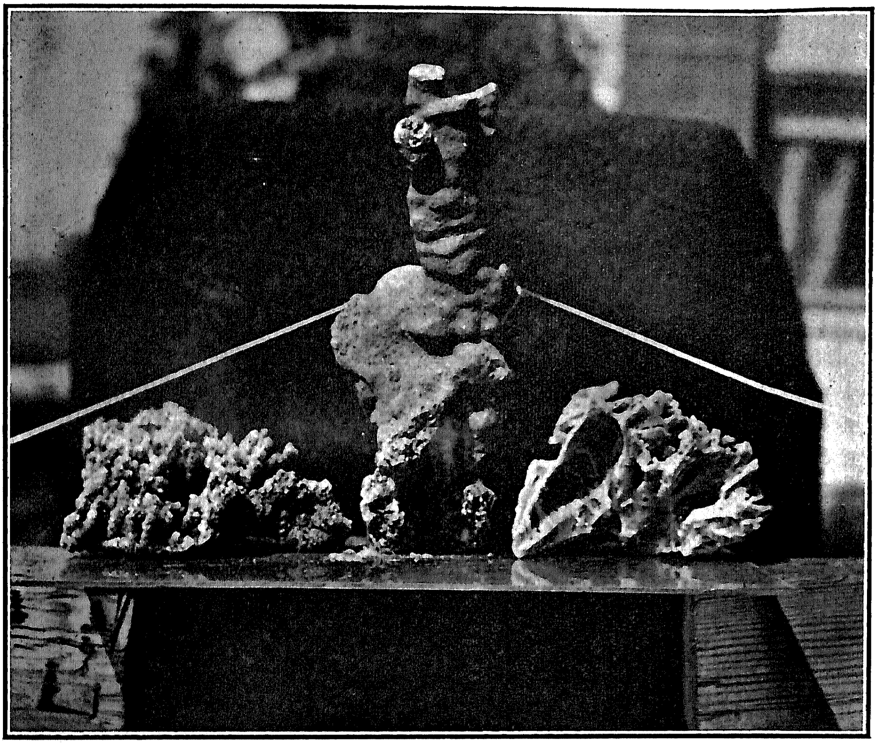
In this area it occurs chiefly as a pseudomorph after marcasite and pyrite. A large quantity of ferric iron occurs in the tallow clay, giving it a deep, reddish brown color. It has no commercial value.

*Hematite* ($Fe_2O_3$). Iron sesquioxide. Crystallizes in the Rhombohedral system. It is frequently twinned and has an uneven fracture. It has a metallic or sometimes dull earthy lustre. Its color is dark steel gray or iron black and when earthy it is red. Hardness=5.10-6.5; specific gravity=4.9-5.3. When pure it contains 70% of iron and 30% of oxygen.

In this area it occurs chiefly as an alteration product of pyrite and marcasite, and with limonite it imparts to the tallow clay a reddish to reddish brown color. In this area it has no commercial value.

*Pyrolusite* ($MnO_2$). Manganese dioxide. Crystallizes in the orthorhombic system. It is usually soft and has a metallic lustre. The color is iron black, sometimes bluish. Hardness=2-2.5; specific gravity =4.82.

In this area it occurs occasionally in small, black, mucky looking spots usually associated with tallow or soft clay. It does not occur in sufficient quantity to be of commercial value.



STALACTITE OF CARBONATE OF LEAD IN MIDDLE, WITH STALACTITES OF CALAMINE ON BOTH SIDES.

(Specimens in John T. Kingston's collection.)

## NON-METALLIC MINERALS.

*Dolomite* ($CaCO_3 . MgCO_3$). Carbonate of calcium and magnesium, commonly known to the miners as spar. It crystallizes in the rhombohedral system. It is commonly twinned and has a perfect cleavage. The lustre is vitreous and the color may be white, reddish, green, brown, gray or black. It is transparent to translucent. Hardness=3.5-4; specific gravity=2.8-2.9. When pure it contains 47.8% of carbon dioxide, 30.4% of CaO, and 21.7% MgO.

In this area it occurs intimately associated with the metallic minerals. Crystals are frequently saddle-shaped and generally have curved faces. It usually has either a white or pink color and is accordingly known either as "white spar" or "pink spar." Everywhere in this area it is thought to be a secondary mineral, being one of the principal gangue minerals in the ore bodies.

A gray dolomite rock, having the texture and appearance of fine grained compact limestone, occurs in beds in many of the mines. This will be discussed under the head of rocks.

*Calcite* ($CaCO_3$). Calcium carbonate, known to the miners as "tiff." Crystallizes in the rhombohedral system. Twinning is common. This mineral has a highly perfect cleavage, on account of which it breaks into small rhombs. The lustre is vitreous to earthy. The color varies from white through various shades of gray, red, green, blue, brown, yellow and black. Hardness=3; specific gravity=2.713-2.723. When pure it contains 44% of carbon dioxide and 56% of calcium oxide.

In this area calcite occurs abundantly, there being many rare and beautiful forms. Individuals 10 to 12 inches in diameter are not uncommon, and in some localities the surface coloring is very beautiful. One of the common colors is a light reddish brown caused by a thin coating of iron oxide on the surface.

The Mississippian formation, in which the ores chiefly occur, consists mainly of limestone having 95 to 98% calcium carbonate. The calcite crystals are secondary, while the calcite of which the limestone is composed, is chiefly primary.

*Aragonite* ($CaCO_3$). Calcium Carbonate. This mineral, although having the same chemical composition as calcite, crystallizes in the orthorhombic system. It is commonly twinned and has a distinct cleavage. It occurs either crystallized or in massive or fibrous forms. The color is usually white, gray or yellow and the lustre is vitreous. It is transparent to translucent. The hardness is 3.5-4 and the specific gravity 2.93-2.95. When pure it contains 44% of carbon dioxide and 56% of calcium oxide.

This mineral was observed in two localities in this area. In both cases it occurs in gray acicular crystals covering the exterior of limestone boulders in the conglomerate at the base of the Pennsylvanian shales. It was not found in any of the mines.

*Quartz* ($SiO_2$). Silicon dioxide. Crystallizes in the rhombohedral system. It is frequently twinned, but the cleavage is very imperfect, usually wanting. It is transparent to opaque and has a splendent to nearly dull lustre. Hardness=7; specific gravity=2.653-2.654. When pure it contains 53.3 of oxygen and 46.7 of silicon.

In this area crystals of quartz are occasionally found lining small cavities. However, they are not abundant and not especially characteristic. In the Goldenrod mine near Webb City beautiful crystals of quartz have been found coating the blende.

The sandstone belonging to the Pennsylvanian and the chert or flint belonging to the Burlington are composed almost wholly of silica. These will be discussed under the head of rocks.

*Pseudomorphs.*—Many beautiful pseudomorphs have been found in this area. They are especially abundant in the shallow mines and for that reason were met more frequently during the early history of the camp than at present. Among the more important are smithsonite and calamine after calcite; calamine and smithsonite after sphalerite; cerussite after galena; leadhillite after calcite; and limonite after marcasite. Superintendent John Kingston of the Granby Mining and Smelting Company has in his collection many beautiful pseudomorphs illustrating all these various types. Some of these are shown in the accompanying illustrations.

### ROCKS AND RESIDUAL MATERIALS.

The rocks of this area all belong to the sedimentary series, having been formed entirely by chemical or mechanical precipitation from water. Covering the entire area, there is a mantle of soil, clay, gravel and broken flint resulting from the disintegration of limestone, sandstone and shale.

*Soil.*—The surface of this area is usually covered with a thickness of from several inches to two feet of soil depending upon the location of the land. In the river bottoms the soil is in places eighteen inches to two feet in thickness, while on the upland or prairie the thickness seldom exceeds ten or twelve inches.

*Sub-Soil.*—Underneath the surface soil there is a varying thickness of mixed clay and flint constituting the sub-soil. This may be only a few feet in thickness or it may extend to a depth of from 60 to 75 feet. The clay has a red to reddish brown color and is very soft and sticky. It is very fine grained, forming when dry an almost impalpable powder. It is so fine that when mixed with water it flows through cracks and crevices in the rock to a depth of over 200 feet. The "tallow clay," which occurs so abundantly in the shallow mines, is thought to have been derived from these residual deposits near the surface.

*Gravel.*—Along all the streams tributary to Shoal creek there is considerable gravel, deposited chiefly during the times of heavy freshets. It consists chiefly of flint or chert removed from the neighboring hillside. Very seldom does one find any fragments of limestone in the gravel banks along the streams. Occasionally there is a fragment of sandstone, probably derived from the isolated outcrops of sandstone.

*Clay.*—The broken flint resulting from the decomposition of the limestone is usually embedded in a matrix of reddish brown clay. There is an ordinary surface clay everywhere over this area, and another variety, known to the miners as tallow clay, which occurs chiefly associated with the lead and zinc ores in the mines. The tallow clay has an exceedingly fine grain and is extremely plastic. Its shrinkage upon drying is very great, causing it to break up into small somewhat irregular cubical pieces. This clay frequently contains from 20 to 30% of calamine. The calamine and clay are in such extremely fine particles as to render a mechanical separation impracticable. For this reason the zinc is not being recovered at present.

The tallow clay is evidently the last material to enter the openings in which the lead and zinc minerals have formed. In the Blue Jacket No. 2 a medium sized opening was observed partly filled with chocolate colored tallow clay. Covering this there was a soft red clay, in which were embedded small pieces of the chocolate colored clay, forming a conglomerate mass. This clay occurs not only in the interspaces between boulders of flint, but also between the flint layers.

It is thought that this clay has been derived chiefly from the Pennsylvanian or Coal Measure shales, of which only remnants remain in this area. It may have been derived in part from the Mississipian limestone, but the purity of the limestone argues against the possibility of a very large quantity of the clay having resulted from its decomposition. The red color indicates that it was deposited under oxidizing conditions. A sample of this clay collected at random from the dump of the Dirty Seven mine and analyzed in the Bureau gave 23.68 per cent ZnO.

In 1890 Professor W. H. Seaman made the following analyses of this clay, each of which shows a high content of zinc:*

No. 1 The bright yellow clay from New Butler Shaft.
No. 2 The light brown clay from New Coon Shaft.
No. 3 The brown clay from New Butler Shaft.
2 Bbls. No. 1. No. 4 White streak in large lump from Leathers & Cockrums Shaft.
No. 5 Brown streak in large lump from Leathers & Cockrums Shaft.
No. 6 Pale Red streak in large lump from Leathers & Cockrums Shaft.
No. 7 Another red streak in large lump from Leathers & Cockrums Shaft.
1 Bbl. No. 2. No. 8 Dark Brown clay from Cockrum's Shaft.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Silica | 35.07 | 37.60 | 38.43 | 34.37 | 40.36 | 42.08 | 44.07 | 36.00 |
| Zinc Oxide | 34.83 | 39.53 | 38.23 | 37.12 | 32.50 | 32.24 | 29.94 | 41.47 |
| Alumina and Iron Oxide | 14.26 | 9.40 | 8.67 | 10.43 | 10.42 | 9.64 | 9.64 | 7.11 |
| Loss on ignition | 16.83 | 12.66 | 15.40 | 17.98 | 16.74 | 16.11 | 16.11 | 14.71 |
| | 100.99 | 99.19 | 100.73 | 99.90 | 100.02 | 100.07 | 99.76 | 99.29 |

The following is an analysis of tallow clay made in 1905 by Mr. E. J. Jones, chemist of the Granby Mining and Smelting Company:*

| | |
|---|---|
| Zinc Oxide | 9.02% |
| Ferric Oxide | 5.37% |
| Alumina | 29.33% |
| Silica | 42.20% |
| Calcium Carbonate | .83% |
| Loss on ignition | 13.30% |
| Lead | Trace. |
| Total | 100.05% |

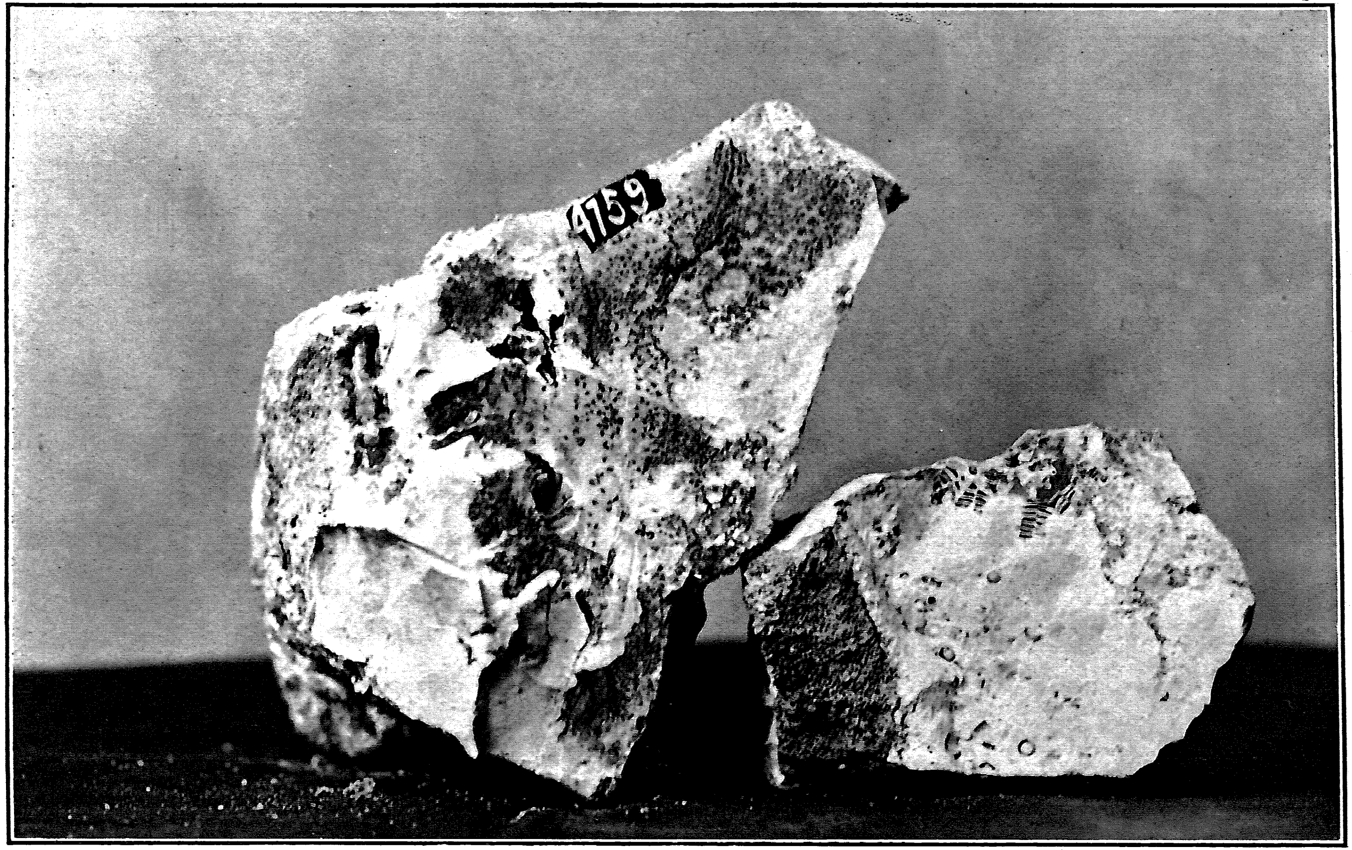
*Flint or Chert.**—This is by far the most common rock found at the surface throughout this area. Some of the hillsides are strewn with a mantle of broken chert, which extends to an unknown depth beneath. (See Plate XI.) Wherever the slopes are steep, the soil and clay are largely removed, exposing great quantities of angular chert fragments, of all sizes up to those weighing several hundred pounds.

As explained in a preceding Chapter, three generations of chert have been recognized in this area—a white non-fossiliferous variety, which is to a large extent original; a light gray or bluish fossiliferous variety, sometimes forming a periphery about the original flint; and a much darker colored, sometimes black variety, filling the interspaces between the white chert fragments, in the solution breccias, as illustrated in Plate VIII.

The two first named varieties occur together in heavy beds, forming in places the wall rock and the openings in which the ore is found;

*These analyses were furnished us by Mr. Elias S. Gatch, Secretary of the Granby Mining and Smelting Company.

*These names are used synonymously in this report.



CASTS OF CRINOIDS IN FLINT, CONTAINING ROSETTES OF CALAMINE.

as a breccia within the openings; and as lenses and beds of varying thickness within the limestone. These cherts have a white to bluish white color and are vitreous, hard and brittle when fresh, and often chalky or porous when decomposed. The second variety often contains casts of fossils, as shown in Fig. XX, and where partial decomposition has taken place it forms a light porous mass known as "chalky flint." Elsewhere, this decomposed flint is known as tripoli. In places where chert beds occur near the surface and solution has been active, they are often completely decomposed. Such beds are known to the miners as "cotton rock." The color of the chalky flint is either white or red, depending upon the amount of iron oxide present. Wherever flint of this character occurs in the openings, it is considered by the miners a very good indication of ore. Although the lead and zinc minerals fill the spaces and openings around this flint, they are not found within the flint, it being of earlier origin.

The third variety of chert, which is the youngest, is usually fine grained and usually has a dark gray to almost black color. Blende is usually disseminated through it, and everywhere it is closely associated with the earliest concentration of the ore. As pointed out elsewhere, the color of this chert is due to carbonaceous or organic matter, which was probably brought in simultaneously with the silica, which makes up the major portion of the chert.

That the black color is due to organic matter is shown by the following analysis of the black flint made by L. G. Eakins of the U. S. G. S.:*

| | |
|---|---|
| $SiO_2$- | 95.26 |
| $Al_2O_3$- | 0.57 |
| $Fe_2O_3$- | None |
| Fe O- | 0.69 |
| MnO- | None |
| MgO- | 0.05 |
| CaO- | 0.25 |
| Water- | —— |
| Organic matter-Large | |

Tests made in the Bureau laboratory also show that the black color is chiefly due to carbonaceous matter.

Wherever oxidizing solutions have acted upon this chert, the organic matter has been removed and the color changed to a gray or light brown. These same oxidizing conditions have usually re-

*"The Lead and Zinc Deposits of the Ozark Region," by H. Foster Bain, 1902, p. 121.

sulted in the solution and removal of the blende, leaving the flint as a gray vesicular mass, commonly known to the miners as "cod rock" or "gray sand." Plate XXI is an excellent illustration of the alteration of the black flint to the so-called "cod rock."

*Limestone.*—The Mississippian formation which immediately underlies a greater portion of this area, consists chiefly of limestone, interbedded with flint, and containing nodules or lenses of flint. This limestone is coarsely crystalline and usually contains myriads of fossils, chiefly crinoids. The abundance of the crinoids in this limestone is beautifully illustrated in Plate VI. These fossils are best exhibited on the weathered surface.

This limestone is very pure, often containing 98 to 99% calcium carbonate. In this area the weathering of the limestone is accomplished almost entirely by solution. Seldom, except where Shoal creek impinges against the bluffs on either side, is the limestone actively disintegrated.

In mining, the limestone is seldom encountered except as boulders or perhaps along one side of an opening in which the ore occurs. The ore is never attached to or embedded in the limestone. The ore body may go over or around the limestone, showing that it has in a measure directed the flow of the solution, but it never goes into it.

*Dolomite.*—As a rock, dolomite is not abundant in this area. Beds of fine grained, gray dolomite, having much the appearance of limestone, were observed in Blue Jacket No. 2, in the Cuba shaft and upon the dumps of the Sunset ground. These beds are thought to be dolomitized limestone and of secondary origin.

*Sandstone.*—In this area the sandstone consists chiefly of rounded grains of quartz. The grains are of medium size and well cemented, in some places forming a quartzite. It occurs in thin beds, and in a number of places has been quarried to furnish stone for buildings and foundations. It is found in isolated areas, which are remnants of the Pennsylvanian strata. The beds usually contain an abundance of fossils.

*Shale.*—Small areas of bluish black, carbonaceous shale occur at different localities over this area. The shale is usually soft and breaks down readily when exposed to the atmosphere. It is thinly bedded and usually contains considerable pyrite and some blende. These areas are fully discussed in the chapter on Geology.

*Bitumen.*—In some of the mines there are found small cavities filled with a black muck, most of which is thought to be of a bituminous nature. They present conditions favorable for reduction, but no re-

SPECIMENS OF FLINT "BRECCIA."

The specimen on the right contains crystals of zinc blende. In the one on the left the blende has been chiefly leached out, leaving small cavities. Some of the blende has been altered to calamine. The veinlet in right-hand specimen is chiefly calamine.

lation has been made out between them and the deposition of the ores. A viscous black tar occurs in many of the mines in the Joplin area, but it was not observed in any of the mines of this area.

*Conglomerate.*—At the base of the sandstone and shale members of the Pennsylvanian, there is a conglomerate. Everywhere the fragments are chiefly chert. Occasionally they are well rounded, but usually they are angular. At the base of the shale the matrix is shale and at the base of the sandstone the matrix is sand. The shape of the fragments composing these conglomerates has led some to speak of them incorrectly as fault breccias. These conglomerates are discussed more at length in the chapter on Geology.

## THE ASSOCIATION OF MINERALS.

The association of the different minerals of this district was studied in detail by Schmidt in 1873. At that time only the shallow mines were being operated, and for this reason the relations existing between the minerals and rocks at any considerable depth below the level of ground-water could not be determined. The observations made at that time are especially valuable, because very few of the mines at this time are working at a depth of less than 75 feet below the early workings. The paragenesis of the minerals is well shown by their association.

*Sphalerite or Blende.*—The association of the blende in this area with two distinctly different gangues shows that it was not all deposited under the same conditions, and probably not during the same period.

The earlier generation of blende occurs in part disseminated through the black flint and is well illustrated in most of the mines. In the shallow mines, in which calamine is the predominant mineral, blende often occurs in small quantities. Wherever present, it is disseminated through black flint, in which white flint fragments are embedded, forming a so-called breccia. The blende occurs with crystalline form embedded in the fine grained flint, and was undoubtedly deposited contemporaneously. In places this matrix is largely black flint, while in others it is chiefly blende. Where oxidizing solutions have acted upon this blende-black flint matrix, the organic matter incorporated in the chert has been oxidized and the blende has been taken into solution and removed, leaving the porous vesicular "cod rock" which has been referred to above. In many places the flint breccia has been under oxidizing conditions a sufficient length of time not only to alter blende into calamine, but also to entirely oxidize the black flint. However, where, through natural conditions, the blende has been removed from the action of oxidizing solutions, it is still unaltered. The relations between the blende, calamine, black flint and white flint are well illustrated in the Breakup, Crab Apple, Blue Jacket No. 2 and We-tak-er mines. In the two first named, the transition from unaltered black flint and blende to completely altered cod rock containing calamine is well illustrated. The following sketch from the Breakup mine shows clearly the relations above described. (See Plate XXII.)

The later generation of blende mainly occurs associated with dolomite crystals or "spar." However, some of the blende occuring with the spar is probably contemporaneous with the black flint and blende. In the Blue Jacket No. 2, small nodules of blende occur embedded in pink spar. The regularity with which the blende is disseminated through the pink spar is strong evidence that the two were deposited contemporaneously from circulating ground waters. In the Ida M. mine resin colored crystals of blende occur associated with spar and shale. In this mine the spar and blende constitute the matrix in which are embedded white flint boulders forming a breccia. The shale, which occurs in small quantities, has a dark bluish color and has evidently furnished in part, at least, the reducing agents. The materials are all so intermingled that contemporaneous deposition is evident, although in places crystals of dolomite occur alone, lining cavities in such a manner as leads one to suppose that the deposition continued later than the blende.

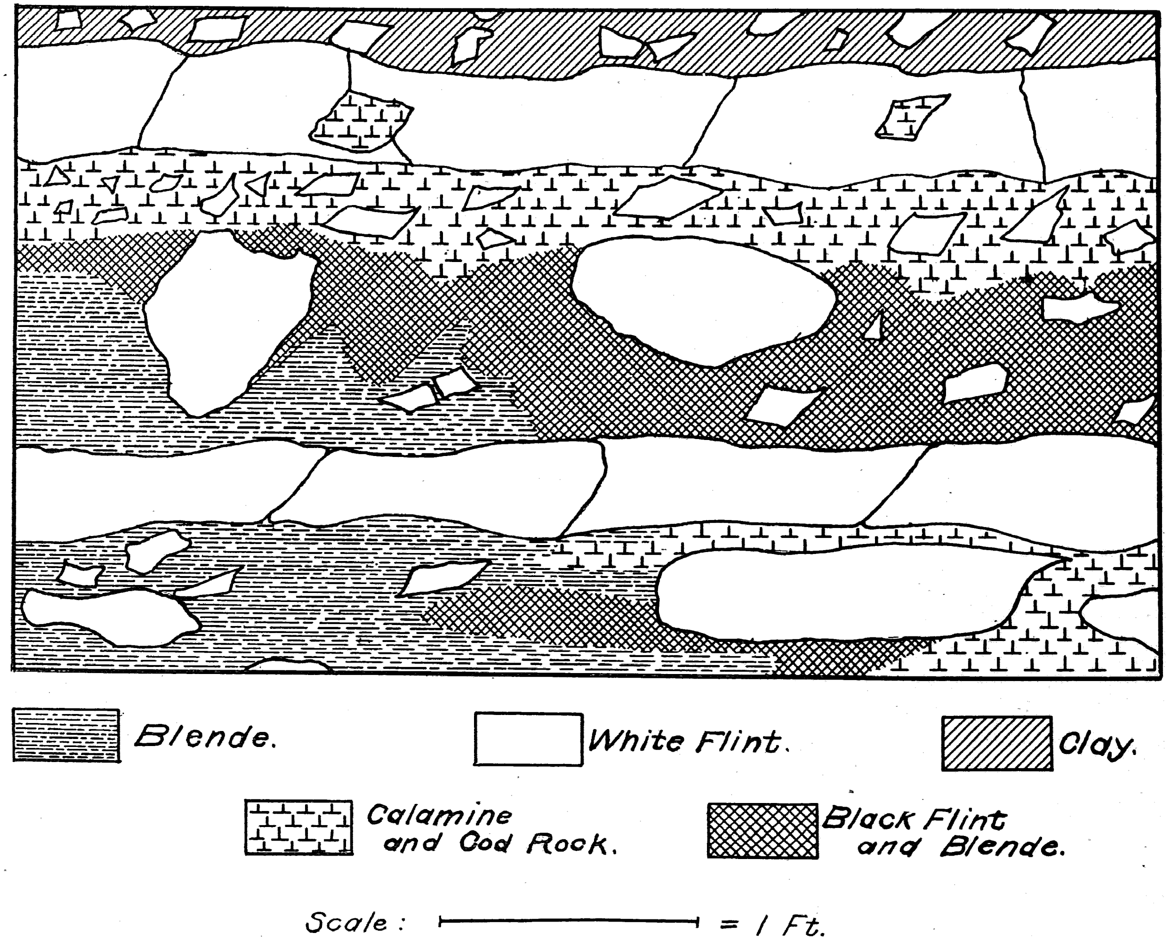
In other mines, as the Willow Tree and Sunset group, the blende occurs mainly in small crystals in the "gray spar," while the pink spar and calcite, which cement brecciated pieces of gray spar, show but little blende. The blende which is associated with the dolomites is thought to be mainly a later concentration than that disseminated in the black flint described above.

In the Homestake and Mascot mines some of the blende is associated with bluish flint, as shown by the rock on the dump. These mines were under water and could not be examined. It is probable, however, that the blende was in these cases deposited contemporaneously with the black flint.

A small quantity of "pebble jack" has been found in the shale pockets of this area. The crystals are low conical forms showing partially rounded faces.

Wherever decomposition is taking place, the blende faces are very black, the color of the interior remaining unchanged.

*Calamine.*—This mineral often occurs in large irregular masses en-




MANNER OF OCCURRENCE OF THE ORES IN THE BREAKUP MINE.

WHITE FLINT AND CALAMINE.
The light colored portions are flint and the darker colored areas, having a hackly appearance, are calamine.

closing small pieces of white flint and clay. (See Plate XXIII.) In a number of the old mines deposits of calamine over five feet in thickness have been reported. Where the black flint and blende have been subjected to the influence of oxidizing solutions, the resultant cod rock is often highly impregnated with calamine. This mineral often fills the cavities left by the removal of the blende. So constant is the association of calamine with the so-called cod rock that it is often followed where the ore becomes very thin until the calamine comes in again. The relations existing between the calamine, black flint and blende are well illustrated in Plate XXI. Calamine is often found cementing fragments of the original white chert, filling the minutest cracks and crevices in the breccia. It has also been observed covering large boulders and it frequently occurs between the layers of white flint. Pink spar and calamine are often associated, and either may be prior in deposition. Specimens have been obtained in which the calamine is surrounded by spar. In this case the calamine may have been deposited prior to the spar. Small veinlets of calamine also occur in the pink spar. These are undoubtedly later than the spar. This later deposition is also shown in many of the mines where the calamine occurs in cavities or thin tabular crystals studding the surface of the spar.

In the Blue Jacket No. 2, the calamine has replaced much of the original blende which was associated with the spar. As a result of the oxidation of the blende, it often becomes covered with a layer of calamine.

Thin layers of calamine, containing a considerable percentage of smithsonite, occur between layers of tallow clay in several of the mines. It has also been observed coating crystals of calcite in the clay. The oxidizing conditions, under which calamine naturally forms, brings it into intimate relationship with the clay found in the so-called "openings." The massive calamine, or "chunk" ore, often contains cavities filled with clay. A hand specimen obtained from the Sunny South mine shows an irregular surface of calamine covered with a thin layer of clay and this in turn covered with another layer of calamine.

Crystals of galena are often found embedded in the crystals of calamine, which would argue contemporaneous deposition. Fine tabular crystals of calamine are also found attached to the surface of galena crystals.

The secondary nature of the calamine is shown wherever it occurs. In some instances it has been deposited contemporaneously with the other secondary minerals, but elsewhere it is later than all the minerals with which it is associated.

*Galena.*—The galena is largely associated with the clay and flint. It occurs in blocks or crystal aggregates up to twelve inches in thickness, lying loose in a layer of clay between flint beds. Blocks occurring in this position usually have rounded edges and sometimes etched faces. The galena also occurs attached to the roof of the opening, the crystals projecting into the soft clay underneath. These two common methods of occurrence are well illustrated in the Tennessee mine. (See Plate XXIV.)

From the reports of the mining in the early days, it is evident that the galena near the surface occurred, chiefly, in large pockets. Blocks are reported to have been found which were two feet in thickness lying free in the clay.

Galena also occurs in thin seams along the bedding planes and filling small fissures in the flint. Crystals of galena associated with both pink and gray spar and blende are of common occurrence. The manner in which these crystals are associated with the spar would lead one to believe that they were deposited contemporaneously.

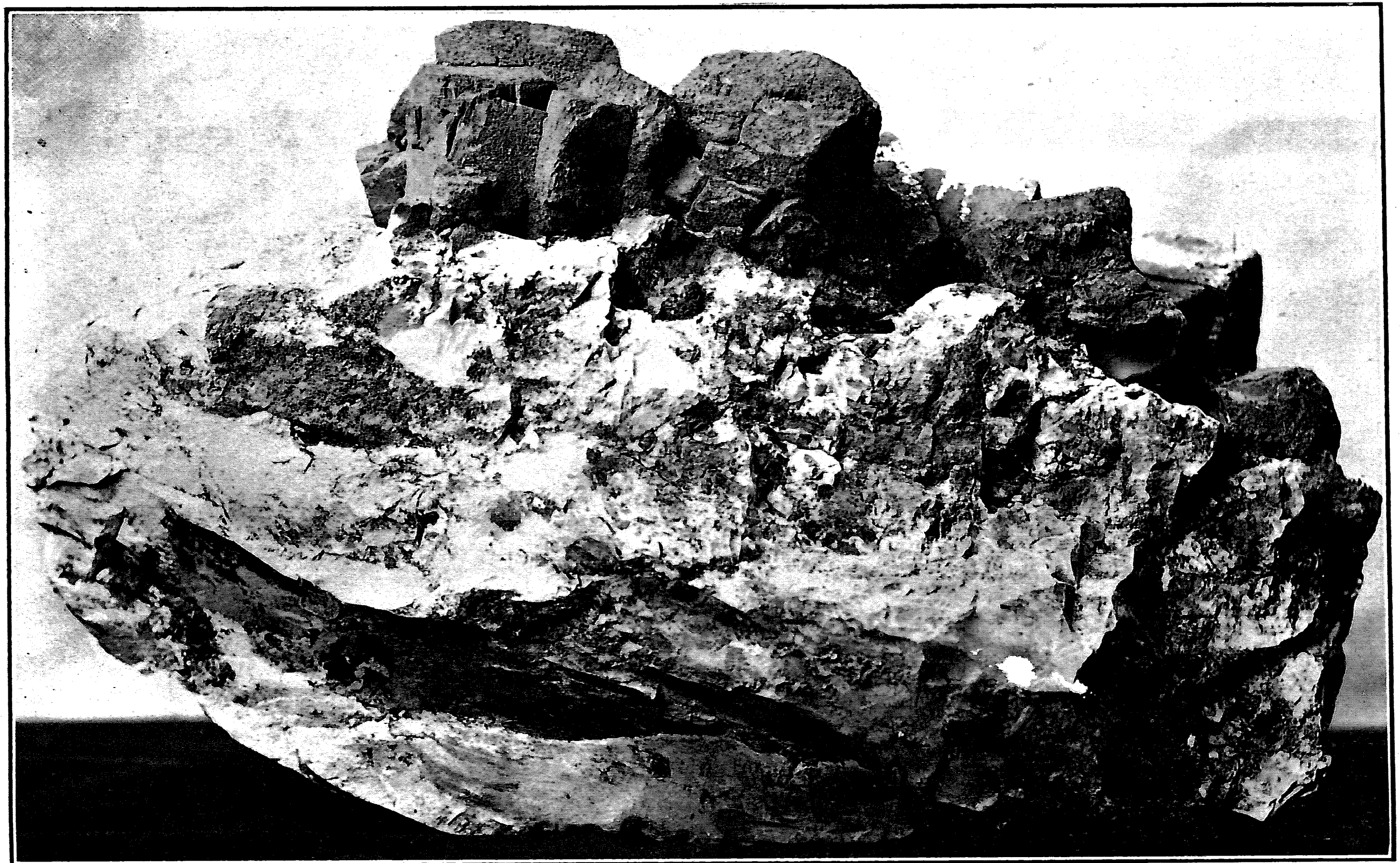
Wherever the galena has been subjected to oxidation, it is covered with a thin coating of cerussite or small crystals of anglesite.

*Calcite.*—Calcite is found everywhere associated with the metallic minerals deposited later than the early concentration of the blende. The deposition, solution and redeposition of calcite has apparently been going on since the ore bodies of this area were first deposited. The only place where it is seldom found is in association with the black flint and blende.

*Miscellaneous Minerals.*—Smithsonite, according to Schmidt, was found in some of the mines in beds eighteen inches in thickness. At present it occurs chiefly as pseudomorphs after calcite, and associated with calamine in the tallow clay. No pure carbonate was recognized in any of the mines during the examination which was made in the preparation of this report.

Hydrozincite was observed in the North Star mine, where it occurs associated with calamine.

Greenockite is associated with blende in many of the mines. It occurs chiefly coating the surface with a thin, bright yellow layer.



CUBES OF GALENA ATTACHED TO FLINT. GALENA BADLY CORRODED.
Specimens taken from the roof of a drift in the Tennessee mine.

# CHAPTER VI.

## MANNER OF OCCURRENCE OF THE ORE BODIES.

The ore bodies of the Granby area, both in kind and manner of occurrence, are very similar to those in the Aurora area. In both areas the chief production of the mines in the early days was calamine and galena, while at present it is blende. Nowhere else in the Southwestern Missouri district have such extensive deposits of these minerals occurred.

Although the origin of the lead and zinc minerals in the Carthage, Joplin and Webb City areas probably have had the same origin as those at Granby, the position, shape and relation of the ore bodies to the country rock are different.

The relatively great length of the ore bodies compared to their breadth has given rise to the use of the term "run" among the miners. Thus, an ore body is commonly spoken of in this area as a "run." The different ore bodies which have been worked in the four most productive sections are shown on the map, Plate XXV.* All of the shafts shown on this map have been accurately located by transit survey. The outlines of the underground workings that have been surveyed are in solid lines. The abandoned underground workings that could be located, but not surveyed, are shown by the dotted lines. The information concerning the location and size of the abandoned drifts was obtained by going over the ground with those who had worked the various "runs." Knowing the shafts through which the "runs" have passed, and the directions in which the old drifts extended from these shafts, it is thought that the outlines as given on this map show very nearly the location and shape of the "runs." At least the "runs" are located with sufficient accuracy to give one an excellent idea of shape, extent and general relation of the ore bodies to one another.

With few exceptions the mines are located upon "runs." Isolated bodies of ore are seldom met with in this area. The length and breadth of the ore bodies that have been worked and connected, either in the upper or the lower levels, are well shown upon the map referred to. The prairie run or "circle," which is located mainly

*See map, page 120.

in the S. E. 1/4 of Sec. 12, is said to be cut, with the exception of about 400 feet south of the Will Pierce, from the Mascot near the center of the section, north, east and then south in a roughly circular direction to the Cheap Screw, near the center of the S. E. 1/4 of Sec. 12. As indicated by the abandoned shafts, the entire distance has been mined with the exception of a few hundred feet along the depression, 1/4 mile east of the center of the section, where it is said that the ore became too lean to work with profit. Southwest of the Cheap Screw to the Mascot the run has never been located, and probably does not extend in that direction, because the pre-Pennsylvanian drainage, as shown by the location of the sandstone west of these mines, was deflected at this point. The total length of this run is approximately 1 1/4 miles.

The Trent Hill-Graveyard run, which starts at the We-tak-er mine in the N. E. 1/4 of the S. E. 1/4 of Sec. 7, and ends with the abandoned Republic mine in the S. E. 1/4 of the S. E. 1/4 Sec. 1, follows a sinuous east and west course for approximately two miles. With the exception of three places—one just west of the Brigham, another west of the Breakup and a third east of the Tennessee—this run is said to have been cut together over the entire distance. At the west end of the run the ore became too poor to work. However, it is thought that, in this direction, it will probably connect with the irregular run in the W. 1/2 of the S. E. 1/4 of Sec. 1.

The runs of ore bodies occurring near and within the limits of the city of Granby, are from one-half to three-fourths of a mile long. Although smaller than the two previously described, they are in all other respects very similar.

The ore occurs from the surface (grass roots) down to a depth of 215 feet. However, the major part of the mining has been above 150 feet. The mining in the early days was practically limited to the superficial zone above the level of underground water. Schmidt, in 1873, described the mines as varying from 30 to 70 feet in depth. Oxen were used in hoisting, and barrels used for lifting the water. With the introduction of steam pumps and steam hoists, the mines were sunk deeper, encountering other ore bodies. Several of the mines are now operating at a depth of 200 feet.

The so-called openings in which the ore occurs are described in detail in another chapter. In each run there are usually several openings at different levels. The number of these openings in a run, which have been rich enough to work, varies from one to four, although two or three is the usual number.

In the Village diggings and in other old runs, in and about Granby, the mines were comparatively shallow, seldom continuing beyond a depth of from 35 to 100 feet. In the Trent Hill-Graveyard run the mines have been opened to a depth of 137 feet. The Gold Standard mine, west of the Tennessee, has a shaft 200 feet deep. The mines located on this run vary in depth from 78 feet at the Ruby Trust to 137 feet at the Breakup.

The deepest mines in the area are the Homestake and Mascot, both of which are located on the prairie. In these mines the ore occurs to a depth of 215 feet. The ore bodies which occur in the upper part of these mines are the southern extension of those which have been worked for a distance of half a mile north. At the Little Four mine, calamine was mined at a depth of five feet. This mine was worked for a number of years as an open cut. The mines which are now being worked along this run, vary in depth from 73 feet on the Jack Sprout-Trilby ground, to 100 feet at the Cheap Screw. Very few of the abandoned mines on this run have been worked to a greater depth than 100 feet.

The different openings in a run may vary in height from 2 to 40 feet. The ore body in the Blue Jacket mine has a depth of from 30 to 40 feet. In the Homestake it has been worked 50 feet in depth. In the runs from which calamine is obtained the openings average from 6 to 7 feet. The upper opening is usually the smallest, the size of the openings increasing with their depth from the surface. Wherever the roof of the mine exhibits a steep dip, the ore body may extend parallel to the roof for 40 feet, as in the Hickory and Beckham mines. The ore body, measured perpendicular to the roof, seldom exceeds 5 or 6 feet in thickness.

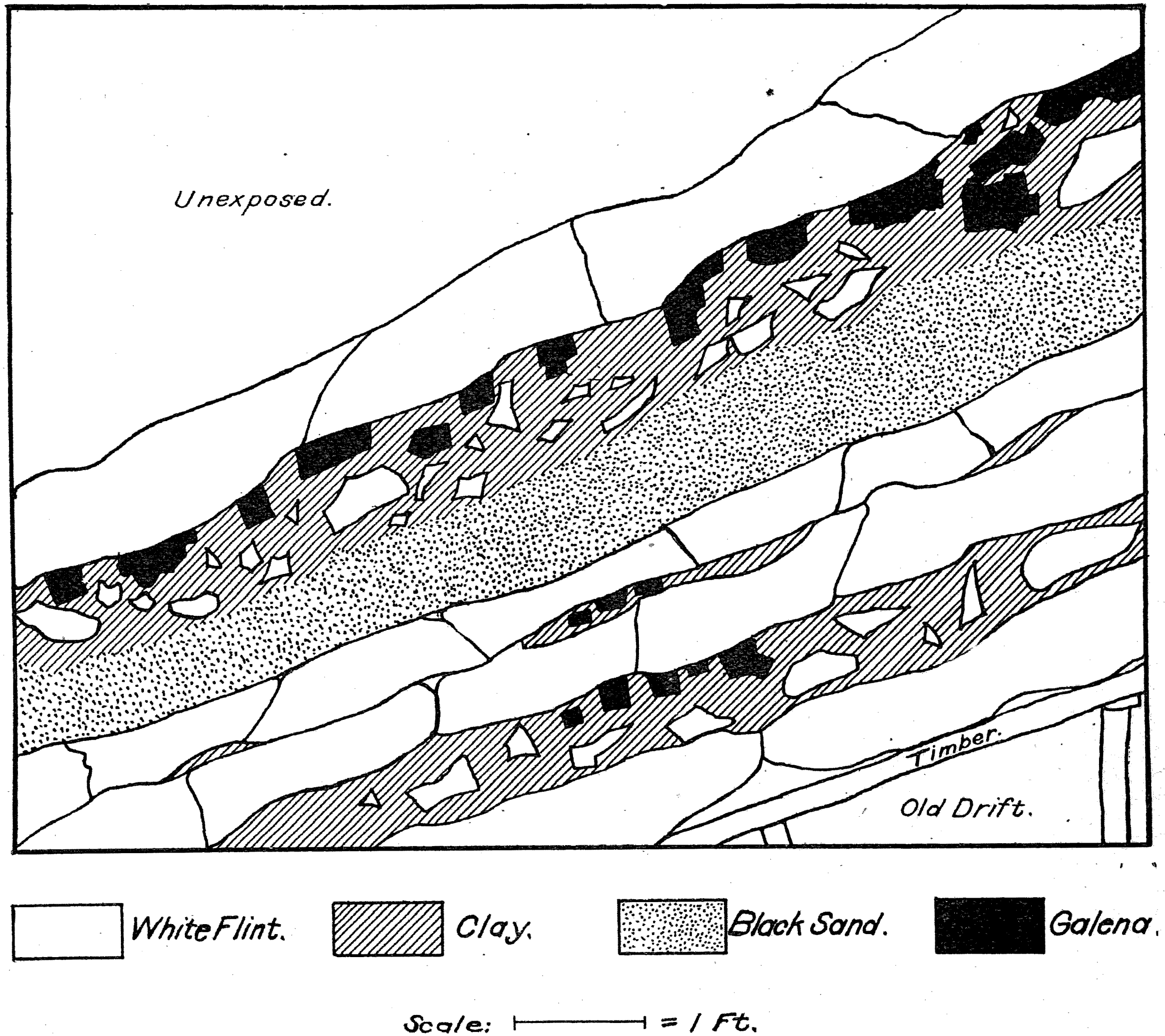
The several openings in a run occur either directly above one another or in a terrace-like succession, the lower openings being always located toward the valley with respect to those above. In the Prairie diggings, where the dip of the strata is comparatively gentle, the different openings occur above one another. As the pre-Pennsylvanian valleys are approached, the dip of the beds is steeper, and the openings occur along a plane dipping toward the valley. This is the relation which exists in the Trent Hill mines.

The different openings are usually separated by thick beds of flint varying from three to twenty feet in thickness. The vertical distance between successive openings is in the neighborhood of 10 feet. In the early days only the upper openings were worked. Later the shafts were sunk deeper and other openings were encountered.

At the Pineapple mine, just east of the Cheap Screw, an opening has recently been discovered 10 feet below what was formerly supposed to be the lowest ore body. It is possible for these openings to occur down to and also beneath the solid limestone. The breadth of the ore bodies is very narrow compared with their length, (see map, Plate XXV). Wherever the different openings occur in a terrace-like succession one above the other, the ore bearing zone may include an area having a breadth of from 500 to 800 feet. The individual openings, however, do not even approximate this width. In general, they do not exceed 150 feet and average from 10 to 15 feet. Where the beds are nearly horizontal, the ore body usually obtains greater breadth. For example, in the Prairie diggings, the ore bodies have had a breadth in some places of 150 feet. In the Trilby-Jack Sprout mines the ore body has been worked for about 550 feet north and south, and about 500 feet east and west, having a maximum width of from 50 to 75 feet. In the older runs located near or within the limits of the city of Granby and in the Trent Hill-Graveyard run, the individual openings seldom attain this width, the average being approximately 15 feet. In the last mentioned runs, the dip of the cap rock is greater than in the Prairie diggings.

Although the runs in general show slight undulations and vary in breadth and thickness in different places, the general nature of the ore bodies remains the same. Cross-sections of the same or different openings often vary greatly in outlines. A cross-section of the Trent Hill-Graveyard run shows a decided anticlinal structure in the Empress mine, and a synclinal structure in the Beckham mine. Throughout a greater part of the run, however, the cap rock is either horizontal or has a monoclinal dip which is often as much as 45°. This change in dip from the horizontal may occur within comparatively short distances, perhaps 30 feet. Cross-sections of the same run in adjacent mines shows similar variations from place to place.

The manner in which the lead and zinc minerals occur within the openings varies widely in different parts of the area, depending chiefly upon the nature of the opening. Where the opening consists of broken flint or boulders of flint forming a brecciated mass, the lead and zinc minerals occur in the interstices among the so-called cod rock, black flint, dolomite and other associated minerals. Where the rock within the opening is more or less stratified and where the flint nodules are still found intact within the opening, the ore is usually in sheets approximately parallel to the roof. Plate XXVI. illustrates this manner of occurrence of galena and calamine.




MANNER OF THE OCCURRENCE OF THE ORES IN THE RUBY TRUST MINE.

In this case the galena is attached to the roof, and the calamine forms a sheet parallel to the cap rock.

The north drift of the Illinois Zinc Co.'s mine exhibits a decided anticlinal structure in which the radius of the fold is about 10 feet. The ore occurs under the apex of this anticline, and its position is practically horizontal, as shown in Plate XXXII. In the mines of the Praire run the ore occurs parallel to the roof and the galena is often attached to the cap rock. The calamine occurs in layers of broken or brecçiated flint, which are separated by solid beds of flint, all dipping gently in the same direction.

### RELATION OF THE "RUNS" OR ORE BODIES TO THE TOPOGRAPHY.

As has been pointed out in a previous chapter, there have been important erosion intervals, the first between Mississippian and Pennsylvanian times, and the second since the Pennsylvanian. Before the Pennsylvanian rocks were laid down, a well defined system of drainage was established over this area. Since Pennsylvanian time, the rocks of that period have been practically all removed, and a new drainage system has been superimposed upon the earlier. There is a very close relation existing between the ancient and modern topography and the location of the ore bodies.

The openings in which the ore occurs were, to some extent at least, formed by solution during pre-Pennsylvanian time. After the deposition of the Pennsylvanian rocks, these openings constituted channels through which the ground waters circulated with the greatest freedom. As explained above, the present drainage is, in a general way, superimposed upon the pre-Pennsylvanian, and the ore bodies, in a large measure, occur along the hillside, where openings were first formed by the pre-Pennsylvanian weathering. The relation existing between the present topography and the ore bodies is best shown on the map, Plate XXV. From this map we may observe that the old shafts in the city of Granby are located chiefly along the hillsides. The Trent Hill-Graveyard run, which has been one of the most productive in the camp, starts at the We-tak-er mine, in the N. E. ¼ of the N. E. ¼ of Sec. 7, and follows closely the hillside as far west as the Breakup, where it crosses, in an irregular way, a small branch and passes into the prairie on the Empress ground.

All of the runs having a general east and west course, extend underneath the north and south valley just west of Granby.

The Prairie run, although the topography is very gentle, is located along the sides of an old valley. West and northeast of this run there is a gentle escarpment, showing the outline of a probable pre-Pennsylvanian river terrace. Other illustrations might be given, but it is a fact that all of the important mines in the Granby area show this relation to the topography. Workable deposits are seldom found at the crests of the hills, but generally occur along the hillsides or in the valleys.

### RELATION OF THE ORE BODIES TO THE PENNSYLVANIAN.

The close relationship which the Pennsylvanian sandstones and shales bear to the ore bodies is well shown in the location of most of the mines now being operated. The remnants of the Pennsylvanian sandstone and shale occupy chiefly the valley and sink hole depressions which were a part of the pre-Pennsylvanian topography. The relation between these early valleys and the ore deposits has been pointed out on the preceeding pages. Although geologists, who have previously studied this area, have attributed the discordant relations between the sandstone and shale and limestone to faulting, the present investigations show very clearly that these are due to unconformity. Practically, all the producing mines are located along the margin or in the vicinity of remnants of the Pennsylvanian shales and sandstones. These conditions are well illustrated by the Prairie diggings in Sec. 12. As previously pointed out, these diggings constitute the only approximately circular run of ore in the area. This follows roughly the margin of an area of sandstone and shale which occupies a pre-Pennsylvanian depression in the Mississippian limestone. Between the Cheap Screw and Mascot mines, there is an almost continuous body of sandstone occupying what is supposed to have been a pre-Pennsylvanian stream channel. Since the favorable position for the concentration of the ores has been along the margins of these old channels, the presumption is against these ore bodies being connected at this point. However, later changes have sometimes so altered conditions as to admit of the concentration of the ore even in such an apparently unfavorable place, making exceptions to the general rule.

The Trent Hill-Graveyard run also illustrates clearly this relationship. The Gold Dollar shaft, which is located just east of the We-tak-er mine, passed through from 30 to 40 feet of shale and conglomerate. Just north of the Mascot and west along the valley as far as the Breakup, there are numerous fragments of sandstone, indicating a continuation of the Pennsylvanian strata close to the run of ore. Near the Beckham, Hickory and Tennessee there are abandoned shafts which show at the surface as much as 18 feet of sandstone. South of the run there is no evidence either of sandstone or shale. South west of the Breakup mine a body of shale was passed through in an abandoned shaft. At the southwest corner of Sec. 6, just east of the J. K. mine, two abandoned shafts passed through shale. In the base ball park and just west of it, there is a body of sandstone of unknown area. Just north and south of this sandstone occur ore bodies of commercial size.

These relations, which are clearly shown on the map, Plate XXV. have been known to many of the miners, and, as a result, a great majority of the shafts have been located between outcrops of sandstone on one side and chert boulders on the other. This relationship is so persistent throughout this area that a detailed knowledge of the geology ought to increase very greatly the intelligence with which prospecting may be carried on.

# CHAPTER VII.

## DESCRIPTIONS OF INDIVIDUAL MINES.

During the spring of 1905, all the mines and prospects operating in the Granby area were examined. The Homestake and Mascot mines could not be examined as they were flooded during the entire year. These mines are the deepest in the area with upper ore bodies, at practically the same level as that portion of the prairie run to the north. The location and the position of their ore bodies make them very important mines for a study of the ore deposits.

The mines examined by Schmidt* in 1873, were comparatively shallow, seldom being more than 60 to 70 feet in depth. These early mines have been abandoned and reopened, in some cases, as many as three times. The gradual advance in the price of calamine has made ore which was worthless at the time the mine was first operated, valuable enough to pay for reworking abandoned diggings.

The first mines were worked almost exclusively for galena, heavy bodies of this mineral being found close to the surface. According to descriptions given by Schmidt, the same general relation existed between the galena and calamine in the shallow runs as exist in the deeper mines of today, viz.: galena above, and calamine underneath. Very little blende was associated with the calamine, it having been almost entirely oxidized in these shallow runs. Some galena and cerussite were found at very shallow depths in the village diggings. In the following pages are brief descriptions of a few of the mines, giving the depth, extent of workings and general characteristics of the ore body.

### BLUE JACKET.

The Peach Tree and shafts Nos. 1 and 2 of the Blue Jacket, located in the N. W. 1/4, N. W. 1/4, S. W. 1/4 Sec. 6, T. 25 N., R. 30 E., have been sunk upon the same ore body, which occurs at a depth of 120 feet.

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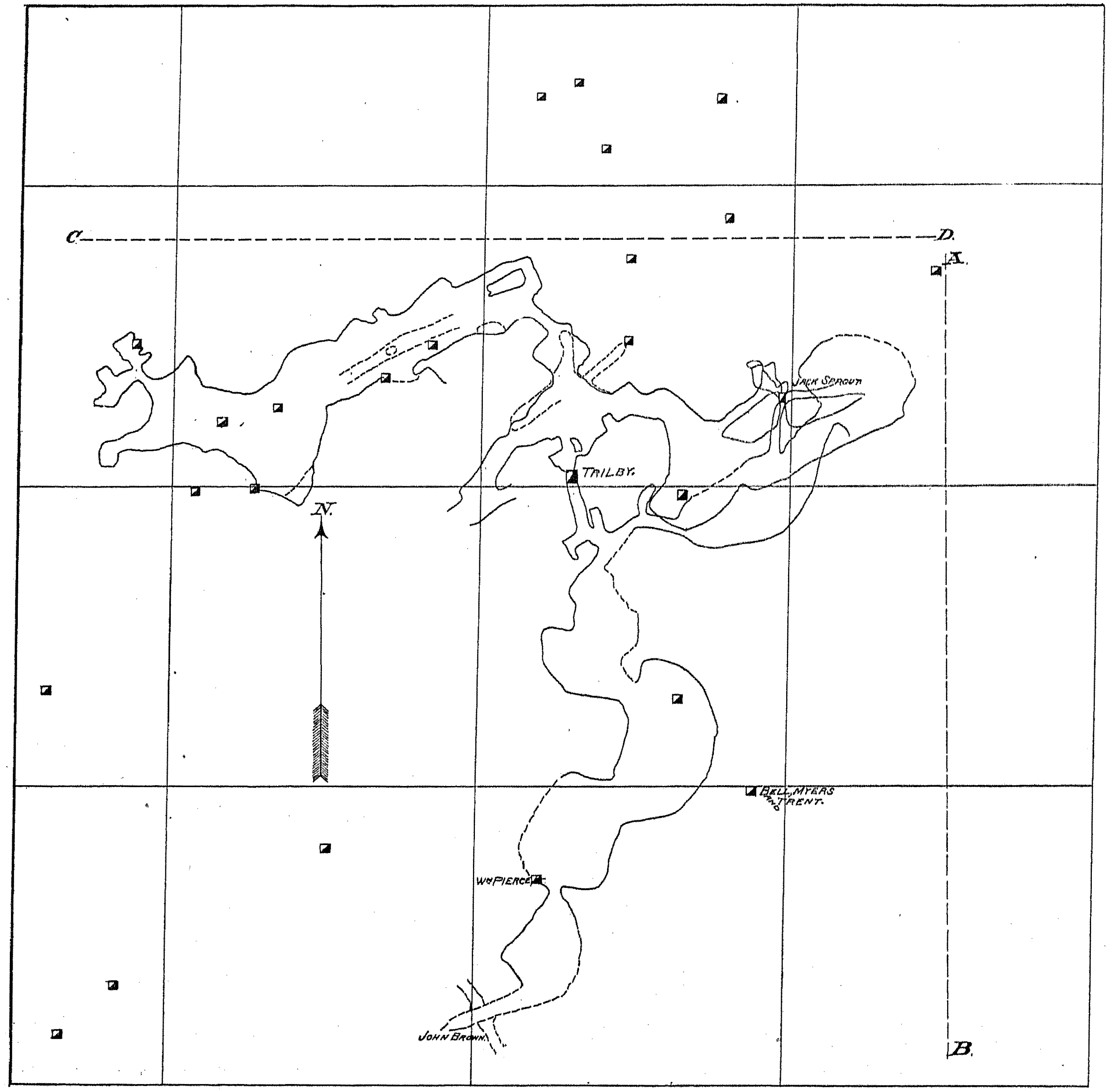
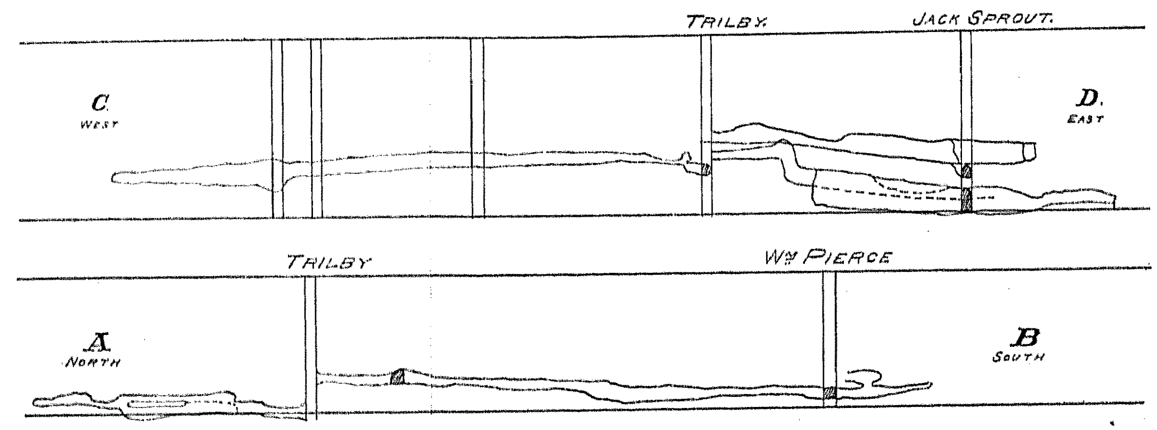
*"The Lead and Zinc Regions of Southwest Missouri," by Adolph Schmidt, Bureau of Geology and Mines, Vol. I, 1873-1874.



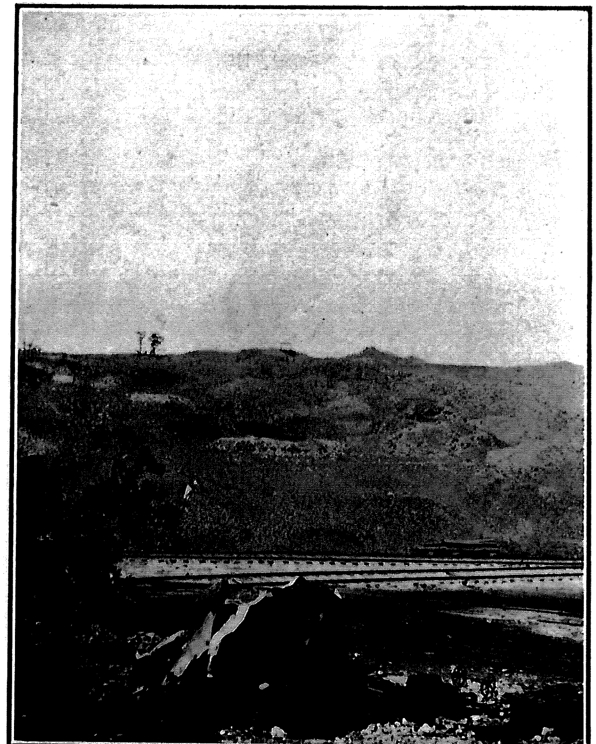

Underground Workings of the Trilby, Jack Sprout and Wm Pierce Mines.

Scale 50ft. 100ft.

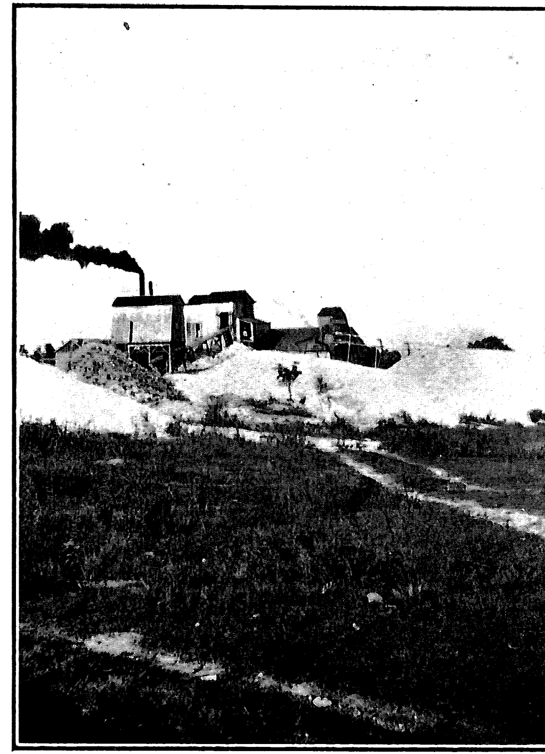



Cross Sections projected along lines A-B and C-D.

Vertical scale }
Horizontal scale } 1 inch = 100 ft.



Present appearance of the hillside south of the smelter, where formerly there were many rich shallow lead mines.



Blue Jacket, viewed from the south.

These mines have been worked for a number of years, and the drifts have a total length of about 525 feet, varying from 25 to 75 feet in width. In places the ore body had a height of 30 feet.

Gentle dips occur in the mine usually in the same direction as the surface contour. No faulting was noted. Jointing occurs throughout the mine. These joints have undoubtedly been instrumental in introducing and directing the flow of the ground waters, and consequently have influenced the location of the ore body. South of the Blue Jacket No. 2 an opening occurs, partly filled with clay, which is apparently of two kinds, the lower being hard and dark, while the upper is red and soft. A sharp line of demarcation separates the two. The opening is lined with massive calcite crystals.

The ore is almost exclusively blende and calamine, and occurs mainly between layers of white flint and around brecciated nodules. Brecciation is not very marked in portions of the mine, the flint beds being practically solid. The blende is associated with black flint and dolomitic spar, both occurring in the same parts of the mine. The spar and blende occur above the black flint. Secondary action has altered considerable of the blende to calamine. Transparent, tabular crystals of the latter mineral occur coating the surface of the dolomitic spar. Occasional galena crystals occur near the top of the ore body.

The ore from this mine, as well as from the Roosevelt, located just south of the Blue Jacket No. 1, is cleaned in the mill at the Blue Jacket No. 2.

### BREAK UP.

This mine, which is located in the S. W. ¼, N. E. ¼, S. W. ¼, Sec. 7, T. 25 N., R. 30 W., is working on what is known as the Graveyard run. The shaft passed through flint and clay to a depth of 137 feet, at which level the mine is now being operated. An upper opening, at a depth of 96 feet, was operated for some time, but has been abandoned.

The workings at the lower level have an irregular semi-circular outline. They are about 250 feet long and have a width of from 10 to 20 feet. At the east end of the mine, where work was being carried on in 1905, old abandoned workings were encountered in the upper part of the face. To the west the workings have not been connected with the others located on this run, but the trend of the ore body is such that it will undoubtedly connect with the abandoned workings to the northwest.

The ore and wall rock show various dips throughout the mine. At the east end the ore occurs between beds of white flint, which show a gentle syncline 20 or 30 feet in width. Near the west end the roof dips 20°-S. 20° E., good ore having been found at this point. Several small joints were observed in different parts of the workings, but they evidently have no special relation to the ore bodies. At the north side of the shaft, where the stope consists of white flint and clay, there is a fault of approximately six inches, which is due to the settling of a block between two joints. This fault is the result of solution of the limestone and has had no effect upon the ore body.

At the northwest end of the mine, the drift has been driven about 30 feet in open ground which contained no ore. This part of the drift consisted of boulders of white flint, which, as a result of settling, had fallen in a heterogeneous mass, the spaces between being filled with tallow clay.

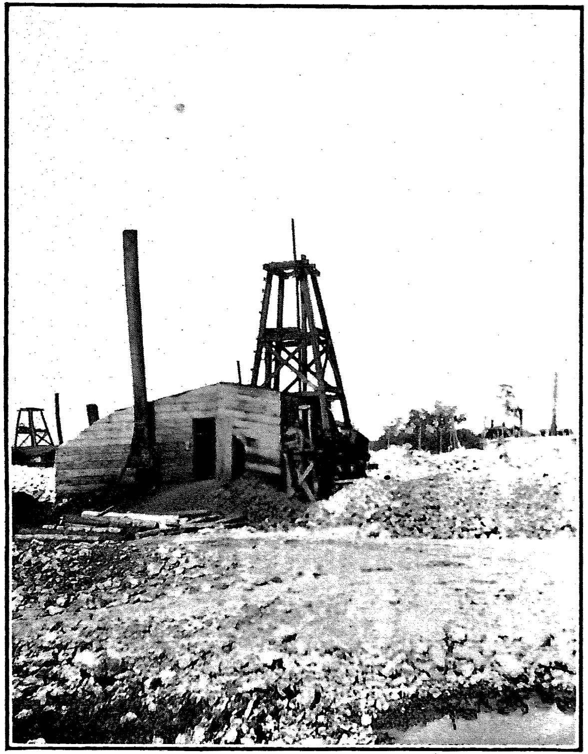
The comparatively large amount of water flowing downward through this portion of the stope, indicates the open character of the ground at this point. The amount of water pumped from the mine varies greatly with the rain fall.

Calamine is the principal product, although some blende occurs throughout the run. The face of the drift at the east end of the mine consists of layers of white flint, between which occur thin layers of calamine. Near the center of the face occurs a two-inch layer of blende with some black flint. Calamine occurs both above and below this blende. At the west [illegible] of the mine the white flint nodules and breccia are cemented with black flint and blende. The blende is often quite massive, while the calamine grades into gray cod rock, which, in turn, grades into unaltered black flint and blende. Transparent crystals of calamine occur in cavities in the white flint above the ore. The secondary nature of the calamine and the primary concentration of the black flint and blende are nicely exhibited at this place. Plate XXIX. is a sketch of this portion of the face.

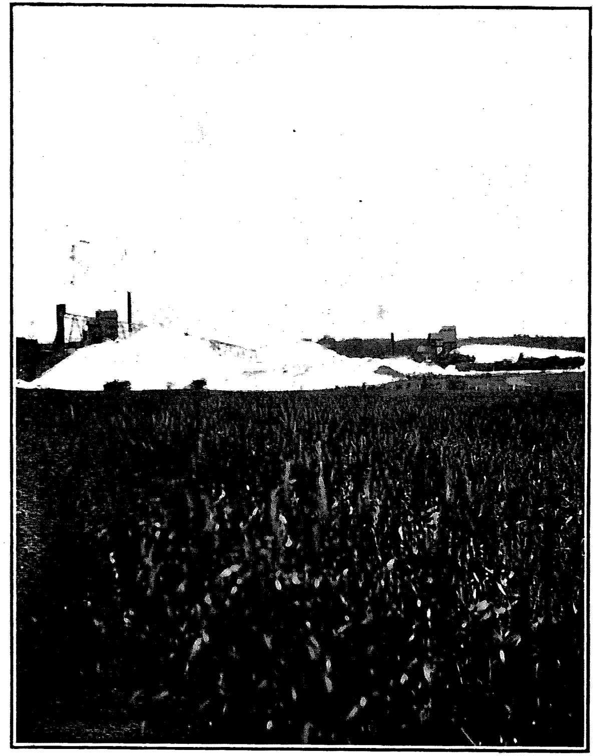
### CRAB APPLE.

This mine is located in the S. W. ¼, N. E. ¼, S. E. ¼ of Sec. 12, T. 25 N., R. 30 W. It is located west of the regular run of the prairie "circle," and the underground workings have not been connected with any other mine.

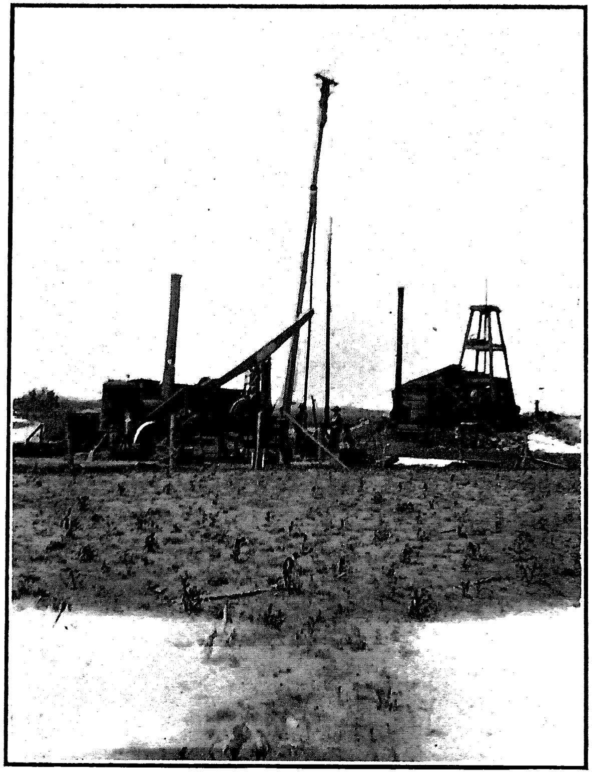
Pennsylvanian sandstone occurs just east of the mine and also in the main valley to the west. The three shafts sunk upon this ore body passed through layers of flint and clay. Pennsylvanian strata



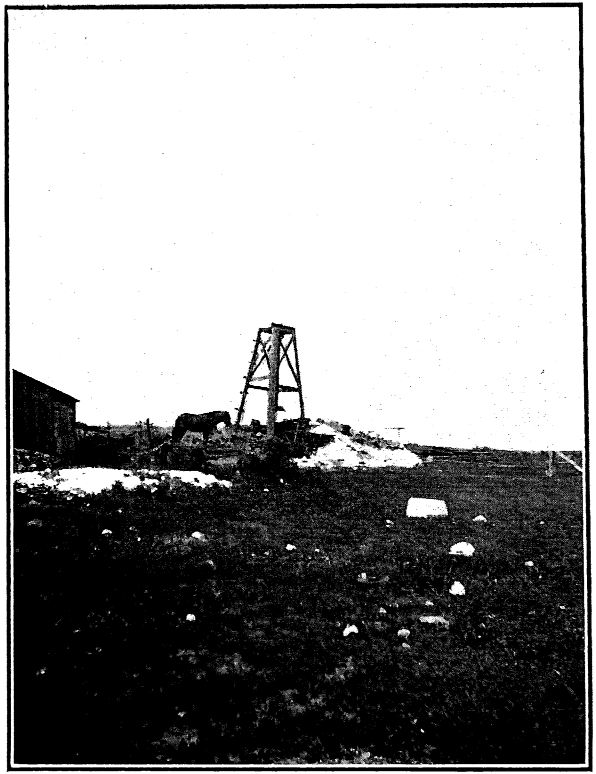
Break Up Mine, with Old Kruger to the right and Liederkranz to the left.



Mascot and Little Four Mines. Viewed from a distance.



CHURN DRILL NEAR THE REED MINE.



CRAB APPLE MINE SHOWING HORSE HOIST.

were not encountered. The hoisting shaft has a depth of 91.5 feet from the platform to the bottom of the opening.

The ore body has been worked in an irregular north and south direction for a distance of 400 feet. It has a maximum width of from 40 to 50 feet and the height of the opening varies from 6 to 15 feet. Only one level has been worked.

No faulting was observed. The flint roof has a gentle dip of 0° to 30° to the west, in which direction the principal pre-Carboniferous erosion channel occurs. These dips are apparently caused by solution removing the interbedded limestone. Towards the south end of the mine the roof shows a decided change in dip, having only a slight dip on the east side, and a 30° dip on the west. At the place where this change of dip occurs there is a joint striking N. 45° W., which has evidently been due to unequal settling of the superincumbent load. The joints occurring in the mine have an apparent general strike of N. and S. and N. 45° W. The roof is rough, irregular and undulating to some extent, especially in the north end.

The water in the mine apparently comes from the roof and sides of the drift and is undoubtedly a part of the descending circulation.

The ore occurs between layers of flint and also cements a white flint breccia, which has resulted from solution and settling. Limestone was encountered north of the shaft, and over it the calamine and cod rock extended for some distance. Red clay is abundant in the mine, especially north of the shaft, where a layer over two feet in thickness occurs underneath the roof. Tallow clay is abundant in different parts of the mine and is usually associated with the white flint boulders.

Calamine, which has been the principal product, occurs associated with dolomitic spar, clay and cod rock. Blende occurs associated with black flint, which cements the white flint breccia. Plate XXXI. illustrates the association of the silicate and blende with both black and white flint as they occur in the north end of the mine. The exterior portions of the black flint and blende have been oxidized to a gray, vesicular cod rock, and later the cavities have been filled, in part, with calamine.

The mine is equipped with a lift pump and steam hoist, one shaft being used for pumping and one for hoisting. The ore is hand picked and jigged in the manner described in a subsequent chapter.

### CUBA.

This mine, which is located on the Wyoming lease in the N. W. ¼, S. W. ¼, Sec. 6, T. 25 N., R. 30 W., has been worked for a distance of 100 feet northwest of the shaft.

The ore body occurs along a channel which follows the northeast wall of the mine. Rich blende and silicate ores occur along this course.

The flint beds have a decided dip to the east, which is toward the valley. The ore is developed between beds of white flint, although along the roof, near the northwest end, there occur beds and boulders of fine grained dolomite.

A well developed slickensided surface occurs along a face of heavily bedded flint in the northwest part of the drift. Above this bed there is no evidence of movement, the flint ledge above projecting beyond the plane of movement. This slickenside is undoubtedly due to differential movement between the individual flint beds, as a result of the solution of the limestone. There is no evidence of pronounced faulting along this plane.

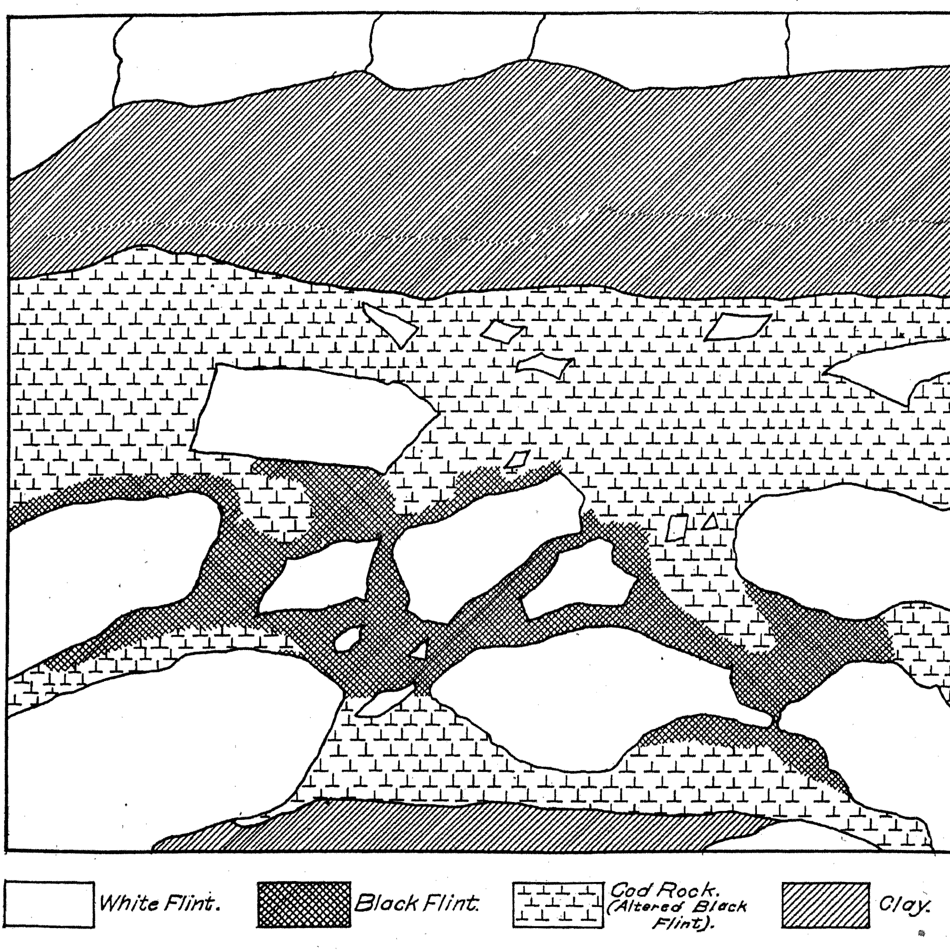
### FORTUNE TELLER AND EVENING STAR.

These mines are located upon the same opening along the east side of a small ravine, in the S. E. ¼, S. E. ¼, N. E. ¼, Sec. 6, T. 25 N., R. 30 W. Two openings have been worked on the Fortune Teller ground at depths of 60 and 86.5 feet. The upper opening is small. The lower opening is much larger and shows a decided dip to the west. This lower opening is being worked at the Evening Star mine, where the bottom of the ore body is at a depth of 68 feet. The mines are cut together on this level. The difference in depths shows the ore body to have a dip to the north of nearly 20 feet, between the two shafts.

The flint cap rock and the ore body underneath show a decided dip towards the valley to the west. The dip is often as high as 40° and the direction of the dip varies from N. 75° W. to S. 75° W. The upper drift in the Fortune Teller also shows a dip to the west and northwest. This opening is very small, the drift being from 4 to 6 feet high.

Both the roof and floor of this upper drift consist of spar and limestone, the intervening space being filled with dolomitic spar, in which the silicate and galena crystals occur. Calcite is also abundant. At the north end of the drift the ore is very thin.

In the lower drift, the west face consists largely of white flint




MANNER OF OCCURRENCE OF THE ORES IN THE CRAB APPLE MINE.

layers showing spar and clay. The east face consists of decomposing limestone boulders, which are the remains of former solid beds, and layers of white flint nodules, which make up a large portion of the face. These are surrounded with clay and some spar. Some silicate occurs in the clay and spar.

In the Evening Star the wall rock consists of white flint and clay and contains both calamine and blende. The upper portion of the working face at the south end of the mine consists of chalky flint and clay, beneath which occur calamine and blende. The blende all shows the evidence of decomposition and alteration to calamine. Just above the present drift old workings have been encountered, which were developed when lead was the principal ore sought.

### RUBY TRUST AND WETAKER.

These two mines are located on the same ore body in the N. E. ¼, N. E. ¼, N. E. ¼, Sec. 7, T. 25 N., R. 30 W., and are working the east end of the Trent Hill run. The ore body occurs at a depth of 77.5 feet in the Ruby Trust shaft and 88 feet at the Wetaker, and has a slight dip to the south. The roof along the west side of the drift in the Ruby Trust has a dip of 10 to 35° to the west and the ore lies approximately parallel to the roof.

Calamine, blende and galena are produced from these mines. The blende occurs in rather massive chunks with some black flint. The calamine and galena are both later or secondary deposits. The calamine is often associated with tallow clay and boulders of white flint.

The accompanying illustration, Plate XXVI., shows the occurrence of the galena in the upper part of the opening. The old drift, which shows near the base, was worked for calamine.

The galena crystals are mainly attached to the flint roof and project down into a layer of clay, containing broken pieces of white flint. Beneath this occurs an 18-inch layer of what is known locally as "black sand," which is in reality a bed of decomposed limestone, having a sandy appearance. Underneath the above occur flint beds with clay and galena, as shown in the illustration.

### GOLDEN RULE.

This prospect, which is located in the N. W. ¼, S. E. ¼, Sec. 12, T. 25 N., R. 30 W., is in a rich deposit of blende at a depth of 89 feet.

East of the shaft the Pennsylvanian sandstone outcrops at the surface, although it was not encountered in sinking the shaft. Between 25 and 65 feet the shaft passed through beds of fine grained dolomite, limestone and white flint. Beneath this a small opening was passed through. This was underlain with 5 feet of bedded white flint, underneath which occurs the ore body, which is being operated.

The mine has only been operated a few months. The drift, which has a general southwest direction, is approximately 50 feet long, 20 to 25 feet wide and has an average height of about 7 feet.

The flint roof has a slight dip to the east. Jointing or faulting were not observed anywhere in the mine. The breast contains nodules and flint layers somewhat brecciated as a result of the settling of the brittle flint beds, due to the solution of the limestone. The slight dip of the opening towards the main axis of drainage, both present and pre-Pennsylvanian, conforms to the general rule in this area.

At the bottom of the shaft, the opening showed a vertical face of 6 feet of nearly solid blende. The working face 50 feet from the shaft, when examined, was found to consist of 3 feet of soft spar, decomposed limestone and red clay, underneath which was a 3-foot bed of blende. The blende contains some white flint, but is relatively very pure. Along the surface, and especially along the edge of the deposit, at the sides of the stope, calamine is developed to some extent. Large crystals of calcite and dolomitic spar are very abundant along the edges of the deposit.

The ore is cleaned by hand at the mine and sold to the Granby Company. After it has been cleaned at the mill it is graded as No. 1 blende.

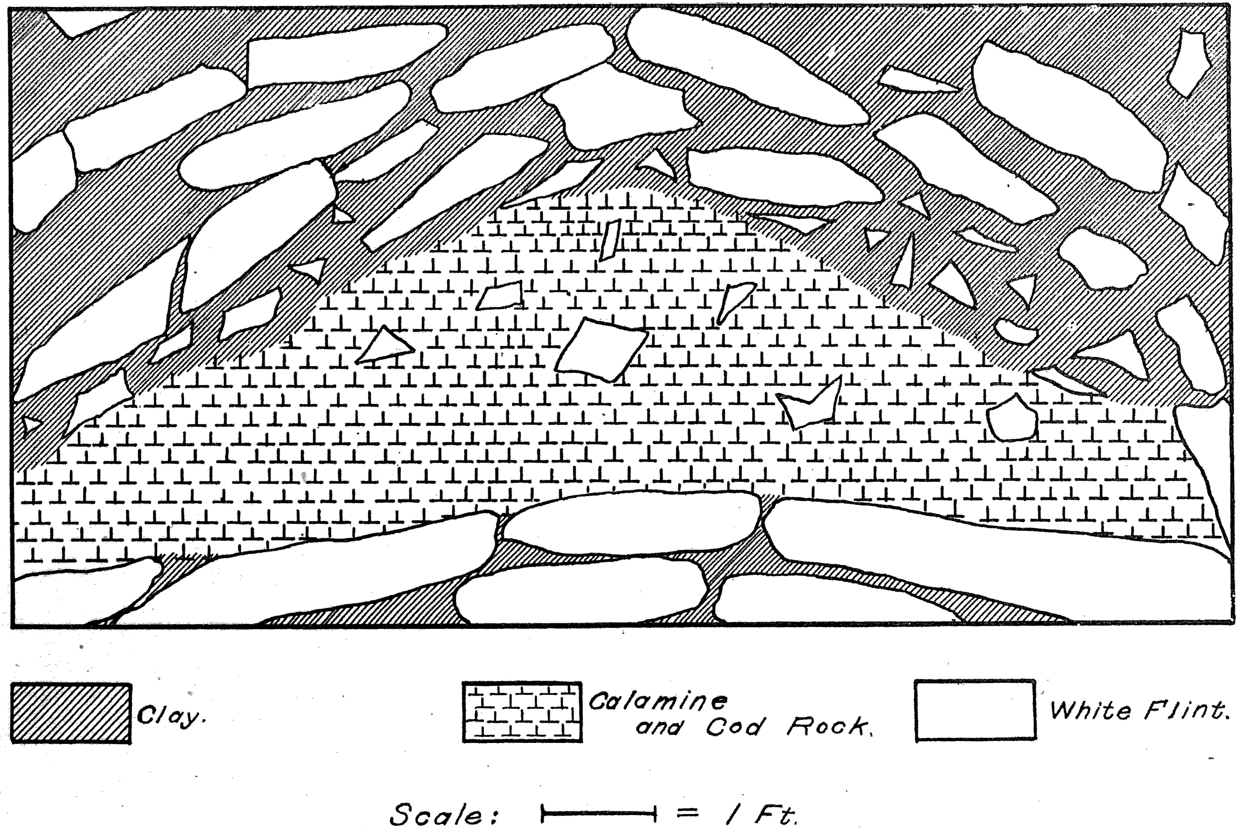
### IDA M.

The Granby Mining and Smelting Company has recently opened this prospect in the S. E. ¼, S. E. ¼, Sec. 1, T. 25, R. 31 W.

The shaft was sunk 92 feet through residual flint, at which depth the ore body was encountered. Two drifts have been started, one west and the other north, each having a face 25 feet wide. At the bottom of the deposit there is an open water channel, which varies in width at different points, being in some places the size of a barrel.

The ore consists of a light yellow, crystalline blende in dolomitic spar. Bluish gray shale occurs through the mass. The ore surrounds the layers and nodules of white flint. In the lower portion of the face the ore is very bunchy. Near the roof there are beds of fine grained gray dolomite, pieces of which are surrounded by ore.

Near the bottom of the deposit calamine occurs in small tabular crystals lining cavities in the spar. At the time the mine was inspected there were approximately 2000 tons of ore on the dump.




MANNER OF OCCURRENCE OF THE ORES IN A MINE OWNED BY THE ILLINOIS ZINC COMPANY.

### ILLINOIS ZINC CO.

The Illinois Zinc Company owns two 80-acre tracts, within the borders of the Granby sheet, consisting of the N. ½ of the N. E. ¼ of Sec. 13 and the E. ½ of the N. W. ¼, Sec. 12, T. 25 N., R. 30 W.

The company, however, is only operating in Sec. 12. Considerable prospecting for galena, which has been found at rather shallow depths by one or two shafts, is being carried on. The company is operating one mine, which is located in the S. E. ¼, N. E. ¼, N. W. ¼, Sec. 12, T. 25 N., R. 30 W.

The ore body is found at a depth of 104 feet. The shaft was sunk through 104 feet of flint and clay, at which depth the ore body occurs. The mine has been worked for a distance of 300 feet north and south and has an average width of about 15 feet. There is one opening being worked, which is six to ten feet in height. A second is reported 4 feet beneath this level, the two openings being separated by heavy beds of flint.

The north end of the mine shows a decided anticlinal structure, the roof consisting of tallow clay and flint nodules. In the southern part of the mine the roof is either level or has a monoclinal dip. The dips and anticlinal structure, as elsewhere, are the result of solution of the limestone by the circulating waters. At present this circulation is entirely descending, as shown by the completely oxidized condition of the ore body. When this mine was examined, prospect work was being carried on in the south end, where the face consisted of tallow clay and white flint. In the north end of the mine the ore occurs beneath the tallow clay and flint roof and had a maximum thickness of 4 feet in the center, thinning out towards either edge. The ore is reported to have been as much as five feet in thickness, and that where the beds became flat or nearly horizontal, the ore was scattered and poor. In some places the calamine is associated with white flint boulders and some cod rock.

The ore, which is exclusively calamine, is cleaned by hand.

The accompanying sketch, Plate XXXII, shows the general relation of the calamine to the clay and flint.

### THE MONTANA.

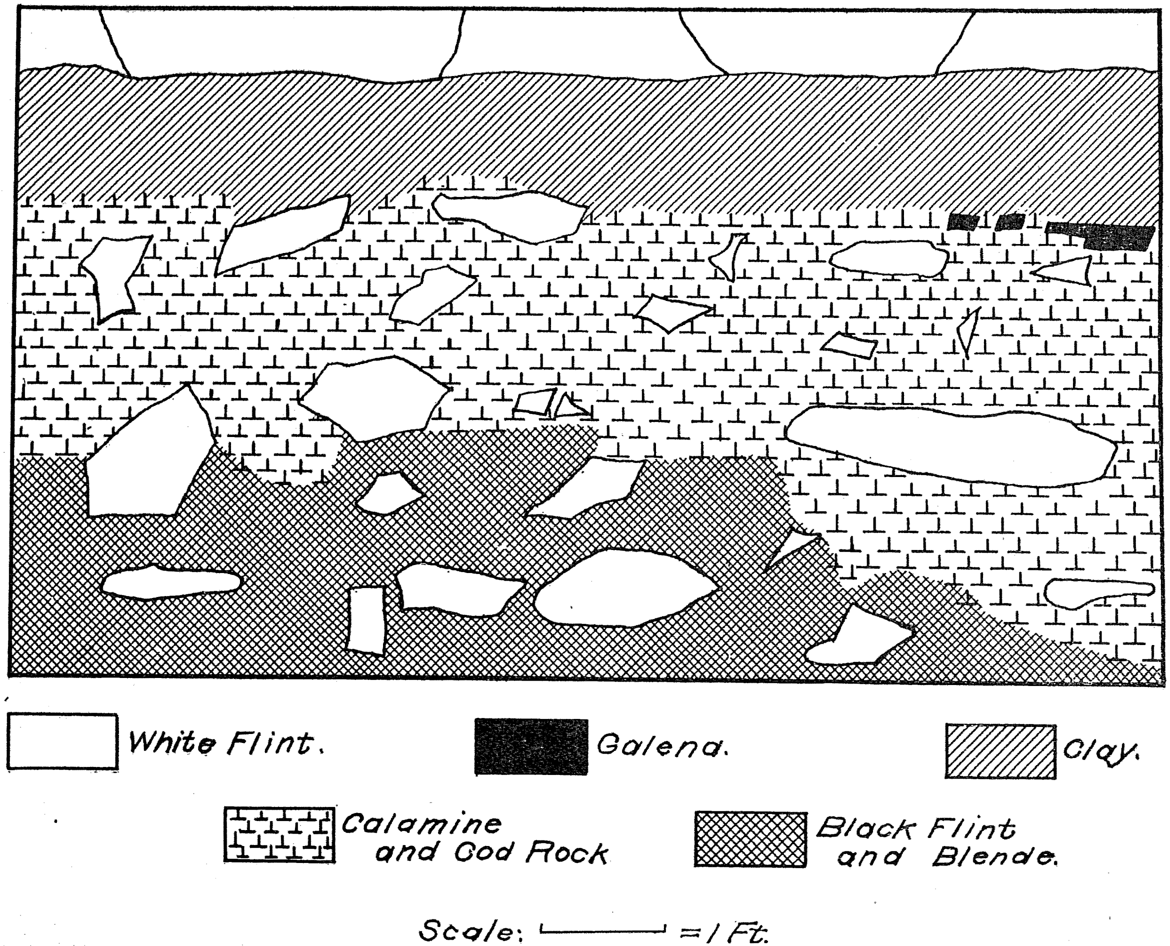
The Montana mine is located on Trent Hill in the S. E. ¼, S. W. ¼, S. E. ¼, Sec. 6, T. 25 N., R. 30 W. The shaft passed through 104 feet of flint and clay to where the ore occurs. The first mining in the present opening was done at the Lucky Boy shaft, which is located on the same lease north of the Montana shaft. The ore body has followed a general north and south direction and has been cut 200 feet south and north to the Lucky Boy. The old workings extending to the Lucky Boy were flooded, which prevented an examination of this part of the ore body. To the south the ore body gradually rises in the direction in which it is being worked. At two points it rose abruptly from 6 to 10 feet, but later returned to the former level.

The flint cap rock and the ore body show various dips at right angles to their strike. The dip is towards the valley to the west. In places the ore lies approximately horizontal and at other points it dips from 40 to 50°. Dips of almost any degree occur between these extremes. The large variations in vertical angle and direction in comparatively short distances show these dips to be the result of solution and not deformation. In driving the drifts occasional boulders of decomposing limestone are encountered. They are the remnants of former solid beds, and are additional evidence of extensive solution. The ore produced by this mine is chiefly galena and calamine. The calamine occurs below the galena, and both minerals are associated with white flint and tallow clay. The abundant calamine, as well as the etched condition of the galena, show that the ore body has been under the influence of oxidizing conditions for a long time. The amount of water in the mine varies greatly with the rainfall, showing it to be a descending circulation. Earlier mining in the immediate vicinity of the Montana resulted in the production of large quantities of galena at shallow depths. The present output is dressed entirely by hand.

### PINE APPLE.

The Pine Apple mine is located east of the Cheap Screw, in the N. W. ¼, S. E. ¼, S. E. ¼, Sec. 12. It has been opened during the past year and is located on the same run of ore as the Cheap Screw.

This shaft passed through 99 feet of bedded flint and clay, openings being encountered at depths of 65, 85 and 99 feet. The upper opening contains galena, but no zinc, and has not been operated. The lowest opening contains chiefly black flint and blende, and has been worked to some extent. The middle opening, which is being worked, has been mined for a distance of 65 feet, and has an average width of 25 feet and a height of 8 feet. The ore has been cut to the wall rock along the north side, but ore still remains to the south. This will be taken out by a return drift.


White Flint.
Galena.
Clay.
Calamine and Cod Rock
Black Flint and Blende.
Scale: = 1 Ft.

No conspicuous jointing or faulting was noted in the mine. The flint roof dips slightly to the north. The opening itself shows a white flint breccia which, as usual, has resulted from solution of the limestone and settling of the flint beds.

The accompanying sketch, Plate XXXIII., gives a general idea of the face of the stope when the mine was examined. The lower 3 feet consists of white flint nodules and black flint breccia containing blende. This grades upward into a gray, vesicular cod rock containing calamine, while solid calamine occurs along the outer portion. The whole mass encloses fragments of white flint. A few etched cubes of galena were observed in one corner just above the calamine. Small pockets of galena have been encountered throughout the run, occurring in practically the same position. The drift above the ore body consists approximately of 18 inches of tallow clay, above which occurs the flint roof. The present product of the mine is mainly calamine, which is crushed and cleaned by hand.

### JAMES A. REED.

This mine is located just north of the Cheap Screw in the N. W. ¼, S. E. ¼, S. E. ¼, Sec. 12, T. 25 N., R. 30 W. Two levels have been opened. The upper, which was being operated at the time the mine was examined, occurs at a depth of 97 feet. The shaft passed through flint, clay and occasional decomposing limestone boulders, the last occurring below a depth of 75 feet.

The mine has never been connected with any of the other workings on the Prairie run. The drifts run in a S. E. N. W. direction, approximately 100 feet, having a maximum width of 50 feet.

The ore produced is mainly calamine, although some blende is obtained, associated with the black flint. The silicate, black flint and blende all inclose white flint nodules and portions of the breccia.

### TENNESSEE.

The Tennessee mine is located on the Trent Hill-Graveyard run, in the N. W. ¼, N. W. ¼, N. E. ¼, Sec. 7, T. 26 N., R. 30 W. It has been worked for a number of years, the earlier workings being south of the present shaft. The shaft has a total depth of 128 feet.

The drift worked from the present shaft has a length of approximately 375 feet, and averages from 10 to 20 feet in width by 5 to 7 feet in height. The wall rock of this drift near the shaft consists chiefly of tallow clay and white flint. The mine produces both galena and calamine, although galena was the almost exclusive product when the mine was examined. At the west end of the drift, the galena occurred in chunks, from 3 to 6 inches in diameter, embedded in clay underneath the flint roof. A small amount of calamine occurs underneath the galena. In the east end of the drift the galena is chiefly attached in a thin layer to the flint cap rock. The roof at this point has a dip of 15°, S. 40° E., and is very regular. A prominent joint in the roof, in this portion of the mine, strikes S. 50° W., and is nearly parallel with the drift. A run of calamine occurs approximately 10 feet below this galena.

### TRILBY, WILL PIERCE AND JACK SPROUT.

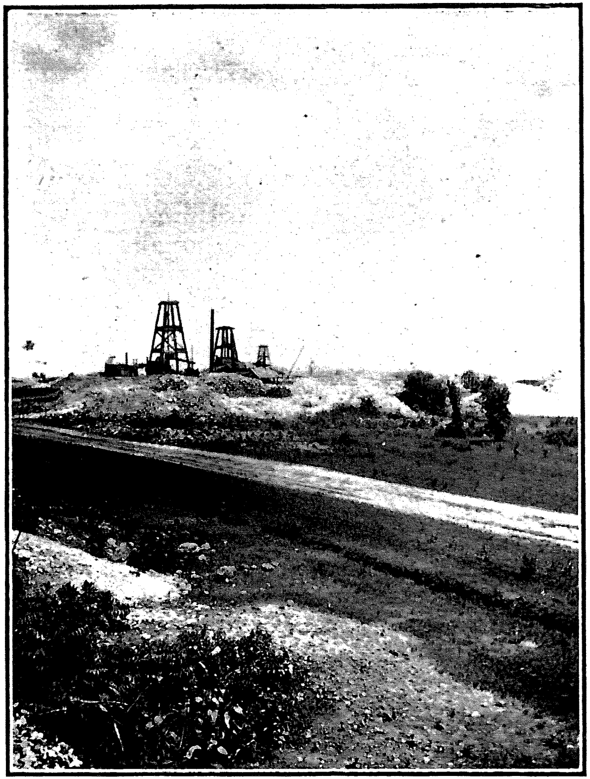
These mines, which are located along the west side of the Prairie run, in the N. W. ¼, N. W. ¼, S. E. ¼, Sec. 12, T. 25, R. 30 W., are all located on the same run of ore. The shafts on the different properties are connected by underground drifts.

Three levels have been worked in this portion of the run. In the Jack Sprout they occur at a depth of 73 feet, 84 feet and 92 feet. The shafts passed through residual flint beds and some clay, with heavy flint beds between the openings.

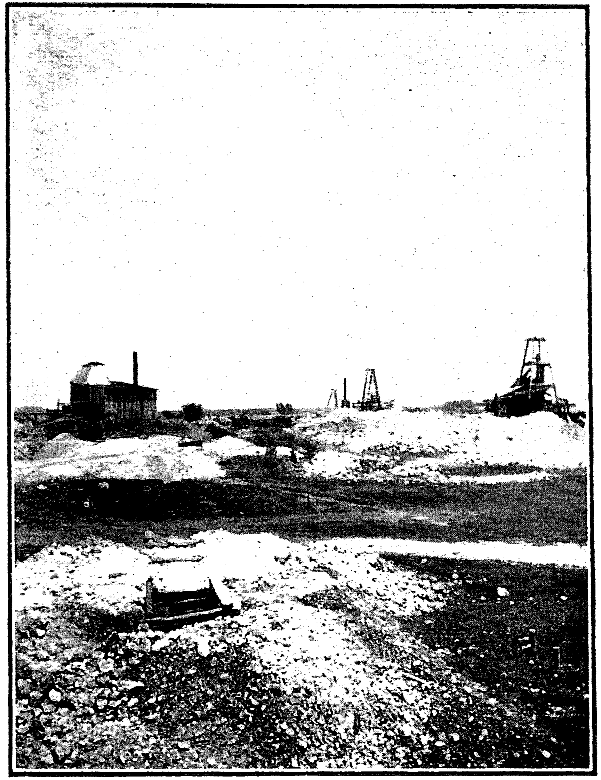
From Plate XXVII. the reader will see the general outline of the ore body, which varies from 50 to 75 feet in width, and is approximately 550 feet long, both north and south and east and west. The two cross sections show the general relations which the different openings bear to each other, as well as the dip of the ore body. They are projections along the planes A B and C D. The upper level of the Trilby is not shown on this map, as it was inaccessible when the survey was made.

The ore body has been connected with other workings on the prairie run to the north, but to the south the run has been lost, and there is no connection with the mines in that direction. It is thought, however, that the Dirty Seven mine, located Southwest of these properties, will probably eventually connect with them.

To the east of these shafts Pennsylvanian sandstone shows in the valley, while to the west solid limestone is encountered at comparatively shallow depths. As seen by the projections, there is a slight dip of the beds to the east. This is also shown in the roof of the north and south portion of the mine. The dips are not pronounced, seldom being over 5° to 8°. From the Trilby to the Will Pierce shaft the roof undulates, but shows a general dip to the east. This dip is more pronounced in the Jack Sprout, but the general di-



JOHN BROWN AND WILL PIERCE MINES.



TRILBY AND JACK SPROUT MINES.

rection is the same. In the Trilby ground to the west the dips vary in direction, but are, in general, north.

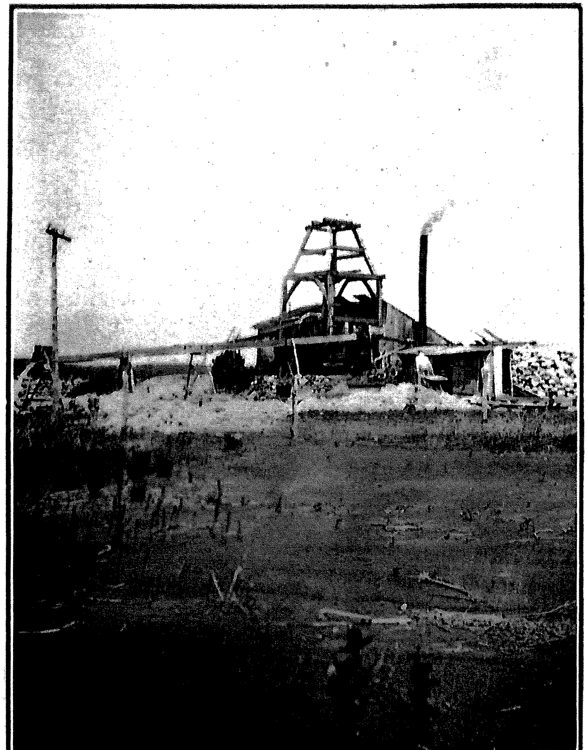
Joints occur in the roof in different portions of these mines. They occur both parallel to and crossing the ore body. In places silicate was noted in these joints. No faulting could be made out in any of these mines. A water course occurs in the Trilby—Jack Sprout ground, which has the trend shown on the map. It is from 20 to 30 feet in width, opening out beneath the flint cap rock. Underneath this open space there is a bed of from 2 to 3 feet of clay. Good ore was found along the course of this water channel, but none occurred in the clay or lining the opening.

Galena and calamine have been the only products of these mines. Large bodies of galena occurred in the upper openings embedded in clay, or attached to the flint roof. In places the galena is reported to have been 4 to 5 feet in thickness. This ore is practically exhausted and at present very little galena is being mined. In the Jack Sprout ground the lower level is now being worked for calamine, which was not taken out when the galena was mined. In the lower level of the Trilby ground there occurs a five-foot face of interbedded calamine and white flint. This ore is not being mined at present, owing to the difficulty experienced in hand dressing it. Dolomitic spar and calcite are abundant along what is known as the "sand" side. They fill the spaces between the white flint beds and contain some ore, but not in sufficient quantity to mine.

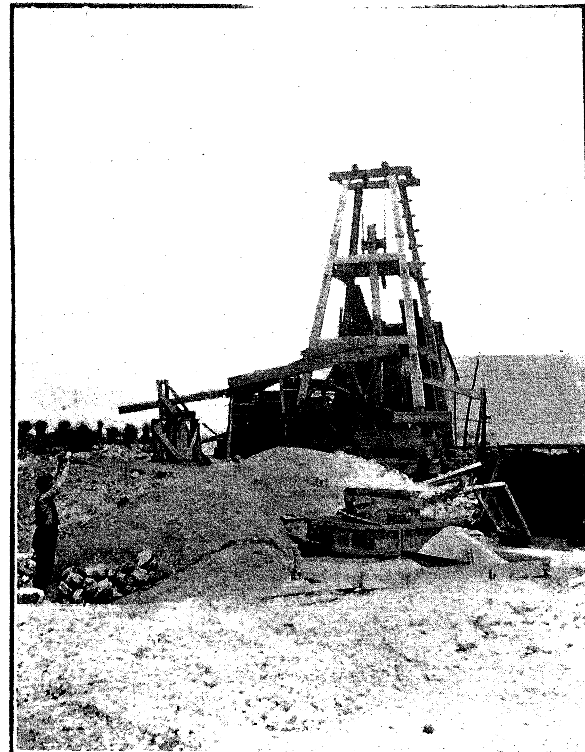
NAMES AND LOCATIONS OF MINES LOCATED AND NUMBERED ON THE GENERAL MAP, PLATE XXV.

| | | | | | | |
|---|---|---|---|---|---|---|
| 1. | Ida M. | S. E. ¼ | S. W. ¼ | S. E. ¼ | Sec. | 1 |
| 2. | Willow Tree | N. E. ¼ | S. W. ¼ | S. E. ¼ | Sec. | 1 |
| 3. | Empress | N. W. ¼ | N. W. ¼ | N. W. ¼ | Sec. | 7 |
| 4. | Mina T. | N. W. ¼ | N. E. ¼ | S. E. ¼ | Sec. | 1 |
| 5. | Happy Jack | N. E. ¼ | N. W. ¼ | S. E. ¼ | Sec. | 1 |
| 6. | H. Price | N. E. ¼ | N. W. ¼ | S. E. ¼ | Sec. | 1 |
| 7. | Central | S. W. ¼ | N. E. ¼ | S. E. ¼ | Sec. | 1 |
| 8. | Jack Rastus | S. W. ¼ | N. E. ¼ | S. E. ¼ | Sec. | 1 |
| 9. | Ben Hur | S. W. ¼ | N. E. ¼ | S. E. ¼ | Sec. | 1 |
| 10. | Pratt Center | S. E. ¼ | N. W. ¼ | S. E. ¼ | Sec. | 1 |
| 11. | Los Angeles | N. E. ¼ | N. W. ¼ | S. E. ¼ | Sec. | 1 |
| 12. | Gee Whillikens | S. E. ¼ | N. W. ¼ | S. E. ¼ | Sec. | 1 |
| 13. | Endless Chain | S. W. ¼ | S. W. ¼ | S. W. ¼ | Sec. | 6 |
| 14. | J. K. | S. E. ¼ | S. E. ¼ | S. E. ¼ | Sec. | 1 |
| 15. | Stingy Baptist | S. E. ¼ | S. E. ¼ | S. E. ¼ | Sec. | 1 |
| 16. | Miner's Pride | N. E. ¼ | S. W. ¼ | S. W. ¼ | Sec. | 6 |
| 17. | Sunset | N. W. ¼ | S. E. ¼ | N. W. ¼ | Sec. | 6 |
| 18. | Sunset No. 6 | N. W. ¼ | S. E. ¼ | N. W. ¼ | Sec. | 6 |
| 19. | Little Tom | N. W. ¼ | S. E. ¼ | N. W. ¼ | Sec. | 6 |
| 20. | Pike | S. E. ¼ | S. W. ¼ | N. W. ¼ | Sec. | 6 |

| | | | | | |
|---|---|---|---|---|---|
| 21. | John Bull | S. W. ¼ | S. E. ¼ | N. W. ¼ | Sec. 6 |
| 22. | Cuba | N. W. ¼ | N. E. ¼ | S. W. ¼ | Sec. 6 |
| 23. | Wyoming | N. E. ¼ | N. W. ¼ | S. W. ¼ | Sec. 6 |
| 24. | Morning Glory | S. E. ¼ | S. W. ¼ | N. W. ¼ | Sec. 6 |
| 25. | Ozark, new shaft | N. E. ¼ | S. E. ¼ | S. W. ¼ | Sec. 6 |
| 26. | Ozark, pump shaft | N. E. ¼ | S. E. ¼ | S. W. ¼ | Sec. 6 |
| 27. | Fontella | S. E. ¼ | N. E. ¼ | S. W. ¼ | Sec. 6 |
| 28. | Fontella, old | N. E. ¼ | S. E. ¼ | S. W. ¼ | Sec. 6 |
| 29. | Dockery | S. E. ¼ | S. W. ¼ | S. E. ¼ | Sec. 6 |
| 30. | Montana | S. E. ¼ | S. W. ¼ | S. E. ¼ | Sec. 6 |
| 31. | Lucky Boy | S. E. ¼ | S. W. ¼ | S. E. ¼ | Sec. 6 |
| 32. | 22 Shaft | S. E. ¼ | S. W. ¼ | S. E. ¼ | Sec. 6 |
| 33. | Millsap | S. E. ¼ | S. W. ¼ | S. E. ¼ | Sec. 6 |
| 34. | Small Hope | S. E. ¼ | S. W. ¼ | S. E. ¼ | Sec. 6 |
| 35. | Idaho | N. W. ¼ | S. E. ¼ | S. E. ¼ | Sec. 6 |
| 36. | Old Times | S. W. ¼ | N. E. ¼ | S. E. ¼ | Sec. 6 |
| 37. | Daisy A. | S. E. ¼ | N. W. ¼ | S. E. ¼ | Sec. 6 |
| 38. | Big Four | N. W. ¼ | S. W. ¼ | S. E. ¼ | Sec. 6 |
| 40. | Old Well | S. W. ¼ | N. E. ¼ | S. E. ¼ | Sec. 6 |
| 41. | Big Hit | S. W. ¼ | N. E. ¼ | S. E. ¼ | Sec. 6 |
| 42. | Second Round | S. W. ¼ | N. E. ¼ | S. E. ¼ | Sec. 6 |
| 43. | Fork of Roads | S. E. ¼ | N. W. ¼ | S. E. ¼ | Sec. 6 |
| 44. | Turn Down | N. E. ¼ | N. W. ¼ | S. E. ¼ | Sec. 6 |
| 45. | Turn Down | S. E. ¼ | N. W. ¼ | S. E. ¼ | Sec. 6 |
| 48. | Road Center | N. W. ¼ | N. E. ¼ | S. E. ¼ | Sec. 6 |
| 49. | Blazing Star | N. E. ¼ | N. W. ¼ | S. W. ¼ | Sec. 6 |
| 50. | Well | N. E. ¼ | N. W. ¼ | S. E. ¼ | Sec. 6 |
| 51. | Well | S. E. ¼ | N. W. ¼ | S. E. ¼ | Sec. 6 |
| 52. | Little Boss | S. E. ¼ | S. W. ¼ | N. E. ¼ | Sec. 6 |
| 53. | Little Boss | S. E. ¼ | S. W. ¼ | N. E. ¼ | Sec. 6 |
| 54. | Little Boss | S. E. ¼ | S. W. ¼ | N. E. ¼ | Sec. 6 |
| 55. | Well | N. W. ¼ | N. W. ¼ | S. E. ¼ | Sec. 6 |
| 56. | Little Boss | S. E. ¼ | S. W. ¼ | N. E. ¼ | Sec. 6 |
| 57. | Richardson Well | S. W. ¼ | S. W. ¼ | N. E. ¼ | Sec. 6 |
| 58. | City Well | N. W. ¼ | N. W. ¼ | S. E. ¼ | Sec. 6 |
| 59. | Well | S. W. ¼ | S. W. ¼ | N. E. ¼ | Sec. 6 |
| 78. | Jack Sprout | N. W. ¼ | N. W. ¼ | S. E. ¼ | Sec. 12 |
| 79. | W. Pierce | N. W. ¼ | N. W. ¼ | S. E. ¼ | Sec. 12 |
| 80. | John Brown | S. W. ¼ | N. W. ¼ | S. E. ¼ | Sec. 12 |
| 81. | Dirty Seven | S. W. ¼ | N. W. ¼ | S. E. ¼ | Sec. 12 |
| 82. | Johnson P. | N. E. ¼ | N. E. ¼ | S. W. ¼ | Sec. 12 |
| 83. | Future Great | S. E. ¼ | N. E. ¼ | S. E. ¼ | Sec. 12 |
| 84. | Johnson and Brewer | S. E. ¼ | N. E. ¼ | S. E. ¼ | Sec. 12 |
| 85. | Cheap Screw | N. W. ¼ | S. E. ¼ | S. E. ¼ | Sec. 12 |
| 86. | Sunny South | S. E. ¼ | N. E. ¼ | S. E. ¼ | Sec. 12 |
| 87. | James A. Reed | N. W. ¼ | S. E. ¼ | S. E. ¼ | Sec. 12 |
| 88. | Pine Apple | N. E. ¼ | S. E. ¼ | S. E. ¼ | Sec. 12 |
| 89. | J. Brackeen | N. W. ¼ | N. W. ¼ | S. W. ¼ | Sec. 6 |
| 90. | Blue Jack No. 2 | N. W. ¼ | N. W. ¼ | S. W. ¼ | Sec. 6 |
| 91. | Peach Tree | N. W. ¼ | N. W. ¼ | S. W. ¼ | Sec. 6 |
| 92. | Blue Jacket No. 1 | N. W. ¼ | N. W. ¼ | S. W. ¼ | Sec. 6 |
| 93. | Rooseveldt | S. W. ¼ | N. W. ¼ | S. W. ¼ | Sec. 6 |
| 98. | Bob Hunter | N. W. ¼ | N. W. ¼ | S. W. ¼ | Sec. 6 |
| 99. | Beckham, Old | N. E. ¼ | N. W. ¼ | N. E. ¼ | Sec. 7 |
| 100. | Young Hickory | N. E. ¼ | N. W. ¼ | N. E. ¼ | Sec. 7 |
| 101. | Young Hickory (old) | N. W. ¼ | N. W. ¼ | N. E. ¼ | Sec. 7 |
| 102. | Young Hickory (new) | N. W. ¼ | N. W. ¼ | N. E. ¼ | Sec. 7 |
| 103. | Tennessee | N. W. ¼ | N. W. ¼ | N. E. ¼ | Sec. 7 |
| 106. | Lady Bird (new) | N. E. ¼ | N. E. ¼ | S. E. ¼ | Sec. 6 |



CHEAP SCREW MINE.



JACK SPROUT MINE.

Hand jig in operation in foreground. Also shows the ordinary beam pump used in this area.

| | | | | | |
|---|---|---|---|---|---|
| 107. | War Eagle | S. W. ¼ | S. W. ¼ | S. E. ¼ | Sec. 6 |
| 108. | Evening Star | S. E. ¼ | S. E. ¼ | N. E. ¼ | Sec. 6 |
| 109. | Fortune Teller (old) | S. E. ¼ | S. E. ¼ | N. E. ¼ | Sec. 6 |
| 110. | Fortune Teller | S. E. ¼ | S. E. ¼ | N. E. ¼ | Sec. 6 |
| 111. | Burn Out | S. E. ¼ | S. E. ¼ | N. E. ¼ | Sec. 6 |
| 112. | William Miller | S. E. ¼ | S. E. ¼ | N. E. ¼ | Sec. 6 |
| 113. | Only Chance | S. E. ¼ | S. E. ¼ | N. E. ¼ | Sec. 6 |
| 114. | Old Devil | S. E. ¼ | S. E. ¼ | N. E. ¼ | Sec. 6 |
| 115. | Lady Bird | N. E. ¼ | N. E. ¼ | S. E. ¼ | Sec. 6 |
| 116. | Ed Reyburn | N. E. ¼ | N. E. ¼ | S. E. ¼ | Sec. 6 |
| 117. | Morlan | N. E. ¼ | N. E. ¼ | S. E. ¼ | Sec. 6 |
| 118. | Sore Head | S. E. ¼ | S. E. ¼ | S. W. ¼ | Sec. 6 |
| 119. | Bois de Arc | N. W. ¼ | N. E. ¼ | N. W. ¼ | Sec. 7 |
| 120. | Free Silver | N. E. ¼ | N. W. ¼ | N. W. ¼ | Sec. 7 |
| 121. | Starve Out | S. E. ¼ | S. W. ¼ | S. W. ¼ | Sec. 6 |
| 122. | Mulberry | N. E. ¼ | N. W. ¼ | N. W. ¼ | Sec. 7 |
| 123. | Brigham Young (new) | N. E. ¼ | N. W. ¼ | N. W. ¼ | Sec. 7 |
| 124. | Brigham Young | N. E. ¼ | N. W. ¼ | N. W. ¼ | Sec. 7 |
| 125. | Tom Johnson | S. E. ¼ | S. E. ¼ | S. E. ¼ | Sec. 1 |
| 126. | Big Girl No. 1 | N. E. ¼ | N. E. ¼ | N. E. ¼ | Sec. 7 |
| 127. | Hard Luck | N. E. ¼ | N. E. ¼ | N. E. ¼ | Sec. 7 |
| 128. | Big Girl No. 2 | N. E. ¼ | N. E. ¼ | N. E. ¼ | Sec. 7 |
| 129. | Republic | S. W. ¼ | S. E. ¼ | S. E. ¼ | Sec. 1 |
| 130. | Ruby Trust (old) | N. E. ¼ | N. E. ¼ | N. E. ¼ | Sec. 7 |
| 131. | Wetaker | N. E. ¼ | N. E. ¼ | N. E. ¼ | Sec. 7 |
| 132. | Ruby Trust (new) | N. E. ¼ | N. E. ¼ | N. E. ¼ | Sec. 7 |
| 133. | Wetaker (new) | N. E. ¼ | N. E. ¼ | N. E. ¼ | Sec. 7 |
| 134. | Ill. Zinc Co | S. E. ¼ | N. E. ¼ | N. E. ¼ | Sec. 12 |
| 135. | Gold Dollar | N. E. ¼ | N. E. ¼ | N. E. ¼ | Sec. 7 |
| 136. | Break Up | S. W. ¼ | N. E. ¼ | N. W. ¼ | Sec. 7 |
| 137. | Liederkranz | S. W. ¼ | N. E. ¼ | N. W. ¼ | Sec. 7 |
| 138. | Craw Fish | S. E. ¼ | N. W. ¼ | N. W. ¼ | Sec. 7 |
| 139. | Kreuger | S. W. ¼ | N. E. ¼ | N. W. ¼ | Sec. 7 |
| 140. | Tom Walker | S. E. ¼ | S. W. ¼ | N. E. ¼ | Sec. 12 |
| 141. | Thos. Bennett | S. W. ¼ | S. W. ¼ | N. E. ¼ | Sec. 12 |
| 142. | Thomas Bennett (Pump) | S. W. ¼ | S. W. ¼ | N. E. ¼ | Sec. 12 |
| 143. | Mosely | N. W. ¼ | N. E. ¼ | S. E. ¼ | Sec. 12 |
| 144. | Crab Apple (Pump) | S. W. ¼ | N. E. ¼ | S. E. ¼ | Sec. 12 |
| 145. | Southern Queen | S. W. ¼ | N. E. ¼ | S. E. ¼ | Sec. 12 |
| 147. | Big Boy No. 3 | S. E. ¼ | S. E. ¼ | S. E. ¼ | Sec. 6 |
| 148. | Big Boy No. 2 | S. E. ¼ | S. E. ¼ | S. E. ¼ | Sec. 6 |
| 149. | Big Boy No. 1 | S. E. ¼ | S. E. ¼ | S. E. ¼ | Sec. 6 |
| 150. | Economy No. 2 | S. E. ¼ | S. E. ¼ | S. E. ¼ | Sec. 6 |
| 151. | New Economy | S. W. ¼ | S. E. ¼ | S. E. ¼ | Sec. 6 |
| 152. | New Economy No. 1 | S. W. ¼ | S. E. ¼ | S. E. ¼ | Sec. 6 |
| 153. | Columbia | N. W. ¼ | S. E. ¼ | S. E. ¼ | Sec. 6 |
| 154. | Mascot | S. W. ¼ | S. W. ¼ | S. E. ¼ | Sec. 12 |
| 155. | Mascot, Little shaft | S. W. ¼ | S. W. ¼ | S. E. ¼ | Sec. 12 |
| 156. | Mascot, North shaft | N. W. ¼ | S. W. ¼ | S. E. ¼ | Sec. 12 |
| 157. | Little Four | N. E. ¼ | S. E. ¼ | S. W. ¼ | Sec. 12 |
| 158. | Climax | N. W. ¼ | S. W. ¼ | S. E. ¼ | Sec. 12 |
| 159. | Blow Up | N. W. ¼ | S. W. ¼ | S. E. ¼ | Sec. 12 |
| 160. | Well | N. W. ¼ | S. W. ¼ | N. E. ¼ | Sec. 6 |
| 161. | Unjust Council | N. W. ¼ | S. W. ¼ | N. E. ¼ | Sec. 6 |
| 162. | Well | N. E. ¼ | S. E. ¼ | N. W. ¼ | Sec. 6 |

# CHAPTER VIII.

## ORIGIN OF THE LEAD AND ZINC.

During the last three years we have been collecting information, through observations in the field, which might throw light upon the origin of the lead and zinc of the southwestern and central districts of the Ozark region. During the period between 1902-1904 a detailed survey was made of Miller, Moniteau and Morgan counties in the Central District. In 1903 an examination was made of the Aurora area. During the fall of 1904 several weeks were spent in the field examining the ore bodies in the mines at Joplin, Webb City, Prosperity, Alba, Neck City and Carthage. Later a detailed examination of the Granby area was undertaken, resulting in the publication of the present volume. Since completing the field work in this area, an examination has been made of some of the important mines in the vicinity of Joplin, Webb City and Oronogo.

As a result of these examinations we recognize an unconformity* between the Mississippian and Pennsylvanian series which is co-extensive with the areas examined. Everywhere it is clearly evident that the geologists who have formerly mapped extensive faults in these districts have mistaken unconformity for faulting. The faults mapped** in the Aurora, Joplin and Granby areas are lines of discordant bedding due to the unconformity between the Mississippian and Pennsylvanian series. In some cases there is evidence of movement between the Pennsylvanian and Mississippian series within or adjacent to the conglomerate beds. These movements, however, are usually slight, although frequently enough to develop slickensides. They have often developed later than the formation of the blende, as shown by the slickensiding of that mineral. Capt. John Kingston and Dr. E. M. Shepard have in their collections several very fine specimens of slickensided blende.

All of the above observations go to show that associated with the

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*The unconformity between the Mississippian and Pennsylvanian has been recognized previously by Arthur Winslow and others.

**"The Leau and Zinc Deposits of the Ozark Region," by H. F. Bain, Part II, Twenty-second An. Rept. U. S. G. S., 1900-1901, pp. 145, 149 and 167-173.

ore bodies in the Granby area, or even in the Southwestern or Central districts, faults, of sufficient magnitude to have any but a very minor relation to the formation or distribution of the ore bodies, have not been recognized.* It is clear that in the Granby area, at least, the faults are not of sufficient consequence to be considered, except incidentally, in connection with any theory of the origin of the ores. It might be of interest to state that the greatest faults recognized in the southwestern and central Ozark districts are not connected in any way with deposits of lead and zinc ores. This fact has been clearly pointed out by Dr. E. M. Shepard, who has made extensive observations covering the entire Ozark region.

It follows as a corollary that there are no fault breccias in this area. The so-called breccias are, in part, basal conglomerates belonging to the Pennsylvanian era, and in part, solution breccias. The latter, however, are often so intimately associated with the conglomerate as to make the separation a matter of some difficulty and greater uncertainty. The origin of this conglomerate and the associated breccias is discussed elsewhere. Suffice it to say, that the mistake of calling the conglomerates and solution breccias fault breccias has been made by most geologists except Winslow, Robertson and Schmidt, who have written reports upon the Southwestern and Central districts. The absence of faults and fault breccias argues that very little, if any, of the deep seated ground water reaches the superficial zone in which the ores occur.

It has been shown by analyses, made in the laboratory of this Bureau and elsewhere, that the waters from the deep wells—those penetrating the Cambro-Ordovician series—contain no appreciable quantity of zinc, while the mine waters contain variable amounts of both, but chiefly zinc. Mr. George Waring of Webb City has made analyses of water from the Herrod well on Allen street, Webb City, from the well on the Missouri Zinc Fields property and from the well at the Goldenrod mine north of Webb City, and has found no trace of zinc. These wells are from 750 to 850 feet deep and down to what is known in this region as the second sandstone, which is in the Cahmbro-Ordovician. An analysis was made of the water from the 1600-foot well at the mill of the Granby Mining and Smelting Company at Granby and only a trace of lead and zinc was found. This well is not cased and the lead and zinc detected probably came from the surface waters which must flow into the well. Mr. Waring has made repeated analyses of the mine waters, which are from within the upper superficial zone,

*The fault on Pierson creek, which has been described by Dr. E. M. Shepard, is probably an exception. We have not had an opportunity to examine this area.

150-200 feet, and finds them to contain from 0.4 to 2.5 grams per liter of zinc. Analyses of mine waters from the shallow mines at Granby (70-100 feet) show measurable quantities of both lead and zinc.

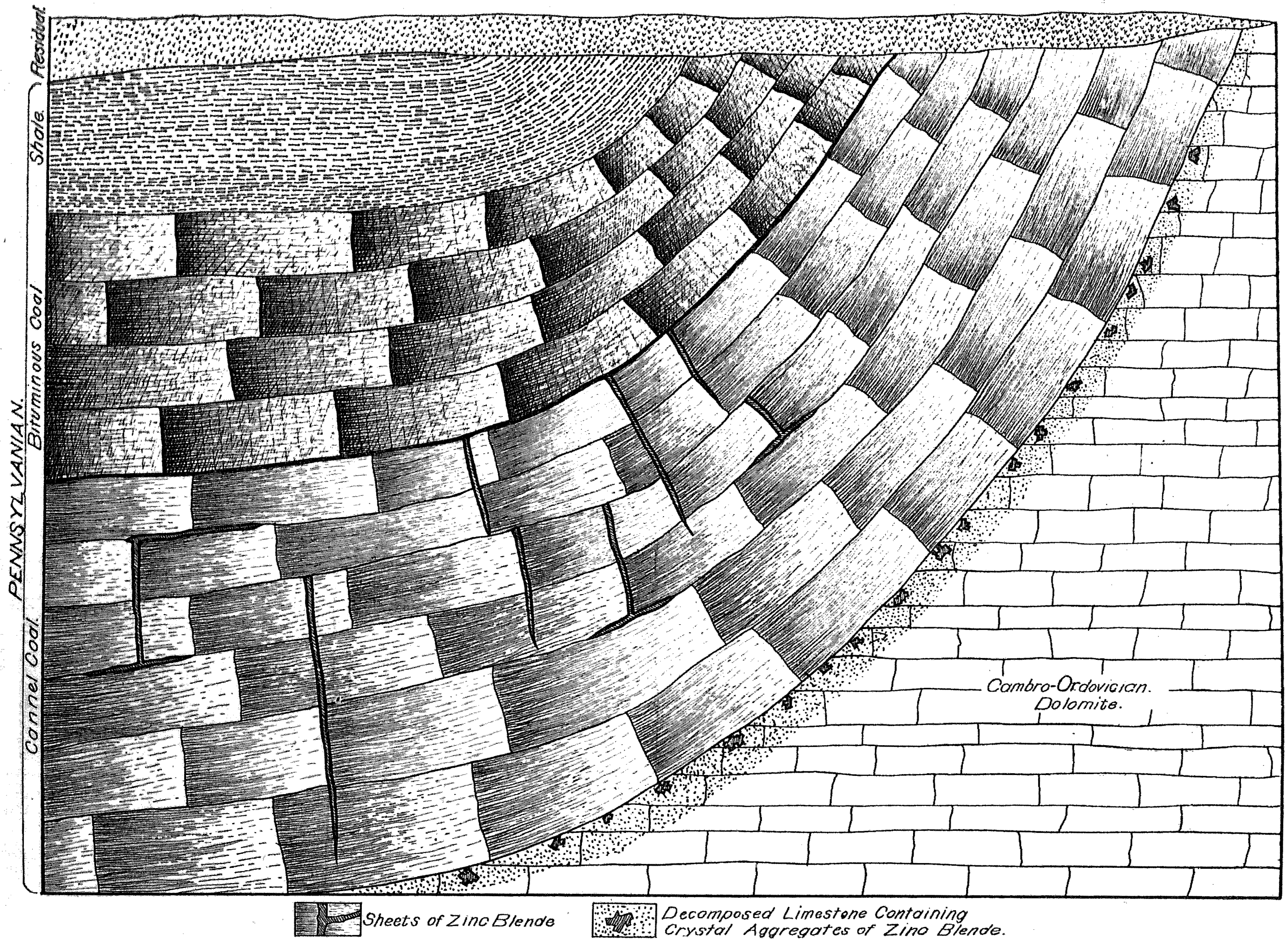
Mr. Waring finds that the water from the city deep well at Webb City contains only a trace of MgO; that the water from the deep well on the Missouri Zinc Fields property contains only 0.0298 grams per liter of MgO; and that the water from the deep well at the Goldenrod mine contains .0327 grams per liter of MgO. Mr. Waring also finds that the waters from the deep wells contain no iron. The mine waters, on the other hand, contain large percentages of both magnesium and iron. These analyses seem to indicate that the deep circulating waters do not contain lead or zinc. If the original source of the magnesia, lead, zinc and iron were the deep seated ground waters, it is strange that these waters at the present time do not contain measurable quantities of the metals other than magnesium.

The absence of lead and zinc in the waters from deep wells and the absence of brecciated or fault zones argue against the lead and zinc having been derived from the magnesian limestones of the Cambro-Ordovician series by an artesian circulation, as held by VanHise, Bain and others.

We therefore hold that the ore bodies from the first to the Nth concentration are the result of converging, *downward circulating* waters, the oxidizing portions of which carried the metallic salts and the reducing portions the organic matter, which was an important factor in furnishing the conditions necessary for precipitation. See Plate XXXVI.

In the Granby area the early concentration of the zinc blende was contemporaneous with the deposition of at least a part of the black flint. Both were deposited after the Mississippian-Pennsylvanian erosion interval. The organic matter which gives color to the flint was derived from the carbonaceous shales, being carried into the broken residual flint beds and the flint conglomerate by downward circulating waters, which probably also carried silica either mechanically or in solution. When the precipitation, either mechanical or chemical, of the silica took place, it carried down with it very finely pulverulent carbonaceous or asphaltic material, with both of which the shales were impregnated. Contemporaneous downward circulating waters carried lead and zinc salts, which were precipitated with the silica and carbonaceous matter, forming what is known as the disseminated black flint ore.

Since a part of the black flint and dolomitic spar were contemporaneous deposits, it is very probable that some of the zinc blende associated with the spar belongs to the early stage of concentration.




CROSS SECTION OF THE COAL POCKET IN MONITEAU COUNTY, SHOWING THE OCCURRENCE OF ZINC BLENDE IN THE COAL.

The extent to which this occurred cannot be given with any degree of certainty.

The evidence at hand goes to show that the lead and zinc were probably derived from the overlying Pennsylvanian shales and limestones, being carried downward as they were disintegrated and eroded. There are numerous occurrences of lead and zinc in the central part of the State, where one can scarcely account for their presence except it be through the disintegration and decomposition of the Pennsylvanian shales. The accompanying illustration, Plate XXXVI., shows a coal pocket in Moniteau county which contains zinc along the jointing and bedding planes of the coal and in the decomposed limestone immediately underlying and surrounding the pocket. There are no faults communicating with the deep underground circulation. The ore bodies do not extend beyond the influence of the solutions passing through the coal pockets, and every condition leads one to believe that these lead and zinc minerals have been brought to their present position by downward circulating waters. The above illustration is only one of many that might be cited from this region. In a paper in the Transactions of the American Institute of Mining Engineers on "Ore Deposits," Mr. Jenney mentions a similar occurrence near Sedalia.

In a preliminary report on the "Iron ores and Coal Fields," published by this Bureau in 1873, Professor G. C. Broadhead cites the occurrence of zinc blende in coal and shale of the Pennsylvanian at a number of localities. He says, "Sulphuret of zinc was often observed contained in the interior of concretions of Septaria. Beautiful examples of this were obtained in a carbonaceous rock on Sugar Creek, Buchanan county, near Platte county line. At Hughes' mines, near Richmond, in Ray county, sulphuret of zinc occurs in the limestone overlying the coal. Minute crystals were observed associated with carbonate of lime in the interior of a fossil near Forest City."

"On Dog Creek, Nodaway county, it was found in calcite veins in limestone No. 196; in concretions of carbonate of iron, at Gilkersen Ford on Grand River, Henry county; in similar concretions at Williamson's coal mines near Windsor, Henry county. Small crystals were seen in limestone No. 80 at Amos', Jackson county." * * * * "Zinc-blende often forms a small nucleus in ironstone concretions, and in this position was found on Walnut Creek, near the Pacific railroad crossing, in the shales over the coal at Long's, and in the concretions at Holden. It is sometimes found in the centre of a plant-stem. A small quantity of zinc-blende was found in limestone No. 83, at Amos's, in Jackson county." * * * * "On Sugar Creek (Platte county), near the line of Buchanan county, about 20 feet below a 7-inch coal-seam numerous remains of plants, probably Cordaites, were observed containing knife-edges of coal, and with numerous transverse cracks, the interstices filled with sulphuret of zinc."

Everywhere through the Pennsylvanian strata there are seams and crystals of iron sulphide, and were we to make careful chemical analyses of the shale and coal tributary to this district, it is thought that there would be found as great a quantity of lead and zinc as has been found in the dolomites of the Cambro-Ordovician.

Some of the lead and zinc may have been originally deposited with the limestone in which the ore bodies now occur, but analyses, although they may show the presence of lead and zinc, are not a demonstration that these metals were introduced at the time the sediments, forming the rocks, were laid down. The samples of limestone analyzed may be from a locality distant from any known ore body, and the rock may contain no particles of galena or blende of sufficient size to be detected with a lens, yet these specimens may contain lead and zinc introduced since the rock was formed. Neither the size of the lead and zinc individuals nor the locality from which the specimens are collected can be used as evidence that the blende or galena were original constituents of the country rock in which the ore bodies now occur.

Galena and zinc blende occur everywhere throughout the Mississippian and Cambro-Ordovician series in Missouri, although there are only a few areas in which these minerals have been sufficiently concentrated to constitute ore bodies. If one were to have before him a map of the Cambro-Ordovician and Mississippian of Missouri, upon which were located all mines and prospects from which galena and zinc blende have been obtained, he would certainly doubt very much the ability of anyone to select samples in which the probability of obtaining originally deposited galena or blende was anything but very remote.

In the geological history of this State we find no conditions more favorable to the deposition of the metallic salts contained in the ocean than those which existed during the Pennsylvanian period. Everywhere there must have been conditions simulating those by virtue of which these metals are now being concentrated within the Mississippian formation. The occurrence of galena, blende, pyrite and marcasite—the latter two in great quantities—within the Pennsylvanian, in many parts of the State, is strong evidence that the metals were thrown down abundantly in some portions of the Pennsylvanian sea. It is a noticeable fact that pyrite is most abundant in the coal and shale where they occur near what is supposed to have been the shore line. It is more than probable that the oxidizing waters from the land area, at that time, precipitated the metallic salts, which they had gathered in their journey, before traveling very far from the shore. This would tend to localize the original deposits within the Pennsylvanian. Later, in the Pennsylvanian, when the reducing conditions became more general or the land area was completely submerged, the introduction of the metallic salts would cease.

We do not presume to point out the original source of the lead and zinc in the oceanic waters of the Pennsylvanian era, although it appears highly probable that the crystalline rocks and the Cambro-Ordovician dolomites have both contributed. If the latter, the lead and zinc must have been precipitated from the sea when these limestones were laid down. As pointed out by VanHise, Winslow and others, were we to trace these metallic minerals to their ultimate source, we would find them to have originated in the igneous rocks. From the time these metals were abstracted from the igneous rocks to the time they were held in solution by the waters of the Pennsylvanian sea, they may have been several times, in part, at least, precipitated with the oceanic sediments and again dissolved.

If .002 of one per cent of zinc and lead deposited from the waters of the Cambro-Ordovician sea, is sufficient to account for the lead and zinc deposits of the Ozark region, very much less would be required by the Pennsylvanian, since, with the removal of the beds of this series by erosion, all the lead and zinc would be transferred to other places. On the other hand, the extremely favorable conditions for precipitation in the Pennsylvanian sea would lead one to suppose that the quantity precipitated would be many times as great as in the Cambro-Ordovician sea.

Our starting point must be the last time the lead and zinc were held in solution by the waters of the ocean. In the case of this area, as well as the Southwestern Ozark district, it is thought to have been the Pennsylvanian sea. We believe, as in the case of the concentration of minerals by the mechanical process as a result of weathering, so in the case of concentration through solution and redeposition as a result of weathering, the ore bodies of the Granby area have been formed.

Not only has there been a concentration of the lead and zinc, but as striking, also, is the concentration of silica, dolomite, calcite and pyrite. Evidently, in all cases, there has been a gradual movement of these minerals, including the lead and zinc minerals, downward, pari-passu with the degradation of the land. That this movement is still in progress is shown by the growth of lead and zinc minerals in mines that have been abandoned and flooded with water. There is a well authenticated case* in the Granby Area of a hob-nailed shoe taken from an old mine which was reopened after being abandoned for ten or twelve years—to each of the nails of which had grown a small cube of galena. Dr. E. M. Shepard of Springfield, Missouri, has in his collection several spikes, to which are attached crystals of galena and blende. These were obtained from a long closed mine on the James river.

The entire process of ore deposition in this district has been one of enrichment, below the level of ground water, brought about through the migration of the materials downward. We are able through the association of the different minerals to recognize an early and a later concentration of the galena and zinc blende, but further than this we have not attempted to separate the ore into different periods of concentration. The process has been one of constant but interrupted concentration, the interruptions probably being due to changes in the level of the ground waters resulting from successive periods of elevation and subsidence. In this our conclusions agree, essentially, with Mr. W. P. Blake, who, in writing of the Wisconsin lead and zinc deposits, says: "The evidence is strongly in favor of the view of the long-continued decomposition, downward flow and recomposition of not only the ores of zinc, but of lead and of the pyrite from the upper formation's to the lower, as the general water level of the region subsided and as the upper formations by long-continued exposure through geologic ages were gradually decomposed in place."

Above the level of ground water, and in many cases far below, a process of abstraction is going on, as a result of which the sulphide minerals are in part taken into solution and in part altered to the carbonate and silicate. The carbonate and silicate are in many places precipitated as such from the underground waters, replacing the limestone and calcite crystals, forming stalactites in caves and caverns, and lining small openings within the flint. Casts of crinoids and brachiopods lined with rosettes of calamine are frequently observed. Capt. John Kingston of Granby has in his collection a small piece of bone, taken from an abandoned mine, which has been altered to pyromorphite, the phosphate of lead.

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*This information was furnished by Capt. John T. Kingston of Granby, Mo.

It is noticeable that the removal of the sulphides, carbonates and silicates from the zone of weathering to deeper levels has in many places lagged behind the surface weathering. Especially is this true of the galena and carbonate minerals, which in the Granby area have been found in their greatest richness near the surface, often at the "grass roots."

It is pointed out in Chapter IX that at least three-fourths of the galena mined in this area has been obtained within sixty or seventy feet of the surface. This in itself, in view of the fact that the Mississippian has been eroded very little since the Pennsylvanian strata were laid down is evidence that there has been very little secondary concentration of the galena. It also shows that such as has been secondarily concentrated has not traveled very far. Runs of galena are sometimes found below blende, although the history of the area shows that the greatest deposits of blende are in the deeper workings while the richest galena horizon is near the surafce. This condition may be due in part to the greater stability of the lead ores within the zone of weathering, but chiefly, we believe, to the fact that it was the chief horizon of the early concentration of the galena from the convergent downward circulation.

# CHAPTER IX.

## CHEMISTRY OF THE ORE DEPOSITS.

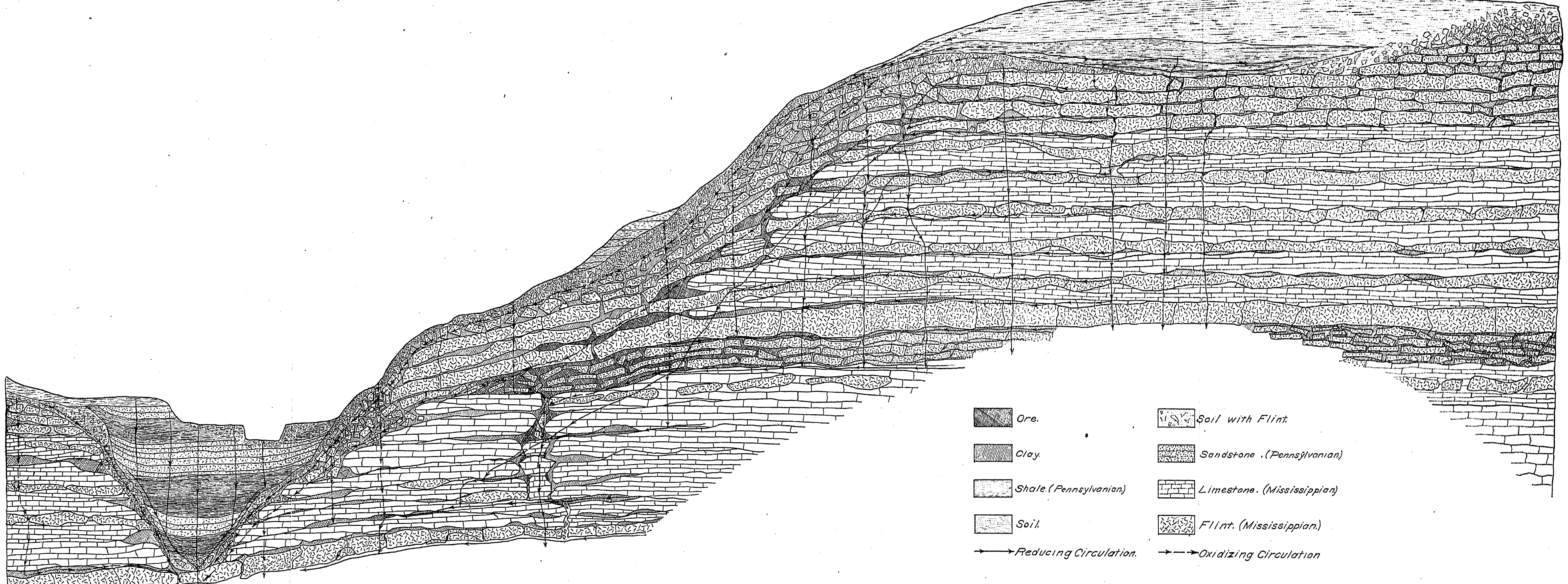
In a discussion of the chemistry of the ore deposits of this area, one should be familiar with the physical conditions of the area at the close of the Pennsylvanian era, and also with the physical changes which have taken place since that time. These are discussed as far as known in the preceding pages of this report.

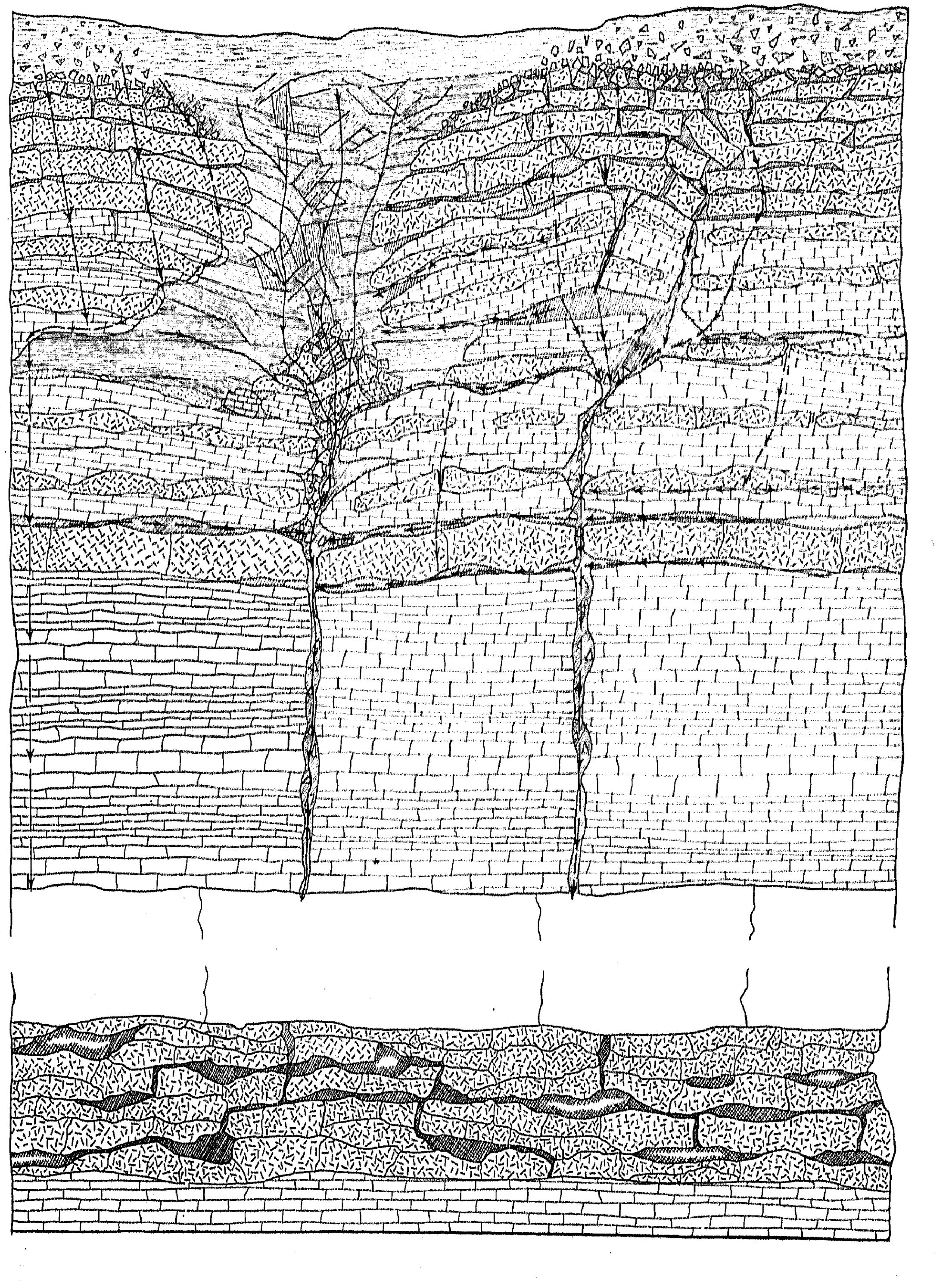
The following discussion is based (1) upon the belief that the ore bodies have been the result of concentration through a process of solution and re-deposition brought about by downward circulating water;* this process may have been interrupted by changes in the elevation of the land as a result of cycles of base-leveling; 2nd, that the original source of the metallic minerals has been chiefly the Pennsylvanian shales, sandstones and limestones; 3rd, that the agent of solution and transportation has been meteoric water; and 4th, that solution and deposition were dependent mainly upon the composition of this water and the nature of the rock through which it might be passing.

Beginning, if we may, at the close of the Pennsylvanian era, we have an unknown thickness of shale, sandstone and limestone in alternating groups of beds, through portions of which the lead and zinc minerals were minutely disseminated. Beneath this a conglomerate and an horizon of residual flint, varying greatly in thickness and distributed over a very uneven floor. Beneath this a limestone horizon (the Mississippian) containing interbedded layers and nodules of flint.

At the close of the Pennsylvanian era, as at present, the meteoric water falling upon the ground was in part evaporated, in part re-

*The downward circulation, as understood in this report, involves lateral secretion. Perhaps if one were to measure the distances traveled laterally and downward by the ground waters, the former would be by far the greater. All water passing into the earth is thought to pass through a stage in which the general movement is downward and another in which the movement is upward. In either stage a part of the movement is lateral.



Drawing to illustrate the present relations between the Mississippian and Pennsylvanian Series, the converging oxidizing and reducing circulations and the position of the ore bodies.

moved by the surface streams, and in part added to the underground circulation. This water must have been charged with oxygen and carbon dioxide abstracted from the atmosphere before reaching the surface of the earth, and was therefore oxidizing in nature when starting on its underground circulation. As disintegration, decomposition and erosion continued, the depth of the oxidized zone increased and portions of the Pennsylvanian strata became completely oxidized and removed, exposing the Granby conglomerate and bringing this formation for the first time under the influence of oxidizing solutions.

The places which first came within this zone were the breaks of the hills and ridges of the pre-Pennsylvanian land surface. When the process of erosion and weathering reached this stage, we had the first differentiation of the descending solutions, into those that were oxidizing and those that were reducing, entering the openings in the Granby conglomerate and residual chert beds.

That portion of the rain falling upon the Mississippian, upon the completely oxidized portion of the Pennsylvanian and upon that portion deflected towards the valley along the upper oxidized portions of the Pennsylvanian was oxidizing in nature. These waters probably contained the oxidized metallic salts, oxygen, carbon dioxide, organic acids and probably some sulphuric acid, resulting from the oxidation of sulphides. These solutions were acid in nature.

That portion of the surface water which gradually percolated downward through the unoxidized portion of the Pennsylvanian strata was soon depleted of its oxygen. It became charged with organic matter, alkaline sulphides and carbonates and hydrogen sulphide and was therefore reducing and alkaline in nature. This solution passed downward into the Granby conglomerate and the openings in the residual flint beds below.

These openings became the course for both the oxidizing and reducing solutions, through the mingling of which the first deposition of the metals was brought about.

As erosion gradually removed the standstones and shales of the Pennsylvanian, the proportion of oxidizing solutions gradually increased and the reducing conditions gradually diminished. At the present time erosion has so far removed the Pennsylvanian as to make the effect of the reducing solutions in this area comparatively little, except in very restricted areas contiguous to the shale pockets.

With the continual increase in the volume of the oxidizing solutions the metallic salts precipitated as sulphides were again oxidized and taken into solution, but the proportion of reducing solutions being small, these salts were reprecipitated largely as oxidized minerals instead of sulphides. The extent and importance of this circulation under oxidizing conditions is shown in the mining of the oxidized minerals to a depth of more than 100 feet below the level of ground water. Plate XXXVII. illustrates graphically one stage of the circulation outlined above.

The metallic sulphides, deposited in minute particles throughout the Pennsylvanian strata, became concentrated into workable ore bodies in the Granby conglomerate and pre-Pennsylvanian residual flint of the Mississippian by the continuous donward circulation outlined above.

In the following pages the reader will find a brief discussion of the chemical reactions possible in the solution, transportation and deposition of the following minerals: Blende, galena, pyrite, smithsonite, calamine, cerussite and dolomite. Also the probable causes for the present distribution and association of these minerals in the ore bodies.

For a detailed discussion of the chemical reactions which may take place during the concentration, of not only the ores of lead and zinc, but those of copper, gold, silver and iron, the reader is referred to "A Treatise on Metamorphism," by C. R. VanHise, Monograph XLVII, United States Geological Survey.

## SPHALERITE (BLENDE).

Two phases of deposition of blende are clearly exhibited in this area, associated (1st) with black flint, and (2nd) with dolomitic spar, cubes of galena and calcite. The calcite and galena vary in abundance and both may be entirely absent.

The zinc may be taken into solution as the sulphide, sulphate, carbonate, chloride and nitrate. There is no evidence that the chloride and nitrate were important factors in the process of concentration, although analyses of mine waters in the Joplin area show the widespread occurrence of chlorides and nitrates in small quantities. Of the remaining three the sulphide is but slightly soluble. Solutions charged with oxygen and carbon dioxide may slowly oxidize the sulphide to sulphate and carbonate. The sulphate is very and the carbonate slightly soluble.

Of these the sulphate has probably been the chief form in which the zinc has been carried in solution in the concentration of the ores in this area. Although the sulphide is but slightly soluble in pure water, Becker* shows that in the presence of sodium sulphide it is soluble to some extent.

The deposition of blende from the above solutions may have been brought about according to several possible reactions. In case the zinc was in solution as the sulphide without the presence of sodium sulphide, it may have been precipitated by the addition of any substance which would lower its saturation point. When the sulphide is in solution, due to the presence of sodium sulphide, it may be precipitated by any substance which will decompose the sodium sulphide, or, possibly, partial deposition may result from simple dilution, as is the case with mercuric sulphide.** However, the slight solubility of the sulphide probably renders the transportation and deposition of the zinc as such of little importance in the formation of the ore-deposits.

The deposition of zinc, which is carried in solution in the oxidized form, may occur as a result of four sets of conditions, as outlined below.

(1) The introduction of hydrogen sulphide or soluble sulphides into an *alkaline* or *neutral* solution of zinc carbonate or zinc sulphate will precipitate the zinc as sulphide, according to the following reactions:

$$ZnSO_4 + H_2S = ZnS + H_2SO_4$$

$$ZnCO_3 + H_2S = ZnS + H_2CO_3$$

In the above reactions with hydrogen sulphide, sulphuric acid is formed in one case and carbon dioxide in the other. In the first case the weight of the sulphuric acid formed is slightly more than that of the blende, while in the second case the weight of the carbon dioxide is not quite one-half that of the blende. The formation of these acids, unless neutralized, would soon tend to cause the formation of blende to cease, since zinc sulphide is not precipitated from an acid solution.

Where both hydrogen sulphide and the alkaline sulphides are present, together with the carbonates of the alkalies, as was probably the case in that portion of the downward circulation coming from the shales, the soluble sulphides and carbonates would neutralize any acid formed during the precipitation of blende by hydrogen sulphide. This reaction in the case of the soluble sulphides would generate hydrogen sulphide according to the following reaction, viz.:

$$CaS + H_2SO_4 = CaSO_4 2H_2O + H_2S$$

*Becker, G. F., Geology of Quicksilver Deposits of the Pacific Coast. Mon. U. S. G. S., Vol. 13, p. 434.

**Ibid., p. 429.

Where a soluble sulphide is introduced the corresponding salts of sulphuric and carbonic acids are formed. In the case of calcium sulphide, gypsum and calcite are products of the reaction, viz.:

$$ZnSO_4 + CaS + 2H_2O = ZnS + CaSO_4, 2H_2O$$

$$ZnCO_3 + CaS = ZnS + CaCO_3$$

(2) Schurmann* has shown that the metals have an increasing affinity for sulphur in the following order—manganese, thallium, arsenic, iron, cobalt, nickel, zinc, lead, tin, antimony, cadmium, bismuth, copper, silver, mercury and palladium. He has also shown that the sulphide of any member of the series will react upon the oxidized salts of those members having a stronger affinity for sulphur and precipitate them as sulphides, the metal of the precipitating sulphide, itself, going into solution. According to the order of affinity given in the above series, zinc should be precipitated as the sulphide from the solution of the oxidized salts of this metal by both pyrite and marcasite, the iron at the same time passing into solution, as follows:

$$FeS_2 + ZnSO_4 + O_2 = ZnS + FeSO_4 + SO_2$$

$$FeS_2 + ZnCO_3 + O_2 = ZnS + FeCO_3 + SO_2.$$

According to this series, the oxidized salts of cadmium should be reduced by zinc sulphide, viz.:

$$ZnS + CdSO_4 = CdS + ZnSO_4$$

The greenokite (CdS), coating blende, which is being decomposed as described on page 53, may be attributed to the above reaction. This also illustrates one of the ways by which blende may, to some extent, pass into solution.

(3) Stokes** has shown that zinc sulphide may be precipitated from solutions without the presence of oxygen at temperatures from 100° C. to 180° C., according to the following reaction, viz.:

$$14ZnCO_3 + 8FeS_2 + Na_2CO_3 = 14ZnS + 4Fe_2O_3 + Na_2S_2O_3 + 15CO_2$$

Calcium carbonate may be substituted for the sodium carbonate, although the reaction proceeds more slowly in this case. In all probability this reaction takes place at ordinary temperatures, but much slower. There would be formed, according to this reaction, practically one-half (.47) as much by weight of hematite as zinc sulphide.

(4) Organic matter has the power of reducing the oxidized salts of zinc to the sulphide. It may do this either by direct reaction upon

*Schurmann cited by VanHise, Treatise on Metamorphism, Monograph XLVII., U. S. G. S., p. 1114—1904.

**Stokes cited by VanHise, Treatise on Metamorphism, Monograph XLVII., U. S. G. S., p. 1152—1904.

the zinc salts or by reaction upon another salt which forms a precipitant for the zinc.

In the first case zinc sulphate may be reduced to the sulphide by the direct abstraction of its oxygen by organic matter. The end reaction may be written as follows:

$$ZnSO_4 + 2C = ZnS + 2CO_2.$$

The reaction is probably not as simple as the above equation, as the organic matter producing the above reduction must be in a state of chemical change in order to provide the necessary reducing conditions.

Although zinc sulphate is rather difficult to reduce directly, the same results may be reached through the action of organic matter upon the alkali and alkaline earth sulphates. These salts are quite readily reduced to the sulphide, under these conditions, forming the soluble sulphides which in turn will precipitate the zinc as sulphide. The soluble sulphides may also, in the presence of free carbonic acid, be decomposed, forming hydrogen sulphide. The two reactions may be written as follows, each producing a reducing compound:

$$Na_2SO_4 + 2C = Na_2S = 2CO_2$$

$$Na_2S + CO_2 + H_2O = Na_2CO_3 + H_2S.$$

It is thought that this indirect action of organic material has probably been of the greatest importance in the precipitation of the ores.

Of these four possible cases, it is thought that the reaction involving $H_2S$ has been by far the most important.

The reaction involving pyrite may have brought about to some extent, the deposition of the secondary blende, but the absence of pyrite or pseudomorphs of pyrite in deposits of either the primary or secondary blende gives evidence that reactions from this cause have been of minor importance.

The reaction outlined by Stokes is thought to have had little if any part in the formation of the ore deposits. The practical absence of hematite in any of the deposits of blende in the Granby area makes this reaction very improbable. The absence of hematite is particularly strong evidence in this case, where the resulting product would contain by weight practically 50% hematite, had it been formed according to the reactions involved in Case 3.

## GALENA.

The galena occurs mainly in large masses of crystal aggregates embedded in red clay; in cubic crystals attached to the flint cap rock;

or in cubic crystals associated with dolomitic spar and blende. Small crystals occur sparingly in the black flint.

In general, the results of oxidizing and reducing solutions are similar to those in the case of zinc, although the greater stability of lead sulphide under atmospheric conditions renders its oxidization much slower than in the case of both zinc sulphide and iron sulphide.

Galena is but slightly soluble in pure water. Becker* also finds it practically insoluble in sodium sulphide. It is thought that the transportation of the lead in the form of the sulphide has been of little or no importance in the concentration of the ore bodies.

As the galena, which is thought to have occurred originally in the Pennsylvanian rocks, was brought into the zone of oxidization, it was gradually taken into solution as the sulphate or carbonate, and may have been later deposited according to any of the reactions involved in the following four cases:

1st. By the introduction of hydrogen sulphide or soluble sulphides into either *acid or alkaline* solutions of lead salts, the lead is at once precipitated as the sulphide, viz.:

$$PbSO_4 + H_2S = PbS + H_2SO_4$$
$$PbCO_3 + H_2S = PbS + H_2CO_3.$$

The same reaction may be written by substituting for hydrogen sulphide in the above equations any soluble sulphide, the only difference in the result being the production of the corresponding salt of the above acid.

As in the case of the precipitation of blende by hydrogen sulphide, the above reactions produce acids which would tend to increase the acidity of the solution. As lead sulphide is insoluble in acid solutions, especially sulphuric, this additional acidity has no effect upon the precipitation of the lead. On the other hand, if zinc salts were present, the acid condition would effectually stop precipitation of zinc until the solution became neutralized. Thus the precipitation of galena through the action of hydrogen sulphide would tend to keep the zinc in solution.

2nd. As shown on page 90, the affinity of lead for sulphur is stronger than either zinc or iron. Consequently the sulphides of the latter metals may precipitate the lead as sulphide according to the following reactions, viz.:

$$PbSO_4 + ZnS = PbS + ZnSO_4$$
$$PbSO_4 + FeS_2 + O_2 = PbS + FeSO_4 + SO_2.$$

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*Becker, G. F., Quicksilver Deposits of the Pacific Slope, Mon. U. S. G. S., Vol. XIII, p. 434.

Similar reactions may be written by substituting lead carbonate for lead sulphate.

3rd. Stokes* has also shown, as in the case of zinc, that lead carbonate may be precipitated as the sulphide by pyrite in the presence of sodium carbonate. The reaction being written as follows:

$$14PbCO_3+8FeS_2+Na_2CO_3=14PbS+4Fe_2O_3+Na_2S_2O_3+15CO_2.$$

The experiments made to demonstrate the reactions involved in this and Case 3 were carried out at a temperature of 100° C.

4th. Organic matter will reduce lead salts to the sulphide. As already cited, under zinc blende this may be accomplished either directly through the abstraction of oxygen or indirectly by the generation of hydrogen sulphide. In the latter instance the hydrogen sulphide is the direct cause of precipitation.

It is thought that a greater part of the galena, as in the case of blende, has been deposited according to the reactions in Case 1, involving $H_2S$. The principal source of the $H_2S$ is thought to have been the same as explained under Blende.

In this area very little galena has been deposited upon the blende, and for this reason it is thought that the reaction involving the sulphide minerals has been of minor importance in concentrating the galena. Those reactions involved in Cases 3 and 4 are also thought to have had little or no influence in the formation of the galena. These conclusions are based upon the field observation. For example, the reactions involved in Case 4 would result in the formation of hematite, which, as pointed out above, is not present, to any extent, in the ore bodies.

## PYRITE.

Bodies of pyrite have been encountered in deep drilling in this area. Several drill holes have shown a considerable quantity of this mineral at depths ranging from 250 feet to 350 feet. In one hole flint containing 10 per cent of pyrite was encountered at a depth of 1378-1392 feet. In this same hole a seven-foot bed of white flint, carrying 6% blende, was passed through. With the exception of small crystals studding the surface of specimens of blende and galena taken from cavities in the Homestake and Mascot mines, no pyrite was observed associated with the ores, although it occurs abundantly in the Pennsylvanian Shale.

*Stokes, cited by VanHise. Treatise on Metamorphism Mon., 47, U. S. G. S., 1904, p. 1149

As observed on page 90, iron does not have as great an affinity for sulphur as either lead or zinc. For this reason, under like conditions, the sulphides of iron are oxidized with much greater rapidity than the sulphides of either zinc or lead. The oxidized salts formed are very soluble and readily pass into solution.

As shown by Schurmann, the oxidized salts of either lead or zinc in solution are precipitated by pyrite and marcasite as the sulphide, the iron at the same time passing into solution.

In alkaline and neutral solutions, the oxidized salts in the presence of hydrogen sulphide are precipitated as the sulphide with the formation of sulphuric acid, as explained under galena and blende.

In dilute solutions, in the presence of an excess of soluble sulphide, the iron sulphide is not precipitated.*

In support of this fact, often noted in the laboratory, Becker** finds that pyrite and marcasite are soluble in sodium sulphide. Upon the destruction of the soluble sulphide the iron is deposited as the sulphide.

In acid solutions the sulphides of iron are not precipitated by hydrogen sulphide.

Although in a concentrated solution the greater portion of the iron will be precipitated in the presence of an excess of carbonic acid, yet the presence of this acid in excess will cause iron to be carried in solution even in the presence of a large excess of hydrogen sulphide. Although the greater number of the chalybeate waters of Missouri contain no hydrogen sulphide, Schweitzer*** gives a number of analyses in which hydrogen sulphide is present in water containing iron salts and carbonic acid.

Peale**** gives analyses of waters from many different parts of the United States, and in some cases these show large quantities of hydrogen sulphide with notable quantities of iron carbonates; and also sulphates in the presence of considerable free carbonic acid. The following table abstracted from this report shows the amount of each gas present in cubic inches, the ferrous carbonate being given in grains per gallon:

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*Ostwald—Foundations of Analytical Chemistry, p. 142.

**Becker cited p. 432.

***Schweitzer, P., Report on Mineral Waters, M. Geo. Sur., Vol. III, 1892.

****Peale, A. C., Mineral Springs of the U. S., Bul. U. S. G. S., No. 32—1886.

| Location. | $H^2S$. | Fe $H^2$ $(Co^3)^2$ | $Co^2$ | Page number. |
|---|---|---|---|---|
| New York | 3.6238 | 0.24 | 2.9412 | 37 |
| Virginia | 3.4 | 3.77 | 11.6 | 59 |
| " | 5.91 | 0.26 | 8.62 | 64 |
| Florida | 0.291 | 1.04 | 2.350 | 85 |
| " | 75.00 | .06 | 52.88 | 85 |
| Alabama | 0.56 | 2.42 | 6.00 | 92 |
| " | 14.96 | 1.92 | 3.19 | 93 |
| " | 30.67 | 4.72 | ........... | 93 |

Many other analyses are given, showing that iron is transportable in the presence of $H_2S$ where the free acid is carbonic.

All the above reactions would have a tendency to concentrate the iron at lower levels. The fact that we nowhere find pyrite associated with the earliest ore deposits, makes the reaction of the zinc and lead salts in solution upon the pyrite in the formation of the secondary deposits quite unlikely.

In the Granby area it is thought that the presence of carbon dioxide in the oxidized solutions carrying the iron salts was the cause of the retention of the iron. After mingling with the alkaline solutions the iron was precipitated only after the carbonic acid had been largely used in dissolving calcium carbonate.

As the circulation of the oxidizing waters gradually became more dominant and reached greater depths, the sulphides deposited by the early circulation again came under oxidizing conditions. This resulted in oxidizing again the sulphides of the earlier deposition. These sulphides were so rich that a part of the oxidized product was undissolved, and today this oxidized residue remains in the form of workable ore bodies.

### SMITHSONITE.

The carbonate of zinc is quite common in this area. It occurs abundantly above and near the level of ground water and, to some extent, associated with the calamine. It may be formed according to the following reactions:

1st. Waters containing oxygen gradually oxidize the zinc sulphide to sulphate. The sulphate will at once react with any carbonate which may be in solution, smithsonite being formed. Both compounds suffer mutual decomposition, as shown in the following equation:

$$ZnSO_4 + Na_2CO_3 = ZnCO_3 + Na_2SO_4.$$

Where calcium carbonate is used, gypsum would be formed at the same time.

2d. Sphalerite may also be acted upon by the carbonate of lead in solution, the result being the formation of galena and smithsonite. The reaction may be written as follows:

$$PbCO_3 + ZnS = PbS + ZnCO_3.$$

3rd. Bischoff* has shown that carbon dioxide, passed through water in which particles of calamine are suspended, decomposes the calamine with the formation of the carbonate of zinc, as follows:

$$(ZnOH)_2SiO_3 + CO_2 = 2ZnCO_3 + SiO_2 + H_2O.$$

This reaction may explain the presence of a small percentage of smithsonite associated with the calamine of this area.

All of the above reactions were possible under conditions existing in the Granby area, although it is thought that Case I was the most important.

### CALAMINE.

Of the oxidized minerals, calamine is the most abundant in this area. It occurs in every part of the area, and as far below the surface as the deepest mines.

The following reaction shows the probable method of formation of this mineral:*

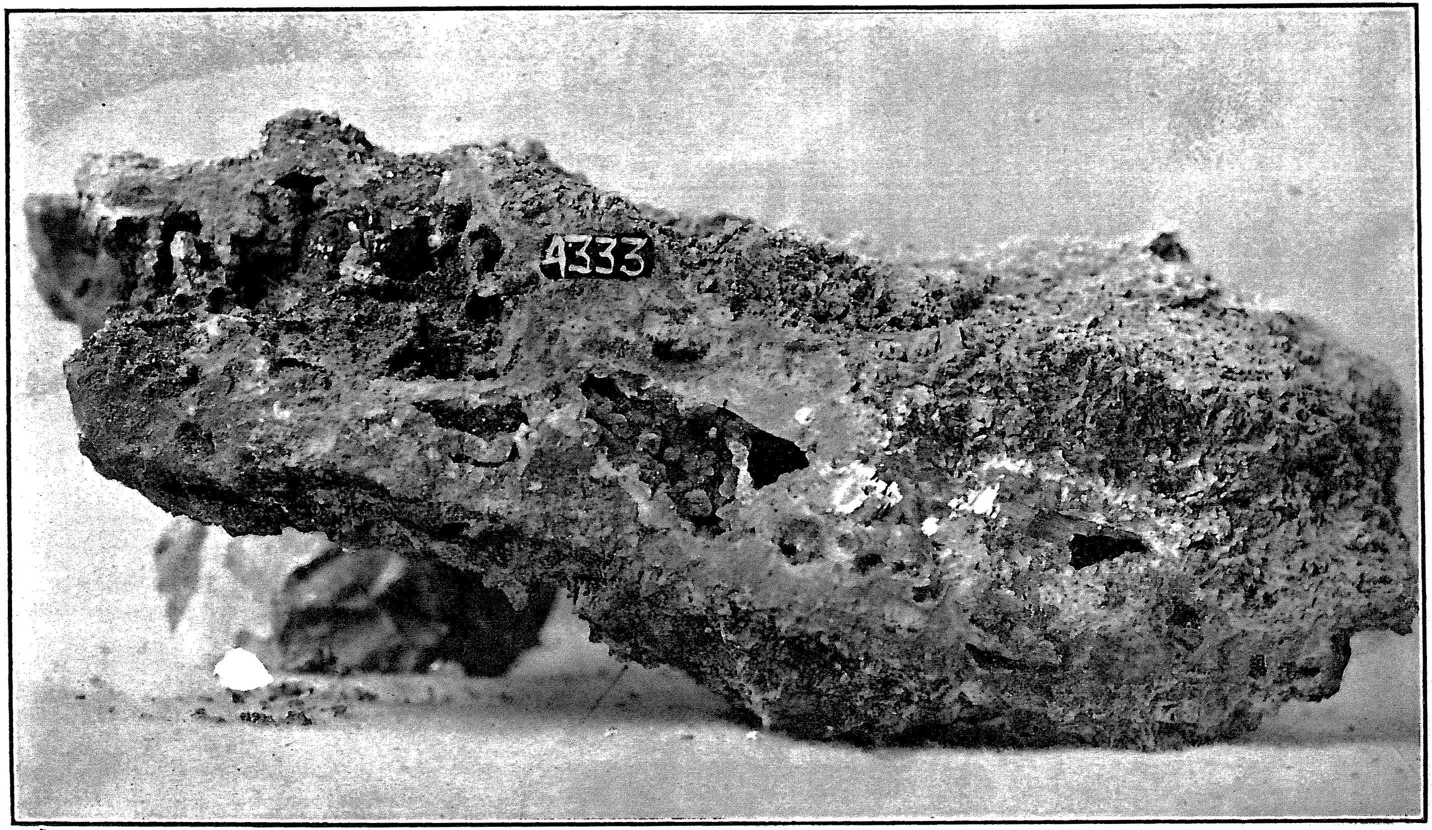
$$2ZnSO_4 + SiO_2 + 3H_2O = (ZnOH)_2SiO_2 + 2H_2SO_4.$$

While the above reaction probably explains the formation of a large proportion of the calamine, the conditions necessary are not shown in the equation. That calamine will not be precipitated from all solutions containing silica and zinc salts, is shown by the contemporaneous deposition of black flint and blende, where the zinc is deposited as the sulphide and the silica as free, gelatinous silica. This form of deposition has occurred where there was an excess of reducing material in a neutral or alkaline solution, while the calamine has been formed in oxidizing solutions which were probably slightly acid as the sulphide of lead is often found embedded in the calamine. It is thought that the calamine was formed largely under the latter conditions.

### CERUSSITE.

This mineral occurs mostly in the upper openings above the level of ground-water, where it occurs either as a heavy white layer coating galena, or as casts of galena crystals, from which the galena has been

*Bischof, G., Chemical and Physical Geology, Vol. 2, p. 610—1859.




CALAMINE COVERED WITH DOLOMITIC SPAR.
There are several crystals of galena imbedded in the calamine.

entirely removed. It also occurs below water level, imparting a gray color to the etched surfaces of the galena.

The direct action of carbonated waters upon the galena gradually changes it into the sulphate.

Lead sulphate and calcium carbonate in solution suffer mutual decomposition, with the formation of lead carbonate and gypsum, as follows:

$$PbSO_4 + CaCO_3 + H_2O = PbCO_3 + CaSO_4 2H_2O.$$

Since deposits of gypsum do not occur in this area, the extent of this reaction must have come within the limits of solubility of the gypsum, which is, according to Bischoff, 1 in 6000. Within the limits of solubility this reaction may have gone on indefinitely, the gypsum being carried to lower levels where, through decomposition, it became the source of $H_2S$ used in the precipitation of the blende or galena of the secondary concentration; calcite also being formed by the decomposition. The position in which a greater portion of the cerussite deposits have been found leads one to believe that they have resulted chiefly from oxidation through atmospheric agencies.

### DOLOMITE.

As explained on page 47, three distinct forms of dolomite occur in this area—(1) fine grained, (2) coarse grained gray, (3) and coarse grained pink. The fine grained beds, as well as a portion of the gray spar, have apparently resulted from the dolomitization of the original limestone. This change resulted in the simultaneous introduction of magnesia and the removal in solution of calcium carbonate. The third form of dolomite, known locally as "pink spar," occurs mostly in crystalline form. It formed later than the gray and fine grained dolomites, and may be either the result of the solution and redeposition of these or the result of the mixing of solutions carrying magnesium and calcium salts.

### GENERAL.

The following discussion is intended to emphasize two important factors bearing upon the deposition of the ores of this area, namely: (1st) That the primary vertical distribution of the sulphide ores is

*VanHise, C. R.—A treatise on Metamorphism, Monograph XLVII., U. S. G. S., p. 1147, 1904.

due mainly to the different conditions under which the lead, zinc and iron sulphides are precipitated from solution; and (2nd) that a continuous or interrupted downward circulation, as already described, rationally explains the present location of the ore bodies. At the close of this chapter some reasons are given to show that a first concentration by upward circulating, either acid or alkaline waters, does not explain the genesis of what we consider to be the oldest known lead and zinc minerals of this area.

Any theory which accounts for the vertical succession and association of the minerals must take into account not only the possible chemical reactions involved, but also changes in the underground circulation, brought about by degradation, subsidence and elevation.

In the discussion of the chemical reactions on the preceding pages the chemistry of the metals alone is considered. Substances in solution may be brought within the zone of chemical affinity by two processes, either by a mixing of the solutions or by diffusion.

The importance of diffusion and of the acid, alkaline or neutral condition of the underground waters has apparently not yet been fully recognized.

It is well known that substances dissolved in any portion of a solution will diffuse throughout the entire solution until homogeneity is reached. In this respect the solution acts precisely as a gas and in a dilute solution follows the law of gases. Thus, substances taken into solution from the wall rock or introduced by the meeting of two solutions, will diffuse throughout the mass. Should the solution, through precipitation at any point, become depleted in any particular salt, diffusion of that salt will take place towards the point of depletion until homogeneity is again reached.

It is also well known that certain substances diffuse with greater speed than others. The acids have a relatively high speed of diffusion, often being double that of the corresponding salts. Each salt also has its own rate of diffusion, and in many cases these are so widely different that a partial separation of different salts can be effected thereby.

Diffusion takes place in all directions, regardless of the movement of the waters, and is effective in all directions in so far as the movement of the water does not counteract it.

Mingling of solutions may be the dominant factor where there is relatively rapid circulation as in fissures, joints, caves, etc., but diffusion becomes of the utmost importance in slowly moving waters, as below the level of ground-water. It is thought that the location of the major portion of the secondary galena in the upper part of the openings, where it is associated with the calamine, is largely due to this factor.

The details of the geological history of this area, since Pennsylvanian times, are very meager. For this reason an exact study of the reasons for the deposition and variations of the ore deposits is attended with great difficulty. The variations in the level of ground-water, in the composition of the Pennsylvanian strata, and in the quantity of the oxidizing and reducing solutions; and the effect of the Cretaceous and Tertiary periods of base leveling are factors which are known only in a general way.

The mining developments in this area show at least three phases of deposition since the metallic sulphides were first deposited. In brief, they are (1st) a deposition of galena, blende and black flint. In this the galena occurs mainly above the black flint and blende, although in the upper portions of the latter there are scattering crystals of galena. These diminish in quantity with depth, and were not noted in the black flint of any of the active mines in the area. At depths of over 200 feet pyrite has been encountered in drill holes. This may have been deposited at the time the black flint was formed or later, there being no evidence upon which to decide this point. (2nd) The deposition of "gray dolomite" or "spar" with both galena and blende, often grading into "pink spar," associated with galena and blende. Calcite was also formed during this period. In the Granby area there is but little field evidence that there is a gradation between the first and second stages of deposition, but in the Joplin area, although no detailed study was made, phases were noted where the "spar" gradually becomes more dominant until the black flint entirely disappears, showing that, at least in parts of the district, there was a gradual change in the solutions, with a consequent change in the precipitate. Many samples were noted on the dumps in which the black flint and spar show a banded structure, as though the conditions for deposition had been fluctuating during the formation with the resultant variations in the deposits. Much of the gray spar was deposited contemporaneously with the black flint, as shown by the crystals of dolomite, which are surrounded completely by this materal. Many occurrences were noted west of Joplin, where the black flint formed later than the spar. It is apparent that the conditions of deposition varied during the two earlier stages of the formation of the ore bodies. (3rd) The late deposits resulting from the solution and redeposition of the above. These, in the Granby area, consist chiefly of silicates and carbonates, although sulphides also occur. Large quantities of calcite were deposited during this period.

As explained elsewhere, we have had in this area, for a somewhat indefinite period, a downward circulation, which, in some places, was reducing and in other places oxidizing. Both of these circulations have derived the substances which they held in solution chiefly from the Pennsylvanian shales. This differentiation of the descending circulation into oxidizing and reducing solutions was probably not inaugurated until erosion had partly removed the Pennsylvanian shales, exposing in places the flint and limestone beds of the Mississippian. Prior to this differentiation the underground waters were probably charged with magnesium salts carried downward from the Pennsylvanian strata. These would result in dolomitization prior to the deposition of the ores. The fine grained beds of dolomite, described in another part of the report, as well as portions of the gray spar, may have been formed at this time.

The oxidizing waters, which derived the substances which they held in solution from the upper oxidized portion of the shales and exposed portions of the Granby conglomerate, percolated downward through the conglomerate and residual flint beds of the Mississippian into the openings below. These solutions contained free oxygen and carbon dioxide derived from the air; organic acid, nitrates and carbon dioxide derived from the decomposing humus of the soil; and the oxidized salts of the metals, obtained through the oxidation of the sulphides of the shale.

Through the reaction of oxygen on pyrite and marcasite, ferrous sulphate and sulphur trioxide are formed, the latter reacting on the water to form sulphuric acid. The ferrous sulphate in the presence of oxygen is oxidized in part to ferric sulphate. This sulphate is, in part, hydrolized by water forming ferric hydroxide and sulphuric acid. The ferric sulphate, reacting with the carbonates and alumina of the clay, is deposited in part as the hydrated oxide, with the consequent formation of the sulphate of the metals and sulphuric acid. This theory is born out by experiments made by Schweitzer,* in which a solution containing free sulphuric acid and sulphates was obtained by washing coal which contained pyrite, with small amounts of water under oxidizing conditions. Digesting shale with this solution for two days most of the ferric sulphate obtained by the first oxidation was precipitated as the oxide. There was an increase in

*Schweitzer, P., Report on Mineral Waters, Mo. Geol. Sur., Vol. III, p. 7, 1892.

the aluminium sulphate formed, and the amount of free sulphuric acid was increased nearly four-fold. The content of silica was also largely increased. From this we may reason that the early solutions, as they left the shale, probably bore free sulphuric acid, unless entirely neutralized by magnesium and calcium salts occurring in the shale. This action of the sulphuric acid and magnesium and calcium salts gives rise to various amounts of the sulphates of these metals.

The following analyses* of spring waters from Virginia show them to be very similar in chemical composition to that just described. It will be noted that these are sulphate waters carrying both free sulphuric acid and zinc suplhate. These waters are not taken from mining regions. They occur mostly in the Devonian shales.

| Constituents. | Rockbridge Alum Springs. | | | Jordan Alum Springs. | |
|---|---|---|---|---|---|
| | Spring No. 5. | Spring No. 8. | Spring No. 9. | Spring No. 4. | Spring No. 5. |
| Solids. | Grains per gal. | Grains per gal. | Grains per gal. | Grains per gal. | Grains per gal. |
| Sodium sulphate | 0.24 | 0.32 | 0.24 | 0.23 | 0.32 |
| Calcium sulphate | 0.32 | 3.02 | 1.84 | 3.31 | 3.01 |
| Lithium sulphate | Trace | 0.01 | 0.01 | 0.02 | 0.01 |
| Magnesium sulphate | 3.15 | 5.36 | 8.21 | 9.22 | 5.37 |
| Potassium sulphate | 0.32 | 0.30 | 0.33 | 0.27 | 0.30 |
| Aluminium sulphate | 11.20 | 26.11 | 27.85 | 81.05 | 26.11 |
| Manganese sulphate | 0.13 | 0.57 | 0.53 | 1.02 | 0.57 |
| Iron protosulphate | 0.29 | 0.23 | 0.32 | 0.52 | 0.22 |
| Iron persulphate | 1.43 | 2.43 | 2.87 | 5.17 | 2.43 |
| Nickel sulphate | 0.10 | 0.26 | 0.41 | 0.46 | 0.26 |
| Cobalt sulphate | 0.08 | 0.31 | 0.31 | 0.32 | 0.31 |
| Copper sulphate | 0.12 | 2.33 | 3.10 | 6.08 | 2.33 |
| Zinc sulphate | 0.07 | 0.21 | 0.28 | 0.61 | 0.22 |
| Cadmium sulphate | Trace | Trace | Trace | 0.03 | Trace |
| Calcium phosphate | Trace | 0.01 | 0.01 | 0.01 | 0.01 |
| Sodium chloride | 0.01 | 0.06 | 0.04 | 0.08 | 0.06 |
| Calcium fluoride | Trace | Trace | Trace | Trace | Trace |
| Silica | 2.00 | 3.30 | 3.42 | 3.08 | 3.30 |
| Sulphuric acid | 2.07 | 7.90 | 5.32 | 4.84 | 7.90 |
| Organic matter | Trace | Trace | Trace | Trace | Trace |
| Total | 21.53 | 52.73 | 55.09 | 116.27 | 52.73 |
| Cases. | Cubic inches. | Cubic inches. | Cubic inches. | Cubic inches. | Cubic inches. |
| Oxygen | 1.33 | 1.35 | 1.62 | 1.11 | 1.35 |
| Nitrogen | 3.76 | 3.33 | 4.04 | 3.19 | 3.33 |
| Carbon dioxide | 11.22 | 9.91 | 11.08 | 10.38 | 9.91 |

That waters of a very similar nature occur in Southwest Missouri is shown by the following partial analyses made by Mr. W. George Waring of Webb City. These waters were either taken from the discharge pipe or the sump of mines, which had been in operation for some time. Be-

*Peale, A. C., Mineral Springs of the United States, Bul. 32, U. S. G. S., pp. 63, 65.

sides the constituents given below, these waters also contain calcium and magnesium sulphates. The following amounts are given in grams per litre:

| Mine. | Zinc. | Ferrous Iron. | Total Iron. | Free Sulphuric Acid. |
|---|---|---|---|---|
| Maggie Murphy | 2.697 | 0.235 | 0.231 | 0.167 |
| Alabama Coon | 2.807 | 0.322 | 0.384 | 0.186 |
| Columbia, N. Y | 1.548 | 0.464 | 0.503 | 0.157 |
| Monte Cristo | 1.905 | 0.210 | 0.240 | 0.127 |
| Blue Goose | 0.175 | 0.190 | 0.190 | None |
| Alexander | 1.540 | 0.420 | 0.692 | 0.363 |
| St. Anthony | 2.465 | 0.480 | 2.267 | 2.352 |

Where the water is taken from drill holes prior to the opening of the mines the water does not show free acid. This would be expected, as in the relatively slow oxidation under present conditions the sulphuric acid would be neutralized by the dolomite now associated with the ores.

In general, the oxidizing portion of the descending circulation contained carbon dioxide, oxygen, organic acids, various sulphates of the metals, sulphuric acid and silica.

In the case of the second, or reducing, descending circulation, the water slowly percolated downward along the joints and bedding planes of the unoxidized portion of the shale. Entering this part of the formation, the waters contained oxygen and carbon doxide, together with some of the oxidized sulphates. The oxygen was soon extracted by the abundant organic matter, ferrous salts or sulphides. The carbon dioxide, decomposing, in part, the alkaline silicates, was partly consumed with the formation of the alkaline carbonates. These carbonates reacted upon pyrite with the production of soluble sulphide, as shown by Stokes* in the case of sodium carbonate. They would also react with any of the sulphates of the heavy metals, which had entered the unoxidized portion of the shale from above, precipitating them as the carbonates with the formation of alkaline sulphates. The organic matter would reduce these sulphates with the production of hydrogen sulphide and soluble sulphides, as has already been shown. Thus, these carbonates become a prolific source of hydrogen sulphide and soluble sulphides.

This second descending circulation also became highly charged with organic matter during its passage through the Pennsylvanian. As it passed into the Granby conglomerate, this solution dissolved silica, due

*Stokes, cited by Van Hise—A treatise on Metamorphism; Monograph 47, U. S. G. S., p. 1107, 1904.

to its alkaline nature. In general, this reducing circulation probably contained organic matter, alkaline sulphide, hydrogen sulphide, alkaline carbonates and silica.

These two descending circulations, the one oxidizing and the other reducing, both flowing towards the major axis of drainage, met and mingled in the openings in the residual flint beds, where occur the principal ore deposits of this area.

The mingling of these solutions and the diffusion which probably became important below the level of ground-water provided the conditions required for precipitation. The hydrogen sulphide and organic matter carried by the alkaline solution would at once react upon the lead salts in the acid solution, precipitating the lead as galena, and forming a notable amount of acid, as shown on pages 92 and 93. And since it is supposed that the larger proportion of the lead is carried as the sulphate, sulphuric acid would be the principal acid formed. The ferric sulphate present would also be reduced to ferrous sulphate with the formation of sulphuric acid. The acid formed during the precipitation of the galena and the reduction of ferric to ferrous sulphate, as well as original acidity of the oxidized solutions, would require neutralization before the hydrogen sulphide could precipitate the zinc as sulphide from these dilute solutions. Since the solutions flow chiefly downward and laterally, this neutralization would only occur beneath the orginal deposits of galena. In many places the blende has been deposited directly underneath the galena; in other places it has been deposited at a considerable depth below the galena; the variation in depth is probably due chiefly to the varying proportions of oxidizing and reducing solutions.

With the neutralization of the solutions and the precipitation of the sphalerite, there was in this area a simultaneous deposition of silica, the reaction possibly being due to the sulphuric acid neutralizing the sodium carbonate in the alkaline solution. This silica was probably in part precipitated in a gelatenous form and carried down with it the suspended organic matter. This soft condition of the silica permitted the sphalerite, as precipitated, to take on its crystalline form.

The iron salts in the acid solution would not be precipitated as sulphide, as shown on page 94, until the free carbonic acid had first combined with the alkalies and alkaline earths to form acid carbonates. The formation of the acid carbonates would take place when the solution came in contact with undecomposed limestone. The fact that iron sulphide will not be precipitated in dilute solutions in the presence of the alkaline sulphides, which were probably present in the early solutions, may possibly account for the absence of iron sulphide in the early deposits. The ore bodies of this area show that in the early deposits the pyrite is strikingly absent.

It may be well to note, at this place, that to the above reaction of the ferric sulphade on the shale, which has resulted in the formation of ferric hydroxide, may be attributed the red color of the clay. To its continued action we attribute the usually deeper red color of the later clays washed into the mines.

The second phase of deposition is one in which there has been a precipitation of large amounts of dolomite. There was introduced, probably by the reducing solutions, during this phase of deposition, large amounts of magnesium salts which united with the calcium salts in solution to form dolomite. The spar is especially abundant in many of the mines west of Joplin, where the limestone is in close proximity to the ores.

The pink spar, which is the most abundant in the Granby area, has been deposited later than the gray spar, and may be a redeposition of gray spar which has been taken into solution.

The abundance of the carbonates probably caused the oxidized solutions to be quickly neutralized upon the mingling of the solutions with the consequent deposition of the sulphides. Both galena and blende are found associated with spar.

At Oronogo, and in the vicinity of Prosperity, there has been no deposition of spar, the relation being entirely one of black flint and blende below the galena.

The variations in the different areas have not been studied in detail, and we can therefore offer no explanation for these phenomena. Apparently they are mainly due to the differences in physical conditions occurring at the unconformity, as well as to possible difference in the Pennsylvanian strata.

That there was undoubtedly considerable difference in the Pennsylvanian throughout the ore producing area of Southwest Missouri, is shown in the abundant sandstones found at Aurora and Granby, while in the Joplin and Webb City areas the remnants of the Pennsylvanian consist chiefly of shale.

With the removal of a greater portion of the Pennsylvanian, the influence of the circulation passing through this formation gradually diminished, until it became practically nothing. At the same time the corresponding increase in the quantity of the oxidizing solutions made the effect of these upon the lead and zinc minerals continually cumulative. In the latter part of this era the oxidizing solution reacted upon the primary deposits, forming oxidized salts, which, in part, were precipitated as such, and in part carried downward and again precipitated as sulphides at lower levels.

In the typical silicate runs these solutions first came in contact with the heavy beds of galena; above and lower down they came in contact with the black flint and blende. Gradually the blende and galena were oxidized and taken into solution, the black flint at the same time contributing organic matter, which established reducing conditions, as already explained. The hydrogen sulphide formed diffused throughout the solution, precipitating the lead which might be present, as galena. The zinc was not precipitated as the sulphide, owing to the acid condition of the solution. The zinc sulphate, however, would react upon the silicic acid in solution, forming calamine and sulphuric acid, which further acidifies the solution. The hydrogen sulphide, continually diffusing throughout the openings, first meets the incoming solutions near the roof and at once deposits the lead as galena near the roof.

This explanation accords with the facts as found in the field. The galena crystals are found in the upper portions of the openings attached to the flint roof (See Fig. XXIV.) and associated with the calamine, while silicate and cod rock (gray, decomposed, black flint), from which the organic matter and blende have been entirely removed, occur underneath. In places the cod rock grades into unaltered black flint and blende in such a manner as to leave no doubt as to its origin. At present a great majority of the deposits of black flint and blende in this area have been altered to cod rock through this process of oxidation. In protected places the black flint and blende are fresh and unaltered. The occurrences of galena embedded in calamine, as cited above, are strong evidence of the difference in conditions under which galena and blende are deposited.

It may be argued that there was not sufficient hydrogen sulphide to satisfy both the zinc sulphate and the lead sulphate ,and that due to the greater affinity of the latter element for sulphur, it was first precipitated. While, in solutions of equal concentrations, the lead would probably be precipitated in larger quantities than the zinc, yet some sulphur would unite with the zinc. In this case the amount of zinc silicate present shows that the zinc salts, formed through the oxidation of the blende, were present in much greater abundance than the lead, and, according to the law of mass action, more blende than galena should have been formed. However, no blende has been formed in these cases, and it is thought that the acidity of the solution combined with diffusion accounts for the present association of the galena and calamine.

Moreover, the lead crystals, even in the deepest of these runs, have corroded and etched faces, and are often covered with a thin coating of cerussite. Plate XXIV., which is a photograph of a specimen taken from the Tennessee mine, at a depth of about 90 feet below the level of ground-water, illustrates this condition. The oxidized condition of the galena, at this depth below the level of the ground-water, indicates that, at present, deposition of galena is not taking place. Consequently, at the time deposition took place, conditions must have been different. This difference in condition is easily provided for by the establishment of reducing conditions through the oxidization of the black flint. As this material is now almost completely oxidized in many of the runs, the galena crystals are again, slowly, being taken into solution, even in the deepest workings in the area.

In the above we have given a possible explanation of the major occurrences of the lead and zinc minerals in the Granby area. The variations in the level of ground-water; the variations in the quantity, as wall as in the composition of the water introduced by either the oxidizing or reducing circulation; and the protection of certain portions from reconcentration, have all tended to make variations in the associations of the minerals in the different mines. Yet, as a whole, the succession given above is by far the most dominant, and it is thought that the above explanation accounts for the distribution of the lead and zinc minerals as observed in the field.

Since the above explanation of the vertical segregation of the primary sulphides is somewhat different from that generally accepted, it may be appropriate, at this place, to discuss the theory of the deposition of these ores as outlined by VanHise and Bain. They attribute the lead and zinc deposits of the Southwest Missouri district, which includes the Granby area, first, to an ascending circulation, by means of which the primary deposits of the sulphides were concentrated, and, second, to a downward circulation by which the primary deposits were enriched and the sulphides segregated at different levels.

The presence of this dual circulation is based upon the following

1st. That the source of the lead and zinc minerals and magnesia is the Cambro-Ordovician strata beneath the Mississippian.

2nd. That faults of sufficient throw to rupture the Devono-Carboniferous shale, and allow the upward circulation of the solutions, occur in the district.

3rd. That the source of the abundant organic matter is the Devono-Carboniferous shale, and to a lesser extent, the Mississippian limestone.*

Granting the above premises, let us start with a solution ready to enter the Devono-Carboniferous shales and then the Mississippian limestone through the fault planes. This solution carries the metals in the oxidized form, and has probably, through its long underground journey, been entirely depleted of oxygen. The solution may be acid, neutral or alkaline, the premise being simply that there is *one* upward circulation.

As this circulation starts upward, through the Devono-Carboniferous shales, it will be brought at once into contact with the very abundant organic matter which the 3rd premise above would cause these shales to contain. As already shown, the presence of this organic matter forms reducing conditions and the source of hydrogen sulphide. The latter is probably the main precipitant of organic origin, and in this discussion will be the precipitant referred to.

The instant hydrogen sulphide is introduced into the solutions carrying lead and zinc salts, we have the conditions for precipitation. As a result, the sulphide would be deposited soon after leaving these shales, if not actually within them. Considering the solutions as either alkaline or neutral, the hydrogen sulphide would at once precipitate, together, the lead, zinc, and probably the iron as sulphides. If the alkaline sulphides were present in abundance, the iron might remain in solution as described on pages 94 and 95, not being precipitated until coming in contact with acids or other salts coming from surface waters, in which case the iron sulphide would certainly be concentrated at a very high level, probably near the level of the underground water.

The deposition of the lead and zinc sulphides, as shown under the discussion of sphalerite and galena above, tends to make the solution acid. If this were the case, a certain proportion of the zinc sulphide would remain in solution and be transported upwards before neutralization could take place. We would obtain, in this case, a continuous vertical deposition of these sulphides, with a tendency, at least, for the zinc to be concentrated, in greater proportions, at higher levels.

Had the upward circulating waters been acid, which would hardly

*While fissures and pockets of organic material occur throughout the Mississippian limestone in Southwest Missouri, the body of the limestone itself shows but slight traces of this material. Chemical analyses made of different samples of this stone taken from many of the quarries in the State show practically no organic material. The occurrence of this material is well shown in the Carthage quarries, where small seams known as "tar seams" occur. This organic material is very similar to that found in the Pennsylvanian sandstones in the vicinity of Lamar and Nevada, and was undoubtedly derived from the overlying Pennsylvanian strata when they covered this region.

be the case under the conditions cited, the hydrogen sulphide would at once have precipitated the galena, while the zinc and iron would have been carried upward until neutralization had taken place, when they in turn would have been deposited. We would, therefore, in the case of an ascending acid solution have obtained a vertical segregation of the ores, with the galena occurring below the blende and pyrite. Thus, no matter what the original nature of the single ascending solution, there would be formed within, or starting directly above, the Devono-Carboniferous shales either an intimate mixture of the sulphides of lead, zinc and iron, showing little or no vertical segregation, or one in which galena has been concentrated largely at the base of the deposits, near the Devono-Carboniferous shales.

If, after this first deposition by an ascending solution, we consider a downward circulation to have been dominant, we would have deposits of the secondary minerals surrounding the original sulphides. This would be brought about by oxidation becoming the predominant reaction near the surface, and the reduction at lower levels of the oxidized salts thus formed.

The slower rate of oxidation of the galena, together with the tendency of the oxdized salts of lead to react upon the sulphides of zinc and iron, throwing them into solution, while the lead is again deposited as the sulphide, would tend to segregate the lead already deposited at higher levels by the ascending circulation, near the top of the deposits, while the blende and pyrite would be again reduced lower down and dedeposited upon the primary sulphides.

We know of no way by which the galena precipitated in the primary deposits in the lower part of the formation could become segregated at upper levels by secondary concentration. Consequently, the galena should occur intimately mixed with sphalerite and pyrite in the primary deposits, under the conditions cited, wherever these primary deposits, are found. Furthermore, galena of undoubted primary concentration should occur down to the Devono-Carboniferous shales.

As already explained, we find at Granby, as well as throughout the Southwest Missouri district, the major portion of the galena occurring above the blende in heavy beds or chunks at comparatively shallow depths. At Granby this heavy deposit of galena has occurred mainly from 15 to 60 feet beneath the surface, in different parts of the area, although some of the ore has been found at the grass roots. The occurrence of the galena is mainly between flint layers, and is often from 1 to 4 feet in thickness. This method of occurrence precludes the possibility of any mechanical segregation excepting that due to settling of the entire mass. The galena must have been deposited largely at approximately its present level. These heavy deposits have furnished at least *three-fourths of the lead* mined in the district, and undoubtedly constitute at least that percentage of the primary deposits. Statistics of production show that since 1893 approximately 22 million pounds of galena have been produced, while prior to that time 154 million pounds were produced. This shows that a vast quantity of the galena was mined at an early date from these heavy deposits of lead.

In the primary deposits by ascending solutions, as shown above, the galena must have been deposited from the neutral solutions in intimate association with the blende throughout the vertical extent of the primary ore body. Considering this massive galena to constitute only three-fourths of the primary deposits, we should have had, in order to have concentrated the lead by a descending circulation, at least three-fourths of the primary ore body extending above the present horizon of the lead. In other words, the present massive segregation of the galena must be near, if not at, or below the base of the first ores deposited by ascending waters.

In order to provide for this vertical distribution of the primary ores, we must conclude that, at the time of their deposition, the Mississippian must have extended, stratigraphically, to a considerable height above its present horizon, probably from 100 to 200 feet, and that erosion has carried off this thickness of the Mississippian since the first deposition of the ores.

That no such extensive erosion has taken place is shown (1st) by the occurrence of the pre-Pennsylvanian conglomerate throughout the area, and, (2nd) by the presence of undisturbed Pennsylvania sandstone and shales in the valleys, and boulders of the same material upon the crests of the ridges. This field evidence shows that erosion has not been very extensive since the reappearance of the Mississippian at the surface.

Field observations furnish no evidence that ore bodies of any considerable extent were deposited above the present horizon of the galena. Some carbonate of lead occurs generally in a small opening just above the major deposit. Any extensive deposits of blende above this level, on being brought under oxidizing conditions by descending water, would form, in part, at least, the stable oxidized salts, calamine and smithsonite. These stable ores would remain as evidence of a former deposit in an analogous form to those now found beneath the galena where the oxidizing solutions are at present operative. In general, no such deposits are found above the galena, and this is strong evidence that no extensive deposits of blende have occurred at that horizon.

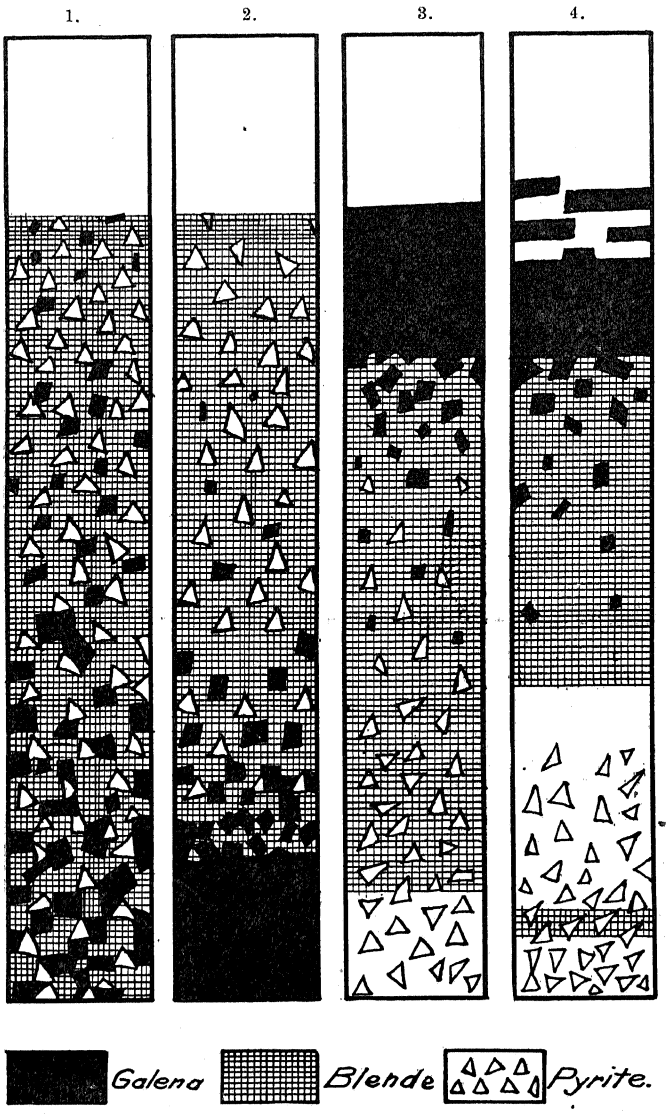
If the present horizon of the galena is near the base of the primary ore body, there has been uniformly, throughout Southwest Missouri, from 250 to 350 feet of Mississippian strata above the Devono-Carboniferous shales traversed by the ascending solutions in which there was no primary deposition of the metals. If this ascending circulation carried the metallic salts and the required organic or reducing material were present in the shales, the conditions necessary for deposition were evidently present throughout this part of the formation. If this were the case, it is hard to conceive why uniformly throughout the district the deposits do not occur in this portion of the formation.

The present deposits, occurring as they do, mostly beneath the galena, must, according to this theory, be almost wholly of secondary origin.

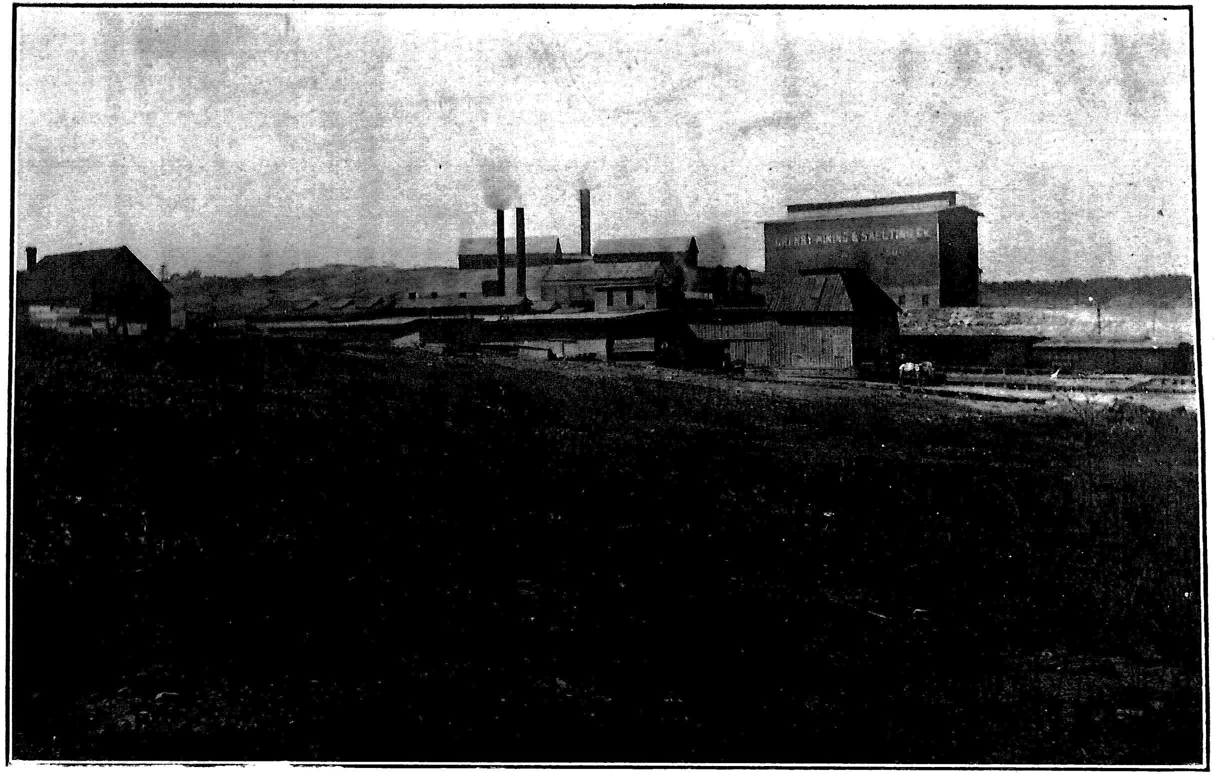
It is not thought by the present authors that any such extensive transportation of the metals has occurred, at least we know of no field evidence in support of the above conditions.

Figure XXXIX. is an ideal graphic illustration of the primary deposition due, (a) to ascending neutral or alkaline solutions; (b) to ascending acid solutions; (c) to descending solutions as outlined in the first part of this chapter, and (d) to solutions as they have existed in this area.

With solutions rising from the Cambro-Ordovician strata along fault planes there should be a pronounced uniformity of deposition of the primary deposits of the metals over the entire Southwest Missouri area. This should be the case, as these solutions have traversed long distances in rocks of relatively uniform chemical composition. Mr. George Waring of Webb City, who has made many analyses of the waters from deep wells, states that they are all very uniform in their composition and do not contain any zinc or iron salts. On the other hand, the variations in the original deposits of the Pennsylvanian, together with the variations in the different surface waters, would be very likely to produce just such deposits as occur in the Southwestern Missouri district.




An ideal drawing to illustrate the position and relation between Galena, Blende and Pyrite deposited from ascending and descending solutions.



GENERAL VIEW OF THE CONCENTRATING AND SMELTING PLANT OF THE GRANBY MINING AND SMELTING COMPANY.

# CHAPTER X.

## METHODS OF MINING, CONCENTRATING AND SMELTING.

The method of mining depends upon the character and size of the ore body which is being exploited. The method employed at most of the mines is about the same as that which was introduced at the time the area was opened up. Several of the so-called deep, hard-faced mines are equipped with machinery similar to that used in the Joplin area. These include the Mascot, the Homstake, the Little Four and the Blue Jacket. All of the land on which producing mines are located is owned by three or four different companies. Most of it is divided into quarter sections and these in turn into 200 foot and fractional lots. Anyone wishing to engage in mining on the land owned by the Granby Mining and Smelting Company may locate and sink shafts upon this land, two lots being reserved for each shaft. The Granby Mining and Smelting Company, on whose land most of the mines are located, furnish all of the machinery necessary to sink the shafts, with the exception of the hoist, which the miner may rent at the rate of $3.00 per week. A shaft is usually started by two or three men, with no other equipment than a hand windlass, a rope and a bucket. The hand windlass is later supplanted by a horse hoist, and finally, if sufficient ore is developed to warrant the same, a full equipment of machinery, consisting of a boiler, a derrick, an engine, a beam pump and a hoist is installed. The company furnishes all fuel needed in sinking a shaft and pays in addition at the average rate of $1.50 per foot for a shaft 100 feet deep. Should the persons sinking the shaft encounter an ore body, they are required to reimburse the company to the extent of the cost of the fuel, plus the money paid by the compny for sinking the shaft. If ore is not encountered, the company loses what they invested, the individual sinking the shaft being held in no sense indebted to the company. The miners are permitted to use the machinery as long as the mine is worked.

The usual method of opening a mine is for one or more miners to form a partnership with one or two merchants living in Granby, The merchants are known as "paying in partners," since they pay in money their percentage of the expenses for each week.

In the soft faced mines the drifts are usually very narrow and the roof low. The rock is usually broken with dynamite and the ore shoveled into tubs or cans, which are transported under ground on small cars run on steel or wooden tracks. Where the openings are low, a shallow rope baled tub is used, the average can being too high for the drift.

The Granby Mining and Smelting Company now have in operation in this district 41 pumps, 36 of which are lift pumps, 55 boilers, 30 steam hoists and 7 horse hoists.

The deeper, hard faced mines, such as the Homestake and Mascot, are equipped with heavier and better machinery. They produce a larger tonnage of ore and are worked on a somewhat different basis. The company which is now operating the Mascot mine pays a royalty of 15 per cent on the ore produced. They have the privilege of selling their concentrates in the open market, while the smaller operators in the soft faced mines must sell their ore to the company, paying a royalty of 20 per cent for the land and 15 per cent for the use of the company machinery.

The ore which is obtained from the soft faced mines varies largely in the percentage of lead and zinc minerals which it contains. This has compelled the operators to use methods of cleaning which are not practiced in other areas in this district. After the ore has been hoisted it is usually dumped upon a wooden platform and sluiced with water pumped from the mine. This is done to remove the clay and dirt with which the ore is usually covered. The large pieces of galena, blende and silicate are removed by hand, and the remainder is screened to separate that which is finely broken from the larger pieces. Men called "pickers" then take the larger pieces and separate the tallow clay and flint from the lead and zinc minerals, using for this purpose a hammer and a block of iron between which the lumps are broken. The minerals which are separated in this manner are thrown into the ore bin, while the flint and clay are removed to the dump pile. The very fine ore, which cannot be cleaned by this method, is removed to a hand jig, in which the minerals are separated from the flint and clay.

The purity of the concentrate which is produced in this manner depends chiefly upon the thoroughness with which the ore is cleaned and the freedom of the ore from flint and clay as it is removed from the mine.

HAND WINDLASS HOIST IN OPERATION.

The lead concentrates delivered at the mill will run from 20 to 100 per cent galena. The galena assays approximately 82 per cent lead. The zinc blende concentrates, as delivered at the mill, will contain from 20 to 95 per cent blende, which assays from 57 to 63 per cent metallic zinc. The calamine is delivered at the mill either in the form of lumps or as concentrates from the hand jigs. The lump calamine, when free from impurities, will assay about 44 per cent zinc, and must be essentially free from flint, clay or other foreign substances. The concentrates from the hand jigs, which are known as "nut" and "smithum," contain from 20 to 92 per cent silicate, from which the zinc is estimated on a basis of 44 per cent.

The concentrates of calamine from the hand jigs are reconcentrated in the company's mill. All of the zinc concentrates, both blende and calamine, are shipped to a smelter at Neodosha, Kansas, owned by the Granby Mining and Smelting Company.

The methods of concentrating both the lead and the zinc minerals are shown in the accompanying plan of the mill and smelter, Plate XLII.

The ore received by the company frequently contains galena, blende and calamine, which are separated from one another by crushing, sizing in trommels and classifiers and jigging. The arrows in the diagram show the direction in which the ore travels, and it is thought that the illustration is sufficiently detailed to be understood without further explanation. The method of treating the galena is somewhat simpler than that of the zinc minerals.

The company has lately installed two Wilfley tables to recover the fine lead which formerly passed away in the sludge.

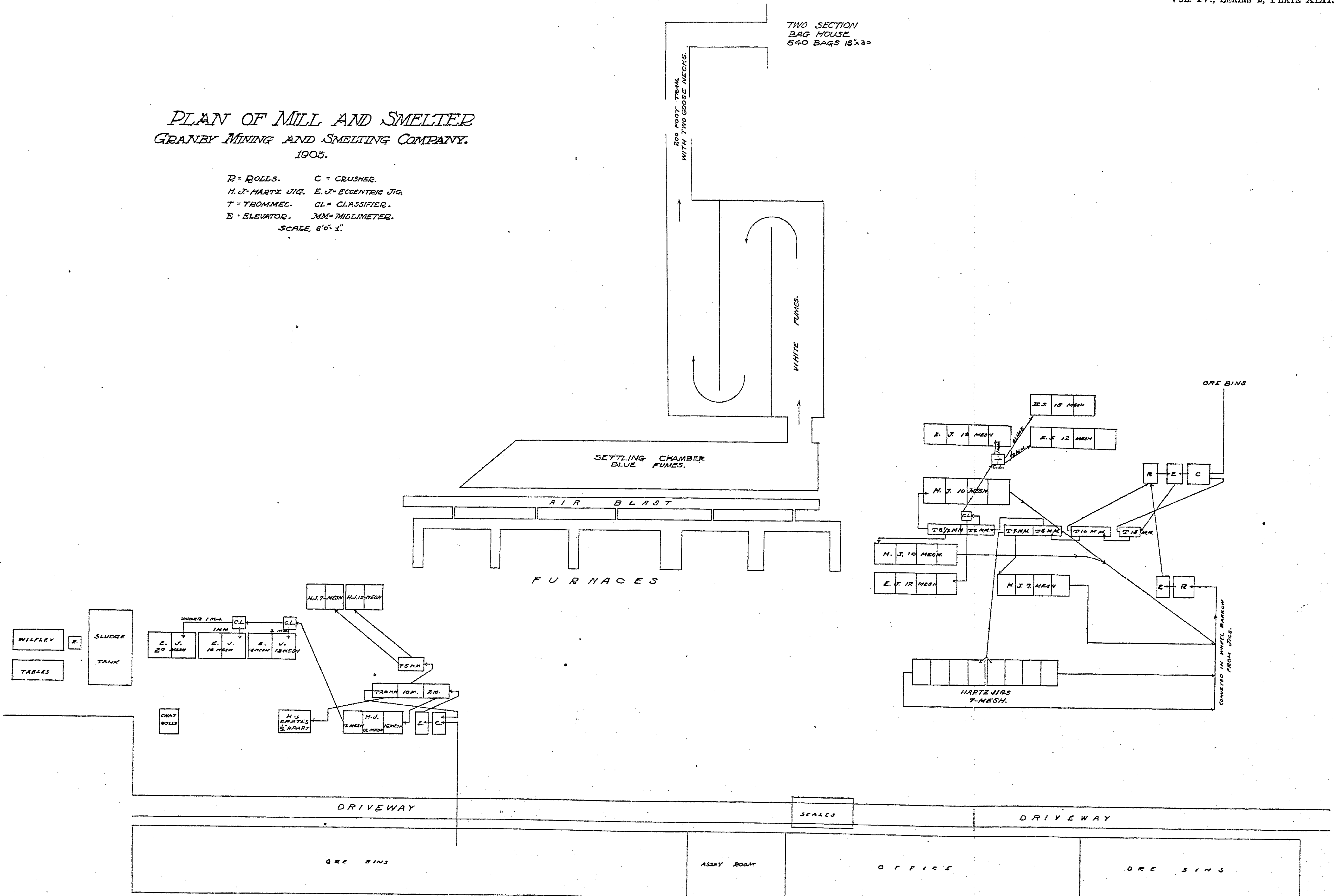
Some of the machinery used in this mill is the oldest in the state. Capt. John Kingston says that they are using the oldest Blake crusher in the state and that it is still performing excellent service. The plan of concentrating the ores is not altogether automatic, but it is remarkably well adapted to the kinds of ore which the company is called upon to concentrate.

The galena is smelted at the company's furnaces, the location of which is shown in Plate XLII. There are five Scotch Eye hearths in constant use. A detailed description of these furnaces is given in "The Metallurgy of Lead," by Hofman, page 120. In this volume they are described as the "American Waterback Orhoff" furnace. Four men are employed at each eye. Two of these work until they have smelted two pigs of lead, when they are relieved by the other two. In this manner the men work and rest, alternately, from 15 to 20 minutes. Two shifts are worked daily at the smelter.

The charge for each eye per shift is 7,000 pounds, consisting of from 5,500 to 6,200 pounds of galena, 500 to 900 pounds of white fume and 200 to 300 pounds of blue fume. The average charge is 600 pounds to 1,000 pounds of fume, the variation depending upon the amount of fume produced by the furnaces. The men at the furnaces are supposed to produce 70 per cent of metallic lead from the galena, 50 per cent from the white fume and 40 per cent from the blue fume. The remainder of the lead is oxidized and passes into the cooling chambers, where it is collected, as shown in the illustration referred to above. A half bushel of lime and 16 bushels of charcoal are used per shift in smelting. It requires approximately six hours for each shift to smelt a charge.

The fumes are passed from the eyes, first, into a large steel chamber, where the blue fume settles out. The remainder of the fume passes into a concrete chamber, having three compartments, as shown in the illustration. From here it passes into a steel trail 200 feet long, near the end of which are two goose necks 20 feet in height. After leaving this trail the smoke enters the bag house, which contains 640 bags, 18 inches in diameter and 80 feet long. Half of the bag house is used at a time. The entire production of fume is resmelted at the furnace, none of it being used in the manufacture of paint.

# INDEX.


PLAN OF MILL AND SMELTER
GRANBY MINING AND SMELTING COMPANY.
1905.
R = ROLLS. C = CRUSHER.
H. J. = HARTZ JIG. E. J. = ECCENTRIC JIG.
T = TROMMEL. CL = CLASSIFIER.
E = ELEVATOR. MM = MILLIMETER.
SCALE, 8'0" = 1".
TWO SECTION BAG HOUSE 640 BAGS 18"x30"
200 FOOT TRAIL WITH TWO GOOSE NECKS.
WHITE FUMES.
SETTLING CHAMBER BLUE FUMES.
AIR BLAST
FURNACES
ORE BINS.
E. J. 15 MESH
E. J. 12 MESH
E. J. 12 MESH
SLIME
C.L.
H. J. 10 MESH
CL
T 8½ MM
T 2 MM.
T 7 MM
T 5 MM.
T 10 MM
T 15 MM.
R
E
C
H. J. 10 MESH.
E. J. 12 MESH
H. J. 7. MESH
E
R
HARTZ JIGS 7-MESH.
CONVEYED IN WHEEL BARROW FROM JIGS.
WILFLEY
E.
TABLES
SLUDGE TANK
UNDER 1 MM.
C.L.
C.L.
1 MM
2 MM.
E. J. 20 MESH
E. J. 16 MESH
E. J. 16 MESH 18 MESH
H.J. 7-MESH
H.J. 10-MESH
T 5 MM
T 20 MM
10 M.
2 M.
CHAT ROLLS
H. J. GRATES ¾" APART
H. J. 12 MESH 12 MESH 16 MESH
E.
C.
DRIVEWAY
SCALES
DRIVEWAY
ORE BINS
ASSAY ROOM
OFFICE
ORE BINS