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ZINC AND LEAD DEPOSITS

OF THE

UPPER MISSISSIPPI VALLEY

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NOTE.

This bulletin is a special State edition (750 copies) of Bulletin No. 294 of the United States Geological Survey and is published in the series of the Wisconsin Geological and Natural History Survey through the courtesy of the Director of the United States Survey. This is in accordance with the plan of cooperation between the two organizations, whereby the State undertook to make the detailed surveys and the National Survey to discuss the general features of the ore deposits. The bulletin is complementary to the Report on the Lead and Zinc Deposits of Wisconsin, with an atlas of detailed maps, by Ulysses Sherman Grant, published as Bulletin XIV of the Wisconsin Survey, and the two should be used together. In printing this State edition certain plates have been omitted as noted below:

PLATE IX. Omitted. See Hazel Green-Benton atlas sheet (No. XII) of Bull. XIV, Wis. Geol. Nat. Hist. Survey.

PLATE XI. Omitted. See Platteville atlas sheet (No. X) of Bull. XIV, Wis. Geol. Nat. Hist. Survey.

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PLATE XIV. Omitted. See Highland atlas sheet (No. II) of Bull. XIV, Wis. Geol. Nat. Hist. Survey.

PLATE XV. Omitted. See Potosi atlas sheet (No. XVIII) of Bull. XIV, Wis. Geol. Nat. Hist. Survey.

GENERAL GEOLOGIC MAP OF THE UPPER MISSISSIPPI REGION

Scale

0 10 20 30 40 50 60 70 80 90 100 miles

1906

LEGEND

Carboniferous | Devonian | Silurian | Ordovician | Cambrian | Pre-Cambrian

Smelters and oxide works | Zinc and lead district

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ZINC AND LEAD DEPOSITS OF THE UPPER MISSISSIPPI VALLEY.

By H. Foster Bain.

INTRODUCTION.

LOCATION AND AREA.

The zinc and lead mines of the upper Mississippi Valley are in the southwest portion of Wisconsin and in adjacent parts of Illinois and Iowa. The boundaries of the region are in part indefinite, since sporadic occurrences of the minerals are found outside the mining region proper. It is usual to define the area as including Grant, Lafayette, and Iowa counties in Wisconsin, Jo Daviess County in Illinois, and an irregular narrow belt of territory in Clayton and Dubuque counties paralleling the Mississippi River in Iowa. In this report a slightly smaller area is discussed, the region being limited on the east by the meridian of 90° west longitude. East of this meridian there are a few scattered prospects, but comparatively little mining has been done in recent years in the area beyond the boundary indicated, so that it is sufficiently accurate for present purposes.

The location and limits and general geology of this area are shown on Pls. I and II. The region is rudely triangular and has a maximum extent of 80 miles from north to south and of 60 miles from east to west, and comprises about 2,500 square miles.

Not all the territory outlined is mineral bearing. Within its limits there are broad areas which, so far as known, are entirely barren, and the mines are clustered around certain centers or in certain districts, between which are stretches of nonmetalliferous territory. This grouping of the mines in districts is very pronounced and has been recognized since the earliest development of the region. Certain districts are not sharply defined, and more or less mining connects one with another, as in the case of the Hazel Green and Benton districts. In general, however, prospecting for more than a century has failed to develop any ore in the territory between the several groups of mines. In this report the following districts will be recognized: Dubuque, Galena, Sand Prairie, Elizabethtown, Hazel Green-Benton, Shullsburg, Meekers Grove, Platteville, Mifflin, Linden, Mineral Point, Dodgeville, Highland, Lancaster, and Potosi. Not all of these are equally well defined, and as a matter of practical convenience certain outlying mines will be taken up in connection with the nearest defined district. The prospects in the Prairie du Chien formation will be discussed separately. Fairplay, Darlington, Calamine, and several other of the older districts had no active mines at the time the survey was made, though mining has since been resumed in them at several places.

The district is a rolling agricultural country, with a deep fertile soil. The farms are large and well improved, and the numerous towns and villages are neat and attractive. Waterworks, electric lights, and telephone service are found in nearly all of them. Dubuque, Galena, Platteville, and Mineral Point are the leading cities. The district lies within 150 miles of Chicago and 300 miles of St. Louis and is well served by railways. The Chicago and Northwestern, the Chicago, Milwaukee and St. Paul, and the Mineral Point and Northern reach the camps at present most active. The Illinois Central affords a direct line to the smelters near La Salle, while the Chicago, Burlington and Quincy affords a direct line to St. Louis. The Chicago Great Western serves the mines at Elizabeth, Ill., and Durango and Dubuque, Iowa.

So far there are not many branch lines to the mines, though a few have been built in the Hazel Green-Benton district. In general, coal and supplies must be hauled to the plants by wagon at a cost of 40 cents to $2 a ton, and the ore must also stand a wagon haul to the cars.

An electric railway line connecting the various camps is projected and probably will be built.

HISTORICAL SKETCH.

The presence of important ore deposits in the upper Mississippi Valley early attracted attention to this region. The ease of travel along the Mississippi permitted its rapid exploration, and long before there was any regular settlement within its limits lead had become a regular article of commerce. It is improbable that the Indians knew anything of the smelting of lead ores or the use of lead until they were taught by the French. Since, however, French exploration of the region began with Nicolet's voyage of 1634, and the occurrence of lead ores was reported as early as 1658, there is no improbability in the statement that as early as 1690[a] lead was purchased from the Indians by traders at Peoria. Yet it was a hundred years before white men settled in the region and took up regular mining. The history of these and the years immediately following has been summarized by Mr. Reuben G. Thwaites,[b] while Dr. O. G. Libby, assisted by F. Belle Stanton, Bernard M. Palmer, and Allard J. Smith,[c] has made a social and economic study of the lead region, based especially upon the history of the first half of the nineteenth century. To these sources in particular the reader desiring fuller historical details is referred. A brief statement only can be given here.

In the eighteenth century the region was practically given up to Indians and traders. The presence of ore deposits was well recognized, and the location of the mines was shown on many of the maps, such as that of Hennepin (1687), of William de L'Isle (1703), and of Guettard (1752). Lead was a regular article of commerce, purchased by traders at posts such as that of Nicholas Perrot, opposite the present site of Dubuque, and Le Gueur (1695), on an island farther up the river. These settlements were, however, essentially temporary, though M. le Guis in 1743 found eighteen or twenty mines in operation along Fever River. In 1769 a concession for mining was granted at St. Louis to Martin Miloney Duralde, who seems, however, to have taken no advantage of it.

The first serious attempt made by white men to settle in the region for the purpose of mining was that of Dubuque. According to Schoolcraft,[d] to whom we are indebted for the first published account of the Dubuque mines, the discovery of lead at this point was made by the Indians themselves, as he states in the following paragraph:

> In 1780 a discovery of lead ore was made upon their lands by the wife of Peosta, a warrior of the Kettle Chief's village, and extensive mines have since been discovered. These were granted by the Indians to Julien Dubuque at a council held at Prairie du Chien in 1788, by virtue of which he settled upon the lands, erected buildings and furnaces, and continued to work the mines until the year 1810. In the meantime (1796) he received a confirmation of the Indian grant from the Baron de Carondelet, governor of Louisiana, in which they were designated the "Mines of Spain."

Under Dubuque's régime several mines were opened, though it seems that no shafts were sunk. The ore was obtained by means of the hoe, shovel, crowbar, and pick from carelessly protected drifts. Good roads were, however, built to the furnaces, one of which was erected

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[a] Senate Doc. No. 87, 29th Cong., 1st sess, 1846.
[b] Wisconsin Hist. Coll., vol.13, 1895, pp. 271-292.
[c] Trans. Wisconsin Acad. Arts, Sci. and Letters, vol. 13, 1902, pp. 188-881.
[d] Schoolcraft, H. R., Narrative Journal of Travels, etc,. Albany, 1821, p. 348.

near the mouth of Catfish Creek, where Dubuque had his house in Kettle Chief's village. It is stated that up to recent years the sites of two of Dubuque's furnaces were well known—one on Eagle Point avenue, near Heebs's brewery, and the other between Main street and the river. Hon. M. M. Ham has given [a] a graphic account of Dubuque and of his life among the Indians. While Dubuque's concession covered only certain lands west of the Mississippi, he seems to have also carried on considerable trade in ore mined by the Indians east of the river.

A visit to Dubuque was one of the objects of Lieutenant (later General) Pike's expedition up the Mississippi in 1805. He found M. Dubuque "polite but evasive" and did not visit the mines, although there is an interesting statement, signed by Dubuque and Pike in 1805, in which it is declared that 20,000 to 40,000 pounds of lead were made per annum, that being a yield of 75 per cent. It is also stated that copper had at that time been noticed, although no attempt had been made to reduce it.

After Dubuque's death the Indians burned his house and fences and destroyed all traces of civilized life. They continued, however, to work the mines intermittently, selling the ore to certain Indian traders who had furnaces located on islands in the river. One of these was owned by George E. Jackson and was on the Illinois side of the river, about opposite the mouth of Catfish Creek. For a decade following Dubuque's death the mines seem to have been practically abandoned to the Indians. In 1810 Nicholas Boilvin, Indian agent, reported that they could produce about 400,000 pounds of metal. In 1815 about twenty rude furnaces were said to be in operation by the Indians in the vicinity of the present site of Galena alone.

In 1819 the influx of white men into the region began with the establishment of Shullsburg by Jesse W. Shull, under military protection, and in 1823 Col. James Johnson began operations on a considerable scale at Galena. With the exception of the period of the Black Hawk war, settlement and development of the area proceeded rapidly from that time till 1850, when the discovery of gold in California and a series of other causes turned the tide of immigration farther west.

In Iowa settlement was held back till 1833, owing to delay in the extinguishment of Indian titles and the determination of the General Government not to recognize the title of Dubuque's heirs. In 1830, under the leadership of J. L. Langworthy, and having previously obtained consent of the Indians and the Dubuque heirs, certain miners from Galena crossed the river and began work. It is said that the Langworthy crevice on Eagle Point avenue, still occasionally worked, was located at this time. The Government held, however, that the country was not yet open to settlement. Troops from Prairie du Chien drove out the miners and burned their cabins and for some years yet the Iowa mines were worked by the Indians. Schoolcraft [b] in 1820 made a canoe voyage from Prairie du Chien to the present site of Dubuque, at that time known as the Kettle Chief's village. The main workings then seem to have been west of the river, although Schoolcraft enumerates, in addition to the Dubuque mines, the "Sissinaway mines" and the "Mine au Fevre," the former the prototype of the Wisconsin mines and the latter the earliest workings at Galena. What are known as the Durango diggings, then passed under the name of the Mine of Maquanquitons. Schoolcraft's description, the first which we have of the mines of Dubuque proper, is as follows:

The district of country generally called Dubuque's lead mines embraces an area of about 21 square leagues, commencing at the mount of the Little Maquanquitons river, 60 miles below Prairie du Chien, and extending along the west bank of the Mississippi 7 leagues in front by 3 in depth. The principal mines are situated on a tract of one square league, commencing immediately at the Fox village of the Kettle Chief and extending westward. This is the seat of the mining operations formerly carried on by Dubuque, and of what are called the Indian diggings. The ore found is the common sulphuret of lead, with a broad foliated structure and high metallic luster. It occurs massive and disseminated, in a reddish loam, resting upon limestone rock, and sometimes is seen in small veins pervading the rock, but it has been chiefly explored in alluvial soil. It generally occurs in beds or veins which have no great width, and run in a certain direction 300 or 400 yards—then cease, or are traced into

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[a] Annals of Iowa, 3d ser., vol. 2, 1896, pp. 329-344.
[b] Schoolcraft, H. R., Narrative Journal of Travels, etc., Albany, 1821.

some crevice in the rock, having the appearance of a regular vein. At this stage of the pursuit most of the diggings have been abandoned and frequently with small veins of ore in view. No matrix is found with the ore which is dug out of the alluvial soil, but it is enveloped by the naked earth, and the lumps of ore are incrusted by an ocherous earth. Occasionally, however, some pieces of calcareous spar are thrown out of the earth in digging after lead, and I picked up a solitary specimen of the transparent sulphate of barytes, but these substances appear to be very rare. There is none of the radiated quartz, or white, opaque, heavy spar, which is so common at the Missouri mines. The calcareous rock upon which this alluvial formation, containing lead ore, rests, appears to be referable to the transition class. I have not ascertained its particular extent about the mines. The same formation is seen, overlain by a distinct stratum of compact limestone, containing numerous petrifactions, at several places between the mines and Prairie du Chien. The lead ore at these mines is now exclusively dug by the Fox Indians and, as is usual among savage tribes, the chief labor devolves upon the women. The old and superannuated men also partake in these labors, but the warriors and young men hold themselves above it. They employ the hoe, shovel, pickax, and crow-bar, in taking up the ore. These things are supplied by the traders, but no shafts are sunk, not even of the simplest kind, and the windlass and buckets are unknown among them. They run drifts into the hills so far as they can conveniently go without the use of gunpowder, and if a trench caves in it is abandoned. They always dig down at such an angle that they walk in and out of the pits, and I descended into one of these which had probably been carried down for 40 feet. All this is the work of the Indian women and old men, who discover a degree of perseverance and industry which is deserving of commendation. When a quantity of ore has been gotten out it is carried in baskets by the women to the banks of the Mississippi, and then ferried over in canoes to the island, where it is purchased by the traders at the rate of $2 for 120 pounds, payable in goods. At the profits at which these are usually sold it may be presumed to cost the traders 75 cents to $1, cash value, per hundred weight. The traders smelt the ore upon the island, in furnaces of the same construction used at the lead mines of Missouri, and observe that it yields the same per cent of metallic lead. Formerly the Indians were in the habit of smelting their ore themselves, upon log heaps, by which a great portion was converted into what are called lead ashes and thus lost. Now the traders induce them to search about the sites of the ancient fires, and carefully collect the lead ashes, for which they receive $1 per bushel delivered at the island, payable in merchandise.

The final opening of the country took place in 1833. Dr. A. G. Leonard has summarized the circumstances as below:[a]

At the close of the Black Hawk war the large tract known as the Black Hawk purchase, including one-third of the present area of Iowa, was ceded to the United States by the Sacs and Foxes. After the completion of the treaty negotiations the miners again crossed over into the coveted region, where they built cabins and commenced to take out much ore. But a second time they were forced to leave because the treaty had not been ratified. In June, 1833, the treaty went into effect and the way was at length clear for settlers to take possession of the land. During the next few years large numbers flocked in; prospecting was actively carried on and many mines were soon in operation.

The first "legislation" in Iowa dated from 1830. In June of that year a number of miners met on the banks of the Mississippi and enacted regulations to govern them in their relations to each other. One of the articles was that "every man shall hold 200 yards square of ground by working said ground one day in six." Much other interesting history clusters around these mines, but it is foreign to our purpose to go into that phase of the subject here.

For a quarter of a century the policy of government ownership of mines was tried. Under act of Congress of March 3, 1807,[b] the mineral lands of this district, as well as 68 sections in southern Illinois and a few townships in northern Arkansas, were reserved from sale with the provision that they should be leased on an annual rental. In the Galena district the reserved holdings amounted to 345,600 acres; in Iowa to 184,320 acres, and in Wisconsin to 1,428,480 acres. No leases seem to have been ever granted in Arkansas. A few only, beginning with one in 1809 issued by the governor of Indiana, were granted in southern Illinois, but in the upper Mississippi Valley the system was carried out for some years. The lands were at first under charge of the Treasury Department, but in 1821 were transferred to the War Department. A superindendent of mines, with suitable assistants, was employed and a royalty of one-sixth to one-tenth, payable in lead or cash, was exacted. The first lease at Galena was taken by Col. James Johnson in 1823, and in 1846, 2,093 leases had been granted, of which 518 were outstanding. The system early provoked opposition, and much friction ensued. Very few leases were ever taken in Iowa the local courts being decidedly antagonistic to the system. In 1846, when it was abolished, a total return of

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[a] Iowa Geol. Survey, vol. 6, 1896, p. 16. [b] Laws U. S., vol. 4, p. 127.

$145,174.40 had been realized between 1841 and 1845, while it had cost $68,464.50 [a] directly to collect the rents, and a considerable additional sum had been spent in litigation. It was therefore decided to sell the lands.

Preliminary to this a survey was ordered in 1839 and placed in charge of that pioneer geologist, D. D. Owen. This survey was in many particulars unique. Owen began field work in September and, with the aid of a large number of assistants, finished it before winter. A report, accompanied by maps, sections, figures, descriptions, and fossils was submitted to the Land Office on April 2 following. This report was printed without illustrations [b] in June of the same year, and a revised edition, including the omitted plates, was printed in 1844.[c] In this survey a large area, including the whole of the mining section, was traversed township by township, and the character of the rocks was noted. In 1847 Owen executed for the Treasury Department another survey of the Chippewa land district and in his report on that region [d] gives certain additional details regarding the lead and zinc region.

In the course of a still later survey he visited the region again, and in his well-known quarto report he briefly discusses the geological formations present.[e] Owen was accordingly the first geologist of note who studied the region in detail, and his conclusions, based as they were upon a long and intimate acquaintance with it, are worthy of the utmost respect. It is curious to note, however, that he entirely overlooked the Maquoketa shale and confused the Galena and Niagara; and it can be readily believed that in this, as well as in his opinions respecting the deep-seated origin of the ore deposits, he was misled by the ideas then currently accepted.

In 1854 J. D. Whitney published his Metallic Wealth of the United States.[f] Having made certain investigations in the region in the course of private professional work, he gave a very accurate though brief account of the mines. His ideas were later elaborated in the course of his work for the three States, Iowa, Wisconsin, and Illinois, for which he successively studied the field. In his reports he covered the whole ground excellently, and it is no disparagement to others to say that together they form the most complete account of the field yet published.[g] Professor Whitney visited the region in the years of the maximum importance of the lead mines and his observations are accordingly particularly valuable. It was, however, after his work was finished that zinc became of value in the region. Industrial conditions have also largely changed, so that there is now much of interest to be added to his report.

Aside from Whitney and Owen, the best known of the earlier investigators in this region was J. G. Percival, who made a study of the lead region for the State of Wisconsin in 1854 and 1855. Accuracy of observation is everywhere characteristic of Percival's work, but his conclusions as to the origin of the ores and the best methods of working them seem to have been unfortunate.[h] Like Owen, he followed the current theory of the period.

The later Wisconsin survey renewed the study of the region, and in the elaborate papers of Moses Strong [i] and T. C. Chamberlin [j] we have the most detailed study of the region extant, with, in the latter case, a notable addition to the discussion of the theoretic considerations involved.

About 1893 attention was again attracted to the soft-lead deposits of the Mississippi Valley, and a few years later the zinc ores of the region became properly appreciated. The most notable resultant contribution to the literature of the subject was the report on the lead

[a] Senate Ex. Doc. No. 87, 29th Cong., 1st sess., 1846.
[b] House Ex. Doc. No. 239, 26th Cong., 1st sess., 161 pp., Washington, 1840.
[c] Rept. Geol. Expl. Iowa, Wisconsin, and Illinois in 1839, Washington, 1844.
[d] Senate Ex. Doc. No. 57, 30th Cong., 1st sess., 134 pp., Washington, 1848.
[e] Rept. Geol. Survey Wisconsin, Iowa, and Minnesota, 638 pp., Philadelphia, 1852.
[f] Philadelphia, Lippincott, Grambo & Co., 1854.
[g] Geol. Survey Iowa (Hall), vol. 1, Albany, 1858, pp. 286–295, 422–471. Geology of Wisconsin (Hall), vol. 1, 1862, pp. 73–424. Geology of Illinois, vol. 1, Springfield, 1866, pp. 153–207.
[h] Percival, J. G., Ann. Rept. Geol. Survey Wisconsin, 101 pp., 1855. [Second] Ann. Rept. Geol. Survey Wisconsin, 111 pp., 1856.
[i] Geology of Wisconsin, vol 2, 1877, pp. 643–752.
[j] Ibid., vol. 4, 1882, pp. 365–571.

and zinc deposits of Missouri by Winslow and Robertson[a] published in 1894. Although nominally devoted to the Missouri field the report covers practically the whole subject, and contains very full notes on the upper mines, but nothing original concerning the latter field. The meeting of the International Engineering Congress at Chicago in 1893, and the reading there of Posepny's famous paper on the origin of ore deposits, led directly and indirectly to the publication of a number of papers in which the phenomena of the region are discussed. Among the more important of these and others of the same period are those of Posepny[b], Jenney,[c] Blake,[d] Winslow,[e] Robertson,[f] Chamberlin,[g] and Roethe.[h] The organization of the Iowa Geological Survey in 1892 and of the Wisconsin Geological and Natural History Survey in 1899 has permitted a rather thorough restudy of the region. The publications of these organizatons, as well as most of the other important geological papers on the region, are listed chronologically in the following brief bibliography. This was compiled originally by Dr. U. S. Grant. A few additions only have been made to his list.

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[b] Posepny, Franz, Trans. Am. Inst. Min. Eng., vol. 23, 1894, pp. 197–369; vol. 24, 1895, p. 967

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PRODUCTION.

PAST PRODUCTION.

It is possible to arrive at fairly accurate figures of the past production of the district as regards lead, but the total zinc production is much less accurately known.

LEAD.

Strong gives the following estimates of the lead production of the region:[a]

Estimated lead production, by decades.

	Tons.
1821–1831	23,244
1831–1841	55,718
1841–1851	215,979
1851–1861	161,334
1861–1871	84,700
Total	538,975

[a] Geol. of Wisconsin, vol. 2, 1877, p. 750.

For the decade 1871 to 1881 the production may be estimated from various sources[a] as amounting to 49,000 tons. After 1880 the production was very small, probably averaging less than 1,000 tons a year up to 1900, at which time the recent revival in mining began.

If the production be estimated at 1,000 tons a year for the entire period up to 1904, the result probably would not be far wrong. The total production would then be as follows:

Estimated lead production, by periods.

	Tons.
1821-1871	538,975
1871-1881	49,000
1881-1904	24,000
Total	611,975

It is less easy to get at the value of this metal, but it will probably be safe to say that it sold for approximately $50,000,000. The maximum production, it may be noted, was between 1840 and 1850. In 1845 and again in 1847 more than 27,000 tons of lead were shipped.

ZINC.

There was no market for zinc ore prior to 1860. In that year the La Salle smelter began to run, and in succeeding years the oxide furnaces at Mineral Point, Wis., the smelters at Waukegan and Peru, Ill., and at various points in Indiana were built, and sent buyers into the region.

Strong[b] has given detailed figures of the production up to 1876. The total amounted to 69,467 tons of carbonate and 57,728 tons of blende. The output of succeeding years is less accurately known, but from the best available data it has been roughly estimated that up to 1904 approximately 425,000 tons of zinc ore had been sold.[c] In 1904 the output was estimated at 19,300 tons.[d] This estimate appears now to have been somewhat too low, and it will probably be conservative to estimate the total production up to 1905 at 450,000 tons, though no great accuracy can be claimed for this figure.

The early prices paid for the ore were very low—$3 to $8 for the carbonate and $4 to $12 for the blende. In recent years the product has been entirely blende, which has sold for much better prices. Nevertheless, it is probable that up to 1905 the total zinc sales of the district had not greatly exceeded $10,000,000 in amount.

PRESENT PRODUCTION.

The zinc production of the district is now rapidly increasing, and for the year 1905 approximated 33,000 tons.

RECENT MINING ACTIVITY.

After the decline of the early lead-mining industry there was a period of forty years during which farming, transportation, and manufacturing absorbed almost the entire attention of the people of this region. A little mining was being carried on always, but the output was small and uncertain. Prices were low, experienced miners were scarce, the old leads had been worked down to water level, and no one knew exactly how to dress the blende-marcasite ores found below.

The rise in the price of zinc ore of 1899 again attracted attention to this region, and since 1903, in particular, its development has been rapid. The following is a partial list of the mines in operation early in 1906. Development has been so rapid recently that even this list is probably not complete. Many of these mines have been opened or equipped since the survey upon which this report is based was made.

At Platteville: Enterprise mine and mill, equipped with roaster; Trego mine and mill, equipped with roaster; Empire mine and mill; St. Rose mine and mill; Klondike mine and

[a] Winslow, Arthur, Missouri Geol. Survey, vol. 6, 1894, pp. 147-148.
[b] Strong, Moses, Geol. Wisconsin, vol. 2, 1877, p. 742-743.
[c] Bull. U. S. Geol. Survey No. 246, 1905, p. 13.
[d] Bull. U. S. Geol. Survey No. 260, 1904, p. 265.

mill; Hibernia mine and mill; Graham and Stevens mine and mill; Kendletown mine and mill; Red Dog mine and mill; Great Northern mine; Eclipse mine and Black Hawk mine; West Empire mine; Cudyn mine; Hodge mine; Morning Star mine; Grant County mine; Big Jack mine; Kohinoor Blende mine; Klar Piquett mine; Tippecanoe mine (not operating); Edgerton mine; Whig mine; Delta mine; Acme mine; Badger mine.

At Hazel Green: Hazel Green mine and mill, equipped with roaster; Kennedy mine and mill, equipped with roaster; Hoskin mine and mill, equipped with roaster; King Bee mine and mill; Scrabble Creek mine; Hills mine; Jefferson mine; Square Deal mine, mill, and roaster; Murphy mine; Sixteen mine; Kendall mine; Whitesides mine; Mills Diggings, mill and roaster.

At Buncombe: Rowley mine, mill, and roaster; Northwestern mine and mill; Buncombe Hill mine; Big Dad mine.

At Cuba City: Doll mine, mill, and roaster; Baxter mine and mill; Roosevelt mine and mill; Wicklow mine and mill; Gritty Six mine and mill; Cook mine; Cuba City lead and Zinc mine; Midway mine; Jarrett mine; Board of Trade mine; Little Dick mine; Anthony mine; Beacon Hill mine; Meekers Grove mine; Hungry Nigger mine.

At Benton: Jack of Diamonds mine (mill arranged for probably will be built in 1906); Century mine (mill arranged for probably will be built in 1906); Dawson mine, mill, and roaster; Benton Development Company's mine; Ollie Belle mine (mill to be erected); Fox Lead and Zinc Company; Frontier mine.

At Livingston: Sunrise mine, mill, and roaster; Sunset mine, mill, and roaster; Coker mine, mill, and roaster; Ellsworth (or Coker) mine, mill, and roaster; La Follette mine.

At Rewey: Crescent mine.

At Mifflin: Gruno mine and mill; Slack mine (mill to be installed in 1906); Peacock mine; Squirrel mine (mill to be installed); Independent mine.

At Linden: Mason mine and mill; Ross mine and mill; Trio mine (mill arranged for in 1906); Glanville mine.

At Mineral Point: Tripoli mine, mill, and roaster; Hazel Patch mine.

At Dodgeville: Williams mine and mill.

At Highland: Kennedy mine and mill; Highland mine and mill; Lewis mine and mill; Milwaukee-Highland mine (mill to be erected); Kent-Whitman mine.

At Galena: Bluvett mine; Waters mine; Stacey mine (sinking).

At Elizabeth: Elizabeth mine and mill; Skene mine and mill.

At Shullsburg: Lucky Hit mine, mill, and roaster; Morrison mine, mill, and roaster; Helena mine, mill, and roaster.

At Centerville: Red Jacket mine (mill to be installed).

At Potosi: Cardiff mine; Kroag and Webster mine.

At Buena Vista: Fitzpatrick mine.

Some of these mines have been paying dividends at a rate of $5,000 or more a month for periods of more than a year on initial investments of $30,000 to $35,000.

SCOPE OF THIS REPORT.

The present paper is primarily an account of the present condition of the district and a statement of ideas relating to the formation of the ores. It includes the results of observations which began in 1899 and extended up to June, 1905. In 1899 and 1900 the writer, associated with Prof. Samuel Calvin, made a study of the geology and mining industry of Dubuque County for the Iowa Geological Survey. The resulting report is frequently cited in these pages, but is also liberally quoted without specific citation. In 1903 the mines of Jo Daviess County, Ill., were studied for the United States Geological Survey by the writer, with the assistance of Messrs. E. E. Ellis and A. F. Crider. A special report upon the area was prepared and published as a bulletin of the Survey.[a] In 1904 the work was extended to cover the Wisconsin mines, and in 1905 the month of June was spent in revisiting the

[a] Bain, H. F., Zinc and lead deposits of northwestern Illinois: Bull. U. S. Geol. Survey No. 246, 1905, 56 pp.

area and noting additional developments. In 1904 Mr. E. E. Ellis assisted in the work, particularly in making maps of various mines and of a special area near Dubuque. In 1905 Messrs. E. F. Burchard, A. W. Lewis, and J. R. Bannister also assisted while engaged in mapping the Lancaster quadrangle and certain outlying portions of the Elkader and Richland Center quadrangles.

From 1903 to the present the writer has had the cooperation of Dr. U. S. Grant—at first when the latter was engaged in making detailed maps for the Wisconsin Geological and Natural History area, and later when he was also surveying the Mineral Point quadrangle for the United States Geological Survey. This cooperation has been close and constant, both in the field and office, and has been carried on under an informal agreement between the Wisconsin and the United States geological surveys. Doctor Grant devoted himself especially to the stratigraphic problems. He undertook the detailed mapping in the area, and has already published a bulletin giving the main results of the work. This is accompanied by an atlas of large-scale maps of the principal mining districts.[a] Portions of many of these maps are reproduced in this report. Doctor Grant and Mr. Burchard have also prepared a report upon the Lancaster-Mineral Point quadrangle for publication by the United States Geological Survey, and Mr. E. O. Ulrich has under way a complete study of the stratigraphy of the upper Mississippi Valley. In the present bulletin, accordingly, the stratigraphic problems are purposely slighted, and only such account is given of the stratigraphy as seems necessary to the understanding of the deposits. In preparing this account the writer has had the assistance of both Doctor Grant and Mr. Ulrich, and has freely used both published and unpublished material. He should, however, be held wholly responsible for the statements here made.

The very important relation of ore deposits to the structural basins of the region were worked out by Doctor Grant and are fully illustrated in the State report already referred to. The remaining phases of the mode of occurrence and genesis of the ores were not discussed there, since, by agreement, that field was left open to the writer. Both the field and office work were, however, carried on in cooperation, and a large share of credit for whatever is new in this report is due to Doctor Grant and the State survey.

In the preparation of the report Mr. Arthur W. Lewis has been of great assistance. He compiled the large map forming Pl. II from the field notes, and made numerous calculations and drawings. To Prof. C. R. Van Hise and T. C. Chamberlin the writer is under much obligation for helpful suggestions and friendly criticisms in this as in other work.

If it should seem that this list of acknowledgments is rather long, and that the citations and quotations in the body of the report are both long and numerous, it should be remembered that this is an old and famous mining region, having many peculiarities, and one in which certain fundamental notions of ore deposits were first worked out. It has been the scene of labor of some of our keenest students of ore deposits, and while the pleasure in studying the region has been great, the need of caution has been ever present. One man can do little toward solving the problems of such an area. It must be the work of many, and perhaps of years. The writer can only regret that so many questions must be left unsettled, and trusts that in spite of a certain inconclusiveness, of which he is well aware, this report may prove serviceable in the development of the region.

TOPOGRAPHY.

RELIEF.

The lead and zinc deposits of the upper Mississippi Valley lie within the well-known Driftless Area. The region seems exceedingly rugged when contrasted with the smooth, drift-covered plains that surround it. There is a total relief of about 1,100 feet, the bottom lands of the Mississippi lying about 600 feet above the sea level, and the tops of the

[a] Lead and zinc deposits of Wisconsin, with an atlas of detailed maps: Bull. Wisconsin Geol. and Nat. Hist. Surv. No. 14, econ. ser., No. 9, 1906, 100 pp. This report can be obtained by addressing Dr. E. A. Birge, Director Geol. Nat. Hist. Survey, Madison, Wis.

highest hills—Blue Mounds—rising a little above the 1,700-foot contour. The dominant topographic feature of the region is an upland plain lying about 900 feet above the sea in the southern portion of the area and rising gently toward the north to 1,250 feet near Highland. Below this plain the rivers have cut their valleys, while above it rise a number of detached hills, locally known as mounds, and a well-defined escarpment, which bounds it to the southeast and southwest. From the fact that this escarpment is made by the outcropping edge of hard chert and dolomite of Niagara age, it may fittingly be called the Niagara escarpment.

NIAGARA ESCARPMENT AND THE MOUNDS.

The most striking and picturesque features of the landscape are the mounds and the frowning range of hills which hem in the district on the south. Viewed from the higher portions of the city of Galena, the isolated mounds southeast of the city, with the high rampart beyond Smallpox Creek in the background, are very impressive (fig. 1). From Dubuque a similar view may be had to the southwest. From almost every point upon the great upland plain of the region either these encircling hills or some of the detached

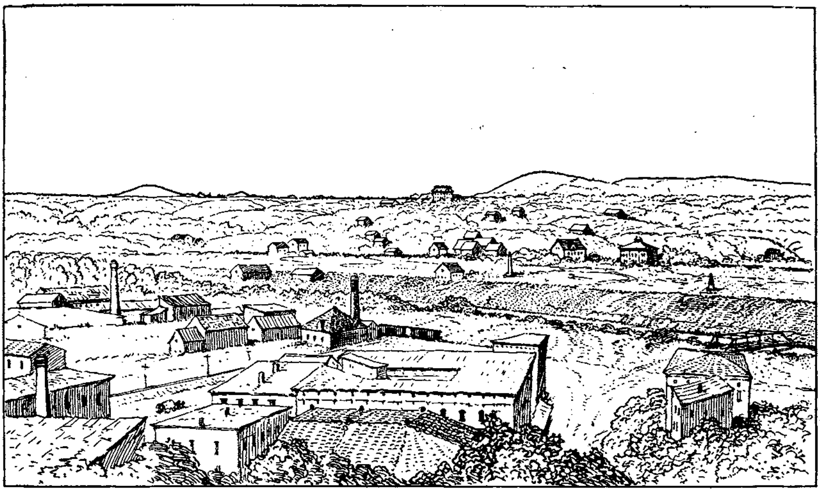

FIG. 1.—The mounds and the upland and river terraces as seen from Galena, Ill. Looking southeast.

mounds may be seen. The Illinois portion of the area has not yet been covered by topographic mapping, so that the height of the escarpment is undetermined. Horseshoe Mound, the nearest outlying hill, rises 430 feet above the Burlington Railway station at Galena, or to an altitude of 1,030 feet, according to observations of the Mississippi River Commission. Southwest of Dubuque the escarpment itself rises approximately 100 feet higher.

Viewed in a large way, the escarpment has an abrupt slope facing the mining district and a long, gentle slope away from it. To the south and west this back slope descends so gradually as to escape attention, finally reaching the same altitude as the plain to the north which the escarpment overlooks. In Illinois the back slope, owing to the encroachment of streams from the south, is not well defined. Apple River and its tributaries have cut back so vigorously that only a narrow ridge is left between its basin and that of Smallpox Creek, which lies to the north. Between Smallpox Creek and Fever River a series of disconnected mounds mark the position of an earlier and still more completely dissected escarpment front.

Southeast of Smallpox Creek the escarpment shows in a somewhat irregular front, with the general trend paralleled by the stream. Southeast of the divide the ridge extends in long, finger-like processes between the various tributaries of Apple River, which lies 7 to 8 miles away. The divide, therefore, is asymmetric, with a short and a long slope, the former facing the plain and the latter corresponding to the general back slope so well defined in Iowa. These relations are shown on the geologic map (Pl. II), the area covered by the Niagara marking the position of the escarpment and the mounds.

To the north the escarpment faces the upland plain upon which are scattered Table and Sherrill mounds in Iowa; Horseshoe, Charles, and Scales mounds in Illinois, and Sinsinawa Mound, the Platte Mounds, Blue Mound, and other isolated hills in Wisconsin. The area occupied by the mounds is limited as compared with the total area of the plain. The distances between them are great and their diameters are small. Their tops rise to the level of the escarpment, and a plane projected from a crest of the latter and touching the top of the mounds would be approximately even and would rise gently to the northeast.

UPLAND.

The plain above which these mounds rise is the most important physiographic feature of the region. It is well displayed at Galena, Dubuque, Platteville, and at various points as far north as the Military Ridge, along which the La Crosse division of the Chicago and Northwestern Railway runs. From Montfort to Cuba the Galena line of the same railway traverses it. The mounds rise 200 feet or more above it, and the streams have cut into it for 200 to 300 feet. To the south it is underlain by the soft Maquoketa shale; to the north by Galena, Platteville, St. Peter, and lower rocks in succession. Near the escarpment fully half the thickness of the shale is below this plane, and at Hazel Green only the thinnest remnant of the basal beds remains. Near Platteville almost the whole thickness of the Galena is present. At Highland more than half of it is gone. The strata are bent up and down as much as a hundred feet in places, but the upper surface is planed smooth. It is therefore a nearly even plain of subaerial erosion, beveling the edges of both hard and soft strata—a peneplain to which Grant and Burchard propose to apply the local name Lancaster. The peneplain marks a period in geologic time when the region stood at a low elevation sufficiently long for the streams to reduce almost the whole area to this level. The mounds are monadnocks and represent interstream areas which were not completely reduced.

The whole of the upland is drained. The streams form a network covering every part of it and make up a normal dendritic drainage system.

VALLEYS.

The upland plain is everywhere interrupted by valleys, and while in general it forms a nearly level surface, in detail it is made up of slopes facing the streams. The most important stream in the area is the Mississippi, its major tributaries from the east being the Wisconsin River, which practically bounds the region to the north, Grant River, Platte River, Menominee River, Sinsinawa River, Fever River, Smallpox Creek, and Apple River. On the west, Turkey River, Maquoketa River, Catfish Creek, and Tête de Mort River are most important.

The Mississippi flows in a sharp-walled valley having a width slightly exceeding 1 mile at Dubuque. The bottom land lies about 600 feet above sea level, and the walls rise abruptly to 750 or 800 feet. The size of the Mississippi Valley is, in this district, out of proportion to that of its main tributaries. Its sharp walls are also exceptional. Between two long tributaries of one of the smaller streams the upland reaches out in a long finger-like promontory; between two tributaries of the Mississippi there is, instead, a sharp canyon wall, as if there had existed promontories which later were truncated half or three-quarters of a mile back from the main stream.

The valley, furthermore, reversing the normal habit of rivers, becomes narrower down the river and wider toward its source. This is shown in fig. 2, made from a tracing of the topographic atlas sheets of the region. The width of the bottom land of both the main stream and certain curious tributaries is shown. It may be noted that Upper Iowa (Oneota) River, Village Creek, the lowermost portion of Wisconsin River, and Maquoketa River turn to the north before joining the main stream. They all have notably wide valleys in their lower courses. Certain other streams show this same tendency in a less marked degree, and in addition Maquoketa River and Catfish Creek now join the Mississippi through new valleys upstream, having deserted old, open valleys having the normal downstream course usual for tributary valleys. It may further be noted that the northern portion of the river course is that which has the highest bluffs; it is the part of the river which has cut deepest into the old peneplain. In Allamakee County, Iowa, the hills rise higher than at any other point between St. Paul and the Gulf of Mexico. This portion of the river's course therefore shows the anomaly of increasing vertical cutting accompanied by increasing valley widening toward its source.

It has been customary to explain these differences in valley width as mainly the result of the great difference in hardness between the sandstones and dolomites of the region, and doubtless this has been an important factor. A comparison, however, of the topographic and the geologic map of the region fails to show as close a concordance between the width of the valley and the character of the wall as the hypothesis would seem to demand. Such comparisons are difficult because of uncertainty of the depth of scour. It seems to be true, nevertheless, that the hard Oneota dolomite, which influences the width of the minor valleys very markedly, as shown by the detailed map of the Wisconsin Geological and Natural History Survey, finds no adequate expression in the Mississippi Valley.

FIG. 2.—Sketch map of Mississippi River Valley above Dubuque, showing gradual narrowing toward the south.

Differences in hardness of strata also offer no explanation of the northward turning of the tributaries and of the truncated promontories. All these features are excellently shown on the Waukon, Elkader, Lancaster, and Peosta topographic atlas sheets of the United States Geological Survey. The narrowing of the valley to the south and the abnormal tributaries are perhaps connected with the periods of peneplanation and warping.

Hershey,[a] who first noted many of these peculiarities, has suggested that the upper portion of the Mississippi was possibly in pre-Glacial times a northward-flowing stream and this suggestion has much to commend it. The river history of the area is, however, too little known as yet to warrant more than the suggestion of such explanations. The truncated promontories make it clear, none the less, that the Mississippi River has had a different history from that of the other rivers of the region—a difference due to conditions existing in the Glacial epoch, by reason of which certain streams, of which class it is a notable example, heading outside of the Driftless Area, received during the melting of the ice large volumes of water, while those within the area had only the normal flow. The first effect of this increased flow was to widen the valley as with a rasp. In this the floods acted much as glaciers do in changing a V-shaped to a U-shaped valley. The second effect, as the amount of water decreased, was to build up a flood plain or terrace by aggregation. During both stages the lower reaches of the tributary streams rising within the district were ponded and silted up.

It has been common to assume that the area formerly stood at a somewhat higher level, and the depth of the valley filling near Dubuque has been cited to sustain this view. This

[a] Hershey, O. H., The physiographic development of the upper Mississippi Valley: Am. Geologist, vol. 20, 1897, pp. 246–268.

matter is discussed in connection with the description of the Quaternary deposits, but it may be noted in passing that the tributary streams show no such filled-in valleys except where backwater has laid down peculiar and easily discriminated deposits, and that the evidence from the main valley itself is possibly not above criticism. To the author the great volume of water temporarily carried by the Mississippi seems an ample agent for producing both the deep valley by scour and the later filling by aggradation.

The minor streams of the area have broad, open valleys near their headwaters, where the slopes of the upland and the slopes of the valley merge in long, beautiful, convex curves. In their lower portions they often have canyon-like phases and well-developed though narrow flood plains. The larger streams joining the Mississippi are marked by a well-defined aggradation terrace. The outer limits of this terrace along most of these streams are indicated on the geologic map, Pl. II.

AGE OF THE PENEPLAIN.

The Lancaster peneplain has been described by Kümmel[a] and Hershey[b]. Kümmel noted the meandering course of the principal rivers of the region and argued that they were superimposed streams. He interpreted the history of the period succeeding peneplanation as one of simple down cutting. Hershey, who has most fully described and discussed the region, gave reasons for considering the Lancaster peneplain as of Tertiary age and correlated it with the Tennesseean of McGee. According to his interpretation the tops of the mounds and the back slope of the Niagara escarpment represent an older, probably Cretaceous, peneplain, here locally bowed up and dissected. In another paper[c] he notes and approves the suggestion made by Frank Leverett that in central Illinois probably the Cretaceous and Tertiary peneplains coincide and correlates the Lafayette subcycle of erosion, which followed the main Tertiary period of peneplanation, with certain broad, shallow basin valleys that he had recognized in northwestern Illinois, in the bottom of which the present gorges of the Mississippi and other streams are cut.

With these general conclusions the present writer finds himself in complete harmony, though he is disposed to question the separation of the Lafayette cycle of erosion from that of the Tertiary in general. The Lancaster peneplain seems clearly to have been developed in the last great period of erosion antedating the glaciers, and in the western interior that period was the portion of the Tertiary known as the Lafayette.

In southern Illinois relations strikingly similar to those in the upper Mississippi Valley have been studied.[d] The Lafayette is there marked by a series of gravels made up mainly of cherts and residue materials, which in Pope County lap up on the edge of an old much-dissected upland. These gravels cover portions of Pope, Massac, and Pulaski counties and extend over a broken, dissected plain, up to a general altitude of 500 feet. This plain is bounded on the north by a southward-fronting escarpment of basal Pennsylvania rocks, comparable to the Niagara escarpment in northern Illinois. This is the south front of Karbers Ridge, which rises to an altitude of 800 to 850 feet and exhibits a long back slope to the north, where there is a general plain underlain by soft Coal Measure rocks and having a general altitude of about 450 feet. The back slope has been shortened to the east by the work of Saline River, so that it is steep rather than gentle. Farther west, where the Illinois Central Railroad crosses the territory, the conditions are very similar to those where the same road passes over the Niagara escarpment west of Dubuque.

The gravels of southern Illinois are regarded as Lafayette, and traces of similar gravels bearing Tertiary fossils have been found in the Mississippi Valley nearly as far north as the crossing of the present 500-foot contour. As noted above, the broad plain north of Karbers Ridge is slightly lower than that to the south. This difference may well be due to differences in the hardness of the rocks. It might also be due to deformation accompanying the northern tilting already referred to as having taken place since the develop-

[a] Kümmel, H. B., Some meandering rivers in Wisconsin: Science, new series, vol. 7, 1895, pp. 714–716.
[b] Hershey, O. H., loc. cit.
[c] Hershey, O. H., Pre-Glacial erosion cycles in northwestern Illinois: Am. Geologist, vol. 18, 1896, p. 72.
[d] Bain, H. F., Fluorspar deposits of Illinois: Bull. U. S. Geol. Survey No. 255, 1905, pp. 14–17.

ment of the peneplain, but in the absence of accurate topographic maps the phenomena must for the present remain unexplained.

The general plain north of Karbers Ridge continues, to all appearances, beneath the drift across the State and connects with the plain in the Driftless Area, and this interpretation is in accord with the general geologic history of the region, the peneplain of the north being correlated with Lafayette deposition in the south, while the gravels found along the Mississippi probably represent the maximum encroachment of the sea.

Preceding this period of peneplanation there were apparently local uplifts or warpings of the plain in the Driftless Area and in southern Illinois. In Lafayette time, if the suggested correlation be correct, these uplifted areas were dissected but not entirely cut away, Karbers Ridge in the south and the mounds and Niagara escarpment in the north remaining as monadnocks. In the same period the great plains between the uplifted areas were merely slightly reduced, having been already reduced to a peneplain in Cretaceous or possibly early Tertiary time. In post-Lafayette time the whole area was uplifted, and the streams cut into the Lafayette plain the sharp channels which they now occupy.

In fig. 3 these relations are illustrated diagrammatically. It will be seen that in central Illinois the older and younger peneplain coincide with the present rock surface. In the Driftless Area the older plain is warped upward and is now preserved only in the back slope of the escarpment and the crest of the mounds, while the younger and more prominent one occupies the dissected area between. In southern Illinois the long spur crossing the State and connected with the Ozark upland shows similar conditions, the older peneplain being preserved by Karbers Ridge and the younger by the general upland between

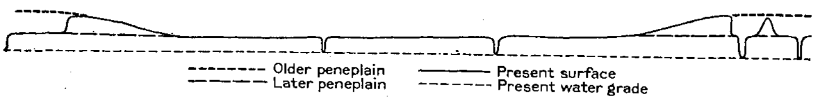

FIG. 3.—Diagram showing relations of present surface to ancient peneplain.

it and the Ohio. That since the formation of the younger peneplain the region has been elevated as a unit rather than with local deformation is shown by the close coincidence between the present river grade and the younger peneplain. The difference in elevation at the north from that at the south indicates that there has apparently been a simple progressive elevation to the north.

GEOLOGY.

GENERAL STATEMENT.

The geology of the upper Mississippi Valley is relatively simple, and its main outlines have been known since the early work of Owen,[a] Hall,[b] and Whitney.[c] The region is one of unmetamorphosed, little disturbed, sedimentary rocks, of Paleozoic age, and there are no igneous rocks in it or recent ones near it. It has been at least once worn down by erosion to mature topographic development and afterwards uplifted, and is now being redissected. The rocks have a very gentle dip to the southwest, superimposed on which are numerous shallow folds of local extent.

Within the ore-bearing district only Ordovician and Silurian beds occur. In order, however, to make the relations clear it seems advisable to review briefly the section found

[a] Owen, D. D., Rept. geol. expl. part of Iowa, Wisconsin, and Illinois, etc.: House Doc. No. 239, 26th Cong., 1st sess., 1840; Senate Doc. No. 407, 28th Cong., 1st sess., 1844; Rept. Geol. Survey Wisconsin, Iowa, and Minnesota, Philadelphia, 1852.

[b] Hall, James, Lower Silurian system, chapters 8 and 9 of Rept. on geology of the Lake Superior land district, by J. W. Foster and J. D. Whitney, Washington, 1851; Geol. Survey Iowa, 1858; Geol. Survey Wisconsin, 1862.

[c] Metallic Wealth of the United States, 1852; Geol. Survey Iowa (Hall), vol. 1, pt. 1, 1858; Geol. Survey Wisconsin (Hall), vol. 7, 1862; Geol. Survey Illinois (Worthen), vol. 1, 1866; Rept. geol. survey upper Mississippi lead region, 1862, 455 pages, a reprint, separately bound, of the portions of the Wisconsin report dealing with the lead region.

in the upper Mississippi region as a whole.[a] The section includes representatives of the Cambrian, Ordovician, and Silurian, while in the area immediately adjacent, to the north and east, pre-Cambrian rocks occur. (Pl. I.) The Ordovician rocks are the only ones which are important from the present point of view. The Cambrian beds are not ore bearing and are not known to have had any direct influence on the formation of the ores. The Silurian beds overlap the Ordovician and limit the fields to the south and west, but are not otherwise related to the ores. (Pl. II.)

STRATIGRAPHY.

GENERAL SECTION.

A general section of the present rocks may be tabulated as below:

Section of the rocks of the upper Mississippi Valley.

System.	Formation.	Character.	Thickness in feet.
Quaternary.		Alluvium. Terrace deposits. Loess. Residual clays.	5–70
Silurian.	Niagara.	Dolomite.	150
Ordovician.	Maquoketa.	Shales.	160
	Galena.	Dolomite.	240
	Platteville.	Limestone and dolomite.	55
	St. Peter.	Sandstone.	80
	Prairie du Chien: Shakopee.	Dolomite.	50
	Prairie du Chien: New Richmond.	Sandstone.	10–40
	Prairie du Chien: Oneota.	Dolomite.	200
Cambrian.	"Potsdam."	Sandstone with minor shale and dolomite.	800
Pre-Cambrian.		Quartzite, with various igneous rocks.	

PRE-CAMBRIAN ROCKS.

Rocks older than the Cambrian do not outcrop at any point in the zinc and lead district, though they are known to underlie the entire area. They have been encountered in deep wells at Lansing and other points and are exposed at many points to the north and east. The quartzite at Baraboo and the eorhyolites of central Wisconsin belong to this group. The pre-Cambrian forms a floor, sloping gently to the southwest, upon which the later sediments rest. It lies 1,000 to 1,500 feet below the surface within the district, and is separated from the lowest Paleozoic beds by a pronounced unconformity, which indicates a long period of erosion.

CAMBRIAN ROCKS.

The Cambrian is represented in the district by about a thousand feet of sandstone, with minor portions of shale and dolomite. The beds have been commonly referred to the Potsdam, though in the later Minnesota and Iowa reports they are called the St. Croix, a

[a] In the preparation of this discussion the writer has made free use of all published material and also of the manuscript of the Lancaster-Mineral Point folio in preparation by Dr. U. S. Grant and Mr. E. F. Burchard. He has also had the benefit of criticism and advice both in the field and in the office of Mr. E. O. Ulrich. To all of these he is under obligations, for which acknowledgment is cheerfully made, but for the particular statements here made the author should alone be held responsible.

local name. This name, however, has not always been consistently used, and pending a complete revision of the stratigraphy it seems desirable to leave the question of nomenclature open. At many points the beds are divided into an upper and a lower sandstone, between which occur dolomites or shales. So far these divisions have not been mapped throughout the field, and it is not certain that they are everywhere present.

ORDOVICIAN ROCKS.

PRAIRIE DU CHIEN FORMATION.

Name and divisions.—Above the Cambrian and extending up to the St. Peter lies a thick formation consisting mainly of dolomite, but including some sandstone. To this Owen in 1840[a] gave the name "Lower Magnesian" to distinguish it from the "Upper Magnesian," under which term were included both the Galena and Niagara of present nomenclature. Since the discrimination of the thick Maquoketa shale between these two the original significance of the name has been lost, and in accordance with present usage a geographic name for the formation as a whole is proposed in the Lancaster-Mineral Point folio. The old name, Lower Magnesian, was retained by Hall, Whitney, White, Chamberlin, and all the earlier workers, but local names have been given to the individual members of the formation.

Where fully developed the formation included (*a*) a dolomite at the base, 200 to 225 feet thick; (*b*) a sandstone in the middle, 15 to 130 feet thick, increasing to the southwest under cover; (*c*) a second dolomite at the top, approximately 40 feet in thickness. These are known, respectively, as the Oneota, New Richmond, and Shakopee or Willow River.

It was to the basal member of the group that McGee in 1891 gave the name Oneota [b] as a substitute for "main body of the limestone," a term used some years earlier by Irving [c] to discriminate the lower portion of the "Lower Magnesian" limestone. McGee considered the Oneota to be the equivalent of the whole of the "Lower Magnesian," and grouped with the St. Peter the overlying sandstone (New Richmond) and the thinner dolomite (Shakopee). Calvin [d] has used Oneota to cover the whole group, discriminating the "main body of the limestone" under the title of Lower Oneota.

The New Richmond sandstone varies from 15 to 130 feet in thickness.[e] It is not always well defined in outcrops, though W. H. Norton[f] found it in deep wells as far south and west as Des Moines.

As explained above, the Shakopee dolomite is the equivalent of the Upper Oneota of the Iowa Survey. It is a massive dolomite, approximately 40 feet thick, and is clearly defined in well records far south and west of the area of outcrop, though not well exposed within the lead and zinc district proper. Over much of the lead and zinc region the New Richmond and Shakopee are poorly defined, and over other parts they seem to be entirely absent. This is believed to be largely due to erosion preceding the deposition of the St. Peter.

Lithologic character.—The dolomite found in the Prairie du Chien is gray to white in color and varies from a very compact, fine-grained rock to one which is porous and coarse grained, but on the average it is less porous and less coarse grained than is the Galena. It also commonly weathers less roughly than does the Galena, though in localities the Prairie du Chien is a markedly rough-weathering rock. In some cases this is due to its brecciated or conglomeratic character. The formation contains masses of flint of different sizes, some as large as a foot in diameter, which are commonly segregated in certain layers. In general, the coarser parts of the formation carry more flints, and the finer, compact portions are entirely free from them. In the dolomite or in the flint masses there are many small cavities which are lined with small crystals or quartz. Near or at the top of the formation there is in many places a marked development of oolite having a siliceous cement. The oolites have a concentric structure and are mainly siliceous, though some are calcareous.

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[a] House Ex. Doc. No. 239, 26th Cong., 1st sess., 1840, p. 17.
[b] Eleventh Ann. Rept. U. S. Geol. Survey, pt. 1, 1891, p. 332.
[c] Am. Jour. Sci., 3d ser., vol. 9, 1875, p. 442.
[d] Iowa Geol. Survey, vol. 4, 1895, pp. 61–68.
[e] Norton, W. H., Iowa Geol. Survey, vol. 3, 1895, p. 183.
[f] Iowa Geol. Survey, vol. 6, 1897, pp. 115–428.

The formation contains in its upper portion considerable sandstone, which is not always easily discriminated from the St. Peter. In general the St. Peter is thicker bedded and more massive, is freer from clay and iron oxide, and does not contain the flint and oolite found in the Prairie du Chien.

Fossils.—Fossils are not common in this formation. Those found consist almost entirely of gasteropods and cephalopods. They occur only or chiefly in the prevailingly cherty upper third of the formation.

Relations and thickness.—The relations of the Prairie du Chien to the Cambrian were not studied in the course of this investigation. The formation is separated from the St. Peter by a marked erosion unconformity. Its thickness ranges generally between 200 and 300 feet.

ST. PETER SANDSTONE.

Name and thickness.—Upon the Prairie du Chien lies a comparatively thin sandstone, long known as the St. Peter from the fact that it occurs along the lower course of the St. Peters (now known as the Minnesota) River. This sandstone varies considerably in thickness, averaging about 70 feet. Its maximum thickness is somewhat over 100 feet and its minimum perhaps 40 feet.

Lithologic character.—Lithologically the St. Peter is a practically pure quartz sandstone, its silica content being very high, in some specimens reaching 99 per cent. The grains are well waterworn and commonly very poorly cemented, so that the rock crumbles and does not at many places stand up in vertical exposures. Exceptionally, casehardening causes it to form well-developed cliffs. The cementing substances present are quartz and iron oxides. In a few places the grains have been enlarged by the addition of silica and now present more or less perfect crystal faces. Near the surface in many exposures the sandstone is stained yellow, brown, or red by iron oxides, but this coloration is mainly superficial.

Fossils.—The St. Peter is a practically unfossiliferous formation, though a few bivalve shells and pelecypods have been reported from it.[a]

Relations.—The St. Peter rests in marked unconformity upon the Prairie du Chien. Its relations to the succeeding formations are less clear. Between the typical sandstone and the basal dolomite of the Platteville there is everywhere a band of blue sandy shale, varying in thickness from a few inches up to 5 feet or more. This is not usually sharply separated from the sandstone, but grades into it. On the other hand, the upper surface of the shale is sharply separated from the overlying massive dolomite. The sand grains extend up through the shale, but rarely, if ever, beyond that horizon. This would seem to indicate that the shale belongs with the sandstone or is a transition bed, indicating continuous sedimentation. In Missouri and elsewhere, however, the two formations are separated by certain beds which are absent in the upper Mississippi Valley. The Joachim limestone has a considerable development in the Ozark region and overlies the undoubted extension of the St. Peter, being at the same time covered by the equivalent of the Platteville. These facts would indicate a period of nondeposition if not of erosion in the upper valley. Owing to the general absence of fossils and the homogeneous nature of the St. Peter, it has so far been impossible to make certain whether the same bed is everywhere present and in contact with the overlying rocks. There is no visible discordance of strata and to that extent no positive proof of unconformity. In the light, however, of the exposures in Missouri and of general studies of the Ordovician it seems best to consider the blue shale as marking the initial deposition of the Platteville and the presence of the St. Peter sand grains and pebbles in it as due to reworking of the loosely consolidated material by the oncoming sea.

PLATTEVILLE LIMESTONE.

Name and thickness.—The beds included under this name have long been known in this district as the Trenton limestone. Since that term has been variously used in this area and only a portion of the beds commonly referred to as Trenton are here discussed, it has been

[a] Sardeson, F., Paleozoic formations of southeastern Minnesota: Bull. Geol. Soc. America, vol. 3, 1892, p. 352.

proposed[a] to use a local name for them. The exact correlation of the Platteville with the New York section is open to some doubt. The closest approach to a synonym is the term Beloit, proposed by F. W. Sardeson.[b] The upper limit of the Beloit is not, however, the same as that here adopted for the Platteville, and as the lithologic development of the two formations is very different it seems best to let the matter of a general term rest, pending complete studies of the entire region.

The Platteville formation is typically exposed in the vicinity of Platteville, Wis., and its entire thickness may be seen along Little Platte River west of that town. It has an average thickness of approximately 55 feet, with a minimum of 40 feet and a maximum of perhaps 65 feet.

Lithologic character.—The formation is made up largely of limestone, which is nonmagnesian or slightly magnesian as contrasted with the succeeding Galena. It contains, however, certain beds of dolomite and considerable shale. The upper limestones of the Platteville are characteristically fine grained and break with a clean, conchoidal fracture. The best-known bed is locally called "glass rock" and is an easily recognized and important datum plane, though there are several beds which are somewhat like it in texture. The shales are generally blue to green, and are essentially argillaceous, containing very little sand. Occasionally they are slightly bituminous, though the bulk of the bituminous shale found in this area belongs to the succeeding Galena formation.

A generalized section of the Platteville includes the following beds:

Generalized section of the Platteville limestone in the upper Mississippi Valley.

	Feet.
4. Thin beds of limestone and shale	10–15
3. Thin-bedded, brittle limestone, breaking with conchoidal fracture	25–30
2. Buff to blue magnesian limestone, heavy bedded, in many places a dolomite	15–25
1. Shale, blue, in some places sandy	1–5

No. 1 of this section forms the base of the Platteville and rests directly on the St. Peter sandstone; in places it is sandy, though commonly it contains a distinct bed of shale free from sand grains of noticeable size. It is nowhere very thick, and while, as already noted, it is here referred to the Platteville, it is possible that future studies may show that it belongs properly to the St. Peter or to a formation which, as developed elsewhere, lies between the St. Peter and the Platteville.

No. 2 of the above section is the so-called buff limestone or quarry rock, so far as it is developed in this particular region. It is always magnesian and is usually a dolomite. It is buff on weathered surfaces, but blue in fresh blocks. Its beds are from 6 inches to 2 feet thick, and it is thus markedly different from the rest of the Platteville. It holds its peculiar lithologic characteristics over large parts of the upper Mississippi Valley, even outside the lead and zinc district. It can be distinguished in the field from the Galena dolomite both by its stratigraphic position and by its more earthy nature. It has been called the "lower buff limestone" and also the "quarry bed."

No. 3 of the section consists commonly of thin beds 1 to 3 inches in thickness. These are separated by very thin shale partings and have an undulating or wavy appearance. At many places these beds are dense, composed of a very fine-grained gray to light-brown limestone, which breaks with a more or less marked conchoidal fracture; on weathered surfaces the rock is usually white or very light gray. When this member has the peculiar lithologic characters just mentioned it is sometimes called the "glass rock," though the main "glass rock" belongs in the next higher member of the section. The peculiar thin, wavy beds are especially characteristic of this member of the section throughout the district. To the east, near Beloit, it is represented by magnesian limestones and dolomites, more like the beds below.

[a] Bain, H. F., Zinc and lead deposits of northwestern Illinois: Bull. U. S. Geol. Survey No. 246, 1905, p. 19.

[b] Am. Geologist, vol. 19, 1897, p. 23.

No. 4 of the section consists of limestone and shale in thin alternating beds which greatly resemble in places the basal portion of the succeeding Galena. It is in this member that the typical glass rock occurs. This rock consists of dense, very fine-grained, hard, conchoidally breaking limestone, which rings when struck with a hammer. It is of a light chocolate color when fresh, but weathers rapidly to white or to very light gray. The typical glass rock beds range from 3 to 8 inches in thickness and are separated by thin partings of chocolate-colored shale. Together they have a thickness ranging from 18 inches to 4 feet, and form what is called the main glass rock. As the rock strongly resists weathering, its exposures and fragments are, as a rule, easily found. In the eastern part of the area this glass rock becomes coarser grained, somewhat magnesian, occasionally cherty, and thicker, being in places 15 feet thick. It still retains, however, some of its usual characteristics and is commonly called glass rock by the miners. Chemically the glass rock is a slightly impure limestone, as is shown by the following analysis:

Analysis of glass rock.[a]

Silica (SiO_2)	6.160
Alumina (Al_2O_3)	2.260
Sesquioxide of iron (Fe_2O_3)	.950
Carbonate of lime ($CaCO_3$)	85.540
Carbonate of magnesia ($MgCO_3$)	3.980
Water (H_2O)	.930
Phosphoric anhydride (P_2O_5)	.055
	99.875

Above the glass rock are usually a few feet of thin-bedded, shaly limestone, containing large quantities of a large long-hinged variety of *Orthis*—*O.* (*Dalmanella*) *subæquata*. While this form ranges higher, it is especially abundant at this horizon, which is taken as marking the top of the Platteville.

Fossils.—Mr. Ulrich supplies the following notes upon the paleontologic characteristics of the Platteville:

The Platteville as a whole is more highly fossiliferous than any other formation in the immediate region. While practically all beds except the basal shale contain fossils in greater or less abundance, certain beds are literally packed with organic remains. A few species, notably *Leperditia fabulites* (Conrad), the most characteristic fossil of the formation, range through nearly all the beds. Many other species, however, occur in only one or two of the beds. The dolomitic member (No. 2 of the general section) contains relatively few fossils, and in some places appears almost barren.

Of species and varieties confined in the Mississippi Valley to the Platteville, *Streptelasma profundum*, *Rafinesquina minnesotensis*, *Orthis deflecta*, *O. subæquata* (long-hinged variety), *Pterotheria rectangularis*, *Leperditia fabulites*, and *Thaleops ovatus* may be found in any of the limestone beds of the formation. All of these species are common in the thin-bedded, nearly pure limestone constituting bed 3. Among species apparently restricted to this bed or occurring so much more abundantly here than elsewhere in the section that they may be considered as characteristic of it, the following may be mentioned: *Maclurea bigsbyi*, *Pterothera alternata*, *Zygospira* (*Hallina*) *nicolleti*, *Hingia inæqualis*, *Rhinidicthya pediculata*, *Phyllopernia sublaxa*, *Monotrypa magna*, *Rhynchotrema minnesotensis*, *Ambonychia planistriata*, *Chonychia lamellosa*, *Salpingostoma buelli*, *Conradella triangularis*, *Hyolithes baconi*, *Encrinurus vannulus*, and sponges of the genera *Anthaspidella* and *Zittelella*.

The characteristic fossils of the glass rock and interbedded shales are *Buthograptus laxus* and other delicate plumose marine algæ.

The top shale of the formation everywhere contains great numbers of a large and rather broad variety of *O.* (*Dal.*) *subæquata* that is confined to this horizon. Other species are few, but one or both of the bryozoa, *Strictoporella frondifera* and *S. angularis*, that occur only in this shale bed, may commonly be found wherever the bed is well developed.

A few of the Platteville fossils, especially the brachipods and notably *Orthis tricenaria*, *O. subæquata*, and *Strophmena incurvata*, pass upward into the lithologically similar basal division of the Galena. But the other fossils associated with these transgressing species are so numerous and distinct that only slight acquaintance with fossils is required to distinguish the representative horizons at once. Moreover, a close study of the species mentioned shows that in passing from one formation to the next they have sustained recognizable modifications.

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[a] Geology of Wisconsin, vol. 2, 1877, p. 681.

Detailed sections.—Owing to the importance of the Platteville in its relation to the ore deposits and the frequent obscurity of the Platteville-Galena contact, it seems desirable to give a few detailed typical sections before discussing the relations. The sections given below are well exposed and each in its way is characteristic. For convenience, the portion of the St. Peter and Galena formations exposed are noted, as well as the Platteville beds. The Spechts ferry section was measured by Calvin and Bain[a], the others by Grant, the fossils having been determined by Ulrich.

1. Section at Spechts ferry.

	Feet.
11. Thin-bedded, brown dolomite, with shaly partings	4
10. Thin-bedded, imperfectly dolomitized limestone, with fossil brachiopod shells only slightly changed; the limestone brown, earthy, noncrystalline, but evidently of the Galena type	3
9. Thick, earthy, imperfectly dolomitized beds (Galena)	3
8. Thin limestone beds with much shale in the partings; in part a true shale. This member is almost entirely shaly a few rods above the station on the road leading to Dubuque. Fossils are numerous, the most common species being *Orthis testudinaria*, *O. bellarugosa*, *O. plicatella*, *Rafinesquina alternata*, and *Plectambonites sericea*	5
7. Limestone, bluish, with poorly preserved fossils, in beds varying from 3 to 6 inches in thickness	25
6. Bluish or greenish shale containing occasional thin beds or discontinuous flakes of limestone. The characteristic fossils are *Orthis subæquata* and *O. tricenaria*; the "green shales" of the Minnesota geologists	12
5. Thin-bedded, bluish, rather coarse-grained limestone, weathering brown in color	5
4. Limestone in rather heavy layers which range up to 15 inches in thickness; bluish on fresh fracture but weathering to buff on exposure	5
3. Brittle, fine-grained, blue limestone, very fossiliferous, breaking up on weathered surfaces into flexuous layers about 2 inches thick	20
2. Lower buff beds, exposed, about	8
1. Unexposed to level of water in river, about	45

Since the above section was measured a new quarry has been opened near by. In it certain of the beds have a slightly different development, a thin, well-defined black shale being found at the base of No. 6 and dark shaly partings appearing in the lower portion of No. 7. From the latter Mr. Burchard collected *Rafinesquina alternata*, *Strophomena filitaxta*, *Ctenodonta astartæformis*, and *Bathyurus spiniger*. While the dolomite phase of the Galena is not found below No. 9 of the section, the top of the Platteville is considered to be marked by No. 6.

The following section was measured at the old quarry on the west branch of Little Platte River in NE. ¼ sec. 8, T. 3 N., R. 1 W.

2. Section near Platteville.

	Ft.	in.
13. Subcrystalline limestone, magnesian at base, but in 2 or 3 feet grading into thick-bedded dolomite	20	
12. Blue to gray calcareous shale or shaly limestone		8
11. Thin-bedded, subcrystalline limestone, containing a few specimens of *Orthis tricenaria* Conrad and *O. subæquata* Conrad	5	
10. Thin, wavy-bedded, glass-rock-like limestone, becoming subcrystalline above. Some beds are very fossiliferous. *Orthis tricenaria* Conrad, *O. subæquata* Conrad, and *O. testudinaria* Dalman	6	
9. Dark-brown or chocolate-colored shale or oil rock	2	
8. Thin, wavy-bedded glass-rock-like limestone, commonly very fossiliferous; a few thin partings of oil rock. *Orthis tricenaria* Conrad, *O. subæquata* Conrad, *Strophomena incurvata* Shepard, *Rafinesquina alternata* Conrad, *Ctedodonta astartiformis* Salter, *Ceraurus pleurexanthemus* Green, *Isotelus gigas* Dekay, *Rhinidictya mutabilis minor* Ulrich, forms the base of the Galena at this locality	8	
7. Blue shale		8
6. Thin, undulating, hard, sometimes glass-rock-like limestone, interbedded with blue shale. The limestone is very fossiliferous. This is the chief horizon for *Orthis subæquata* Conrad (var. *minneapolis* Winchell), which is here very abundant and of large size. *Strictoporella frondifera* Ulrich occurs at the top of this division	2	

[a] Iowa Geol. Survey, vol. 10, 1900, p. 421.

	Ft.	in.
5. Gray to yellow-brown to almost black clay		7
4. Dark-gray shale and bard gray limestone interbedded	1	2
3. The main glass-rock beds. Somé oil-rock bands occur in the lower part and in these are fern-like forms which are probably fossil algæ. *Buthograptus laxus* (Hall)	2	
2. Thin, shaly layers of glass-rock with oil-rock partings; weathers to clay		3
1. Blue, gray-weathering limestone, with dark partings. The upper part is separated by blue shale into 2 beds, each 21 inches thick. The upper of these beds has in places the appearance of thin wavy-bedded glass rock. *Orthis deflecta* Conrad, *Rafinesquina minnesotensis* Ulrich, *Thaleops ovata* Conrad, *Leperditia fabulites* Conrad, *Monotrypa magna* Ulrich, to base of exposure	7	

In this section (Pl. III, *A*) the lower portion of the Galena and uppermost beds of the Platteville are shown. No. 1 belongs to the thin-bedded member (No. 3 of general section) of the Platteville. Nos. 2 to 6 belong to the upper member of the Platteville (No. 4 of the general section), while Nos. 11 to 13 clearly belong to the Galena. Nos. 8 to 10 are probably the equivalents of the main oil-rock horizon which marks the base of the Galena, and No. 7 represents the clay bed usually found beneath it. This section is fairly characteristic for the western half of the Mineral Point quadrangle, except in the extreme northern part.

3. Section at the City quarry, Mineral Point.

	Ft.	in.
11. Residual soil	5	6
10. Decayed dolomite, called by the miners the "brown rock"	4	
9. Oil rock, with some cubes of lead and some decayed limestone	1	6
8. Compact, brownish magnesian limestone	1	
7. Unexposed	17	6
6. Thin, wavy-bedded limestone, "glass rock"	4	
5. Compact, magnesian limestone; brown on weathered surfaces, but blue on fresh surfaces; in beds 3 inches to 1 foot in thickness	10	6
4. Thin, wavy-bedded, hard, glass-rock-like limestone	15	6
3. Coarser, thick-bedded dolomite	20	6
2. Unexposed		6
1. Sandstone	3	

In this section (Pl. III, *B*) No. 1 represents the St. Peter sandstone. The shale (No. 1 of the generalized section of the Platteville) just above this is here very thin or absent. No. 3 represents the quarry rock (No. 2 of the general section of the Platteville) while No. 4 represents the next higher member, and Nos. 5 and 6 probably represent the upper member of the Platteville. The beds above No. 6 are referred to the Galena.

4. Section at Mineral Point near Mineral Point Zinc Works.

	Feet.
6. Débris of limestone, containing *Streptelasma corniculum* Hall and a few specimens of *Orthis subæquata* Conrad	3
5. Compact, fine-grained limestone, "glass rock" (?)	2
4. Thin, wavy-bedded, glass-rock-like limestone. *Orthis tricenaria* Conrad, *O. deflecta* Conrad, *Rafinesquina alternata* Conrad, *Rafinesquina minnesotensis* Ulrich, *Zygospira* (Hallina) *nicolleti* Winchell and Schuchert, *Rhynchotrema minnesotensis* Sardeson, *Leperditia fabulites* Conrad, *Isotelus gigas* Dekay, *Monotrypa magna* Ulrich, *Zitellella typicalis* Ulrich and Everett and *Anthaspidella* sp	25
3. Coarser, thick-bedded dolomite	14
2. Unexposed	6
1. Sandstone	10

In this section No. 1 is St. Peter; No. 3 (and part of No. 2) is the second member of the Platteville; No. 4 is the third member of the Platteville, while No. 5 represents the basal part of the upper member of this formation. No. 6 perhaps belongs to the Galena.

5. Section at Darlington.

	Ft.	in.
11. Coarse-grained, thick-bedded dolomite, with *Receptaculites oweni* Hall	4	
10. Coarse-grained, thick-bedded dolomite	3	
9. Coarse-grained, thick-bedded dolomite with flints	5	

	Ft.	in.
8. Coarse-grained, thick-bedded dolomite	2	
7. No exposure	6	
6. Coarse-grained, thick-bedded dolomite with 3 shaly bands, one-half to 4 inches thick. Near base are a few *Orthis tricenaria* Conrad, *O. plicatella* Hall, *O. subæquata* Conrad	27	6
5. Thin-bedded dolomite	4	
4. Thin-bedded limestone with oil-rock partings which are one-fourth to 2 inches thick. *Orthis tricenaria* Conrad, *O. subæquata* Conrad	4	
3. Fine-grained, compact, magnesian limestone with a few flakes containing *Buthograptus laxus* and a few oil-rock partings. This represents the true glass rock. The upper surface is smooth—possibly waterworn. *O. subæquata* Conrad (var. *minneapolis* Winchell) plastered on top surface, *Streptelasma profundum* Owen in body of bed	15	6
2. Blue magnesian limestone with dark, wavy partings	19	6
1. Very blue, magnesian limestone with more prominent clay partings. *Pleurotomaria subconis* Hall, *Streptelasma profundum* Owen		10

In the above section the lower part of the Platteville is not exposed. No. 2 and probably No. 1 belong to No. 3 of the general Platteville section, while No. 3 belongs to the upper member of that section. Nos. 4 to 11 belong to the Galena.

Section 1 represents the conditions in the extreme western part of the area. Section 2 represents the conditions prevailing in the Lancaster quadrangle and in the western part of the Mineral Point quadrangle, while sections 3, 4, and 5 belong to the eastern half of the latter area. It will be noted that the Platteville grows more magnesian to the eastward. The Darlington section, in fact, belongs to the Beloit or east Wisconsin basin, in which all the rocks corresponding to the Platteville and Galena of the mineral district are dolomites.

Relations.—The relations of the Platteville to the St. Peter have already been discussed. The exact relations of the Galena are somewhat open to question. Lithologically there is no great difference between the basal Galena and uppermost Platteville. The rocks are essentially thin-bedded limestones with interbedded shaly matter, and indicate that locally, at least, mechanical sediment reached the area for a short time both in the closing stage of the Platteville and opening of Galena time. The beds are believed to represent shallow-water conditions, under which local unconformity would be expected to occur. Chamberlin[a] observed some slight evidence of such unconformity above the glass rock at Platteville, and Grant has noted a place near the Tippecanoe mine where the glass rock is absent. This may be explained in another way, but at least accords well with the notion of local unconformity. In the Darlington quarry there is a place where shales recognized by Ulrich as of Galena age occupy a channel of some sort in the underlying rock. This he interprets as a clear mark of unconformity and reinforces his conclusion by evidence (not yet published) derived from the fossils. For the present it can only be stated that the evidence as a whole is not entirely conclusive, and that such unconformity as appears is seemingly very local.

GALENA DOLOMITE.

Name and character.—Above the Platteville limestone, in the mining district, is a thick, massive dolomite, which forms the main ore-bearing rock. It has long been known as the Galena limestone, a name applied by James Hall[b] to the beds in and around Galena, Ill., lying above the so-called Trenton. The exposures around that place are accordingly typical for the formation. They show it to be made up of a granular, highly crystalline dolomite of dark-buff color. Owing to the predominance of solution over disintegration, it presents on weathered surfaces a very characteristic carious surface, marked by pits and rounded protuberances. (See Pl. IV.) In hand specimens it frequently shows small open cavities of very irregular shape. These are often lined with dolomite crystals. When the rock weathers it breaks down into a coarse red sand, made up of individual crystals and crystalline particles of dolomite.

Chert or flint is abundant in the median portion of the Galena, usually occurring through a thickness of about 100 feet. The cherty beds and those above are exposed within the limits of the city of Galena. The highest beds form the surface rock northwest of the town

[a] Geology of Wisconsin, vol. 4, 1882, p. 413.
[b] Foster and Whitney, Geology of the Lake Superior Land District, 1851, pt. 2, p. 146.

as far as the old tollgate. The lower beds come to the surface between that point and the junction of the two branches of Fever River.

General sections.—A somewhat generalized section of the formation is given below.

General section of the Galena dolomite.

	Feet.
5. Dolomite, earthy, thin bedded	30
4. Dolomite, coarsely crystalline, massive to thick bedded	60
3. Dolomite, thick to thin bedded, coarsely crystalline, chert-bearing	90
2. Dolomite, thick bedded, coarsely crystalline; locally the lower portion is nondolomitic and thin-bedded	50
1. Thin-bedded limestone with shaly partings which are highly fossiliferous, and, in part, at least, carbonaceous—the "oil rock" of the miners, usually with a well-defined clay bed at the base	2–10

The basal member of the Galena, No. 1 of the above section, is well known throughout the zinc district. It receives its name from the large amount of organic material which it contains, often sufficient to cause it to burn when lighted with a match. In the mining district it is everywhere recognized as the oil rock; and as there are usually several bands of shale interbedded with thin, brittle limestone, the most important band is there discriminated as the "main oil rock." The individual bands of shale are generally thin and discontinuous. though the oil-rock horizon may be recognized throughout the district. It is a curious and significant fact that the oil rock is best developed in and about the mines, and that it is absent or poorly developed in the quarries and rock exposures between the mining districts. A number of sections given in connection with the description of the mines illustrate the character of the lowermost beds of Galena. A generalized section of the lower portion of the Galena would be as follows:

General section of basal Galena beds.

	Ft.	in.
4. Thin-bedded magnesian limestone, variable in thickness, which depends upon the extent of dolomitization	0–15	15
3. Thin-bedded limestone or dolomite with partings of oil rock	5–8	
2. Brown, shaly material, with minor lenses of limestone; the main oil-rock horizon	½–2	
1. Shale or blue clay containing black phosphatic pebbles	½–3	

In places dolomitization extends down to the top of No. 3 of the above section; in other places No. 1 of the section can not be distinguished from the shaly limestone beds at the top of the Platteville, in which black and brown shale, indistinguishable from the oil rock of the Galena, occurs. The oil rock often occurs in two pronounced bands rather than one, and the difference between Nos. 2 and 3 of the above section is one rather of the relative proportions of shale and limestone than of difference in kind.

The material here called oil rock is a finely laminated brown to black shale. It is commonly of a dark chocolate color. When burned, it gives off a peculiar petroleum odor, and it is from this that it is named. The shale contains fragments of slightly harder rock in a matrix of softer material. These fragments show fracture and are bent and broken, while the soft material has evidently been squeezed in between the fragments. Particularly striking examples of this structure were seen at the Hoskin mine near Hazel Green. In the blue clay bed beneath the main oil rock are numerous small, rounded, black, pebble-like bodies, which, upon test by F. F. Grout, proved to be made up of phosphate of lime. Since they include pieces of fossils it is supposed that they represent either fossils themselves or concretionary masses derived from them.

The oil rock proper is one of the most interesting materials found in the region, and its significance in relation to the ore deposits warrants the following rather full description. Chemically it consists of impure limestone impregnated with organic matter. Partial analyses of three samples[a] showed contents of "carbonaceous" matter of 40.60 per cent, 18.31 per cent, and 15.76 per cent. Recent tests by F. F. Grout on material from the Dugdale prospect west of Platteville show a content of 20.85 per cent of volatile matter, with 7.95 per cent of true carbonaceous material in thoroughly air-dried shale. Leaching the shale

[a] Geology of Wisconsin, vol. 2, 1877, pp. 680–681.

with ether gave a thick, heavy oil, which is doubtless the most important element in the volatile matter and which contains an appreciable amount of sulphur.

Mr. Rollin Chamberlin courteously undertook the further examination of the volatile constituents of the rock with the following results:

The oil rock is very porous and light, having a specific gravity of only 1.98 and yielding gas bubbles when placed in water. One volume of the rock gave 57.46 volumes of gas when heated to a red heat in a vacuum for two hours. A gas analysis of this material gave the following results:

Analysis of gas from oil rock of Dugdale prospect.

Hydrocarbon vapors	11.11
Heavy hydrocarbons	4.00
CH_4	35.98
H_2S	6.79
CO_2	18.12
CO	8.40
O	.26
H_2	13.18
N_2	2.21
	100.05

Under the term hydrocarbon vapors are here grouped various hydrocarbons which are liquid at ordinary temperature and which are soluble in alcohol. Benzine may be taken as a type. They contain more than 6 atoms of carbon per molecule. The heavy hydrocarbons are gases, such as ethylene, acetylene, and their analogues. In making this analysis the hydrocarbon vapors were first removed and determined, then the heavy hydrocarbons were absorbed, leaving only CH_4 of the strictly organic compounds to be determined. What percentage of this material exists in the rock in the true gaseous state is impossible to tell, though it is probably not a very large proportion. Most of the gas, as the analysis indicates, came from the distillation and decomposition of various volatile hydrocarbons which give to the oil rock its name and precipitating properties. None of my analyses, with the exception of one of highly bituminous shale from Tennessee, have shown either hydrocarbon vapors or heavy hydrocarbons present. The excessive volume of the gas, 57, as against an average of 4 volumes per volume of rock, and the usual amount of H_2S and CH_4 are the other notable features of the oil-rock gas. CH_4 rarely exceeds 5 per cent in igneous or sedimentary rocks unless manufactured in the combustion tube from organic compounds present. In this case heavy brown tars were also evolved.

A microscopic examination of slides of the same material made by Mr. David White leads to the following conclusions:

Thin sections of the light chocolate shales show them to contain minute, flattened, generally oval, and discoid translucent bodies of a brilliant lemon-yellow color and highly refractive, the birefringence, as determined by F. E. Wright, being 1.619. These yellow bodies, varying from 8 to 62 microns in horizontal diameter and 5 to 20 microns in vertical, usually thinly lenticular and irregularly rounded at the edges, but often nearly oval, are, in vertical section, seen to lie horizontally matted with other sediments and with crystals of later formation, precisely like the matting of forest leaves beneath the winter snow. While varying greatly in size they accommodate themselves topographically when overlapping or surmounting the coarser rock material and seem to preserve their individuality even when apparently in contact. They are incredibly numerous, constituting over 90 per cent of the rock mass in the richest layers.

Upon proper microscopical manipulation the larger of the yellow bodies appear to include a number of horizontally oval figures, characterized by an extremely narrow and usually obscure marginal ring and a small, roundish, or slightly irregular, denser, and often darker-colored mass near the center. These figures, averaging about 8 microns in length and 5 microns in width, are suspended in the translucent yellow bodies, in which they are similarly compressed horizontally. They are regarded as probably corresponding to the contours of collapsed and flattened unicellular plants, the outer ring representing the cell boundary, the inner, denser portion, the residual contents of the cell, whose original gelosic envelope is preserved as the bright, lemon-colored, environing mass. The smallest yellow bodies appear to have contained a single oval, the larger ones several. The yellow bodies are therefore interpreted as the fossil remains of microscopic, unicellular, gelosic algæ, apparently comparable to the living Protococcales. They appear to have been somewhat enriched in bitumen after the cessation of bacterial disintegration, which, in the buff shales, does not seem to have progressed sufficiently to form a noticeable fundamental jelly.

The black oil shale differs from the light chocolate and buff rock chiefly by its deeper color, probably due to greater humification and bituminization of the gelosic bodies, and more particularly by the suspension of the latter in a dark-brown groundmass or fundamental jelly. The details of the oval figures and the included, denser, small, central masses are much more strongly defined and generally more deeply colored. The slightly smaller size of the yellow bodies in the black shale is regarded as due either to greater shrinkage under the influence of the bitumen or to more extensive bacterial reduction. The dark-brown groundmass appears to consist of a fundamental jelly, largely filled with minute mineral matter and granulose fragmental débris or wreckage due to destructive bacterial action on the gelosic bodies, many of which, like the small fragments of larger associated algæ, are greatly corroded. Many of the gelosic bodies were doubtless completely decomposed. To this bacterial work on the organisms is due, in the judgment of the author, the essential character of the somewhat humified fundamental jelly itself, to which there has probably been accession of attracted bitumen. The more extended bacterial action seen in the black shales is interpreted as antecedent and casually related to the greater bituminization of the organic matter rather than as merely incidental or accidental.

The oil shales owe their volatile hydrocarbon contents either directly or indirectly to the fossilized residues, interpreted as the remains of microscopic algæ, which locally composed over 90 per cent of the sedimentary material. These pelagic or floating algæ fell in prolonged showers in quiet or protected areas where the water was presumably somewhat charged with tannic or humic solutions conducive to the early arrest of anærobic bacterial decomposition. Possibly the bacterial action was arrested by its own products. The original deposits were doubtless several times as thick as those now remaining, since it is probable that the organic residue represents as little as one-twelfth of the original volume.

The Ordovician, like the Carboniferous gelosic algæ, appear to have exercised an attractive or selective influence on bituminous compounds, particularly those of illuminant values, and to have consequently been permanently somewhat enriched. Portions of their hydrocarbon contents have doubtless been lost at various periods, and the great shrinkage of the shale which caused the collapse of the overlying limestone strata may have marked the first of these periods of hydrocarbon reduction. Presumably accelerated loss occurred at all times of rock folding in the region. Such an occasion might be favorable for the deeper zinc deposition.

The general resemblance of this material to the torbanite of Scotland, central France, and New South Wales is striking.[a] These deposits are an important commercial source of certain illuminating gases, particularly desirable for train service and other uses where they must stand compression and of oil for enriching ordinary gas. In the Wisconsin district the only attempt to use these shales as a source of gas was made by Mr. J. W. Murphy of the Enterprise mine, whose experiments have not yet been concluded.

The significance of the oil rock in relation to the ore deposits lies in its capacity to furnish a large amount of material especially well suited to cause the precipitation as sulphides of metallic salts.

Above the basal member the Galena is a very homogeneous dolomite, which through much of its thickness varies mainly in the presence or absence of flint. It is granular, crystalline, and coarse grained. In weathering it breaks down into a coarse yellow sand. The formation is generally massive, the average thickness of the beds being from one to four feet. Near the top thinner beds, ranging from four to eight inches, are characteristic. The dolomite when unweathered is usually of a light bluish-gray color; but in some places, especially in the upper part, it loses the bluish tinge and becomes gray, while in the lower part this bluish shade is sometimes intensified. On weathering the dolomite changes to a light yellowish gray or buff, and in the more weathered parts has a somewhat brownish or reddish color, the exact shade depending on the proportion and character of the iron oxide present in the residual material.

Analyses indicate that the rock is in the main a very pure dolomite. There is a slight range in composition, as is shown in the two analyses made from different layers in the same quarry and quoted below:[b]

Analyses of Eagle Point lime rock.

[J. B. Weems, analyst.]

	I.	II.
Water	0.02	0.04
Insoluble	2.15	8.63
CaO	30.72	28.86
Fe_2O_3	.82	.85
P_2O_5	.60	.57
MgO	19.90	18.82
CO_2	45.91	42.08
Organic	.13	1.07
Total	100.25	100.92

[a] Petrie, J. M., Mineral oil from the torbanite of New South Wales: Jour. Soc. Chem. Ind., Oct. 16, 1905, pp. 996-1002.

[b] Iowa Geol. Survey, vol. 10, 1900, p. 602.

The flints which occur in the Galena vary in size, ranging from small particles up to masses several inches thick. These masses are lens-shaped and are distributed along planes so as to form nearly continuous beds. Flint is not found in the uppermost or lowermost portions of the formation, but ranges through about 100 feet of its thickness a little below the middle. In places the flint is fairly well distributed through this thickness. In others it is segregated mainly in one or two beds.

The most complete exposures of the Galena formation may be seen in and around Dubuque. The section given below shows nearly the entire thickness:

Section of Galena dolomite at Eagle Point, Iowa.

		Feet.
18.	Loess-covered slope above the outcropping ledges of Galena dolomite	15
17.	Ledges of well-dolomitized Galena, varying from 2 to 3 feet in thickness	10
16.	Two or three rather heavy ledges containing large numbers of *Receptaculites oweni* Hall. *Receptaculites* is found sparingly in other members of the section, but at this horizon, the upper Receptaculites zone, it is exceedingly abundant	10
15.	Heavy-bedded, typical Galena; hard, crystalline and relatively free from chert; in ledges 3 to 6 feet in thickness	70
14.	Bed containing pockets of calcite, the calcite in some cases forming large crystals	3
13.	Bed containing large quantities of chert	4
12.	Ledges showing the characteristics of the typical Galena; hard, compact, crystalline, completely dolomitized, with small amount of chert	18
11.	Thick, massive beds with large amount of chert	12
10.	Thick beds of crystalline dolomite, the ordinary type	6
9.	Ledge varying in texture, containing small pockets of calcite and some chert; a single specimen of *Receptaculites* found in this ledge	4
8.	Heavy ledge nearly on level with the top of limekiln	3
7.	Dolomite varying in aspect according to degree of weathering; at Eagle Point showing bedding planes 10 to 18 inches apart, a few nodules of flint and numerous specimens of *Receptaculites oweni* marking the lower Receptaculites zone	15
6.	Massive, crystalline dolomite; bedding planes almost completely obliterated	20
5.	Incompletely dolomitized beds with shaly partings at intervals of 6, 8, or 10 inches	10
4.	Limestone, earthy, incompletely dolomitized	2
3.	Oil rock, carbonaceous shale, weathering to brown earthy matter	½
2.	Glass rock; thin-bedded, brittle, nonmagnesian limestone in 2 to 3 inch layers with irregular clayey partings	3
1.	Shales, green, argillaceous, abundantly fossiliferous; exposed	3

Above the beds in this section is a considerable thickness represented in the following section measured on Hill street by Professor Calvin:[a]

Section of Galena limestone on Hill street, Dubuque.

		Feet.
2.	Thin-bedded Galena limestone, earthy, noncrystalline; the layers ranging from 10 to 12 inches near the base to less than 3 inches in thickness near the top; upper part of this member very shaly; carries as fossils *Lingula iowensis*, *Liospira lenticularis*, and *Conularia trentonensis*	30
1.	Well-dolomitized Galena in layers ranging from 1 to 2½ feet in thickness; with softer beds near the middle, which frequently disintegrate so as to form caverns; basal part only of this member represented above the Receptaculites beds at Eagle Point	30

The beds forming No. 2 of this section are fairly representative of the uppermost portion of the formation. They are thin-bedded, earthy, soft, and noncrystalline. Dolomitization is imperfect. The layers range from 3 to 10 or 12 inches in thickness, the thicker beds being near the base and the layers becoming progressively thinner toward the top. Shaly partings between the strata are more common in this division than elsewhere in the formation. The thickness of the bands of shale in the upper part become equal, indeed, to the thickness of the alternating layers of limestone. As a matter of fact the limestone in the very upper part is not infrequently reduced to mere rows of disconnected nodules embedded in clay. This member of the Galena is directly overlain by the Maquoketa shales. Its thickness is somewhat variable, but averages about 30 feet. This division is not definitely separated by any well-marked line from the member below. It has beds of fairly good

[a] Iowa Geol. Survey, vol. 10, 1900, p. 429.

quarry stone toward the base. The calcareous bands and nodules of the upper part are practically worthless.

Thickness.—The Galena formation in this district has an average thickness of about 240 feet. Toward the north it thins to a possible minimum of 200, but the imperfect exposures make these figures somewhat uncertain. Near Hazel Green and Dubuque, where the entire thickness is preserved, there are approximately 250 feet of this formation.

Fossils.—Mr. Ulrich supplies the following notes upon the fossils of the Galena:

Except at a few limited horizons, in which organic remains are often abundant, the main dolomitic body of the Galena carries comparatively few recognizable fossils. The basal limestones and shales are highly fossiliferous. In these beds a number of brachipods and pelecypods, namely *Orthis tricenaria*, *O. pectinella*, *O. testudinaria*, *Plectambonites*, *Lapurna charlottæ*, certain varieties of *Rafinesquina alternata* and *Strophomena incurvata*, *Ctenodonta astarteformis*, and *Vanuxemia moto* are more or less common, and, except the first, which occurs also in the Platteville, highly characteristic. Over a large part of the area the basal 3 or 4 feet of the Galena contains a thin-bedded fine-grained limestone charged with *Rafinesquina*, *Ctenodonta* and most of the other fossils just named. A very large variety of *Ceraurus pleurexanthemus* is another of the characteristic fossils of this bed. Bryozoa are practically wanting in this bed, but farther northwest, where different conditions prevailed, these are abundantly represented in corresponding strata.

In the section given above it will be noted that reference is made to two Receptaculites zones. These are very important and helpful in working out the stratigraphy of the region. While the fossil *Receptaculites oweni* (Hall) occurs sparingly throughout the formation, there are two horizons at which it is particularly abundant and nearly always present. The lower occurs from 35 to 50 feet above the base of the formation. In other words, it marks rather closely the separation between Nos. 2 and 3 of the generalized section, the first flints in the formation being at this horizon, or just a few feet above or below it. This horizon is exposed at many places throughout the district. The upper horizon occurs about 60 feet below the top of the formation. It is even more marked than the lower one just mentioned, but as exposures of this part of the formation are less common, it is not often seen.

A few specimens of a brachiopod of the genus *Lingula* occur in the Galena, especially in the upper thin-bedded parts—that is, in No. 5 of the generalized section—and at Dubuque there are certain horizons at which gasteropoda are abundant.

Relations.—It is aside from the purpose of this report to discuss the general stratigraphy of this area in its relations to that of surrounding regions. Mr. E. O. Ulrich is now engaged in studies designed to afford the basis for such a discussion. The relations of the dolomite to the nondolomitic phase of the Galena have been discussed in detail by the author and Professor Calvin in connection with their description of the geology of Dubuque County, Iowa.[a] To that paper the reader is referred for fuller details than are given in the following condensed statement.

Field evidence, coupled with that derived from a study of deep-well sections in the area to the southwest, indicate that the beds here referred to the Galena constitute a natural geologic unit marked by persistent life zones at various horizons. Formerly it was customary to recognize as Trenton the beds here referred to as Platteville and in addition such portion of the overlying beds as was not dolomitic. It may, however, safely be assumed that, aside from the shaly portions, the material originally composing the formation was calcium carbonate derived from the disintegration of organic skeletons, and that in certain parts of the geologic basin the calcareous beds, or some portions of them, were altered to dolomite. The process of dolomitization was more complete in some parts of the basin than in others, and affected the strata through a much greater thickness. As a result of the alteration, bedding planes were obliterated where the layers were not separated by bands of shale, and thus the massive ledges that are recognized as characteristic of the Galena were produced. Traces of fossils were, to a very large extent, blotted out; this being particularly true of brachiopod shells and other forms which blended homogeneously with the matrix. It is believed, therefore, that the dolomitic beds in certain portions of the area are the equivalents of other nondolomitic beds elsewhere, and that the process of alteration from limestone to dolomite followed their original deposition.

[a] Iowa Geol. Survey, vol. 10, 1900, pp. 402–431.

Dolomitization.—Neither limestone nor dolomites are formed, with unimportant exceptions, through mechanical means. They must be the result of either primary or secondary chemical action.

Taking first the case of limestones, but little study is necessary to show that while it is possible that they may be formed by direct chemical precipitation from a saturated solution, or by the action of springs, as a matter of fact most limestones seem to have been formed through the action of marine animals which secrete lime to form various hard parts of their bodies, and these shells and other remains, in part broken up by the waves and possibly recemented by percolating water, later perhaps recrystallized into a homogeneous mass, make up the bulk of known limestones. The limestones of this region afford, so far as can be discovered, no exception to this rule. It is further clear that they were formed within relatively shallow water, since they were still within the reach of an occasional incursion of mud.

The dolomitized Galena beds were manifestly deposited under somewhat different conditions. It is clear that they were not generally within the limits of mechanical sedimentation after the basal beds were formed. The manner of preservation of the fossils, the forms which are normally preserved in the limestone occurring in the reverse, or as casts, in the dolomite, seems to indicate that the rocks as originally deposited were not dolomite, but limestone, and that they were changed later.

The partial substitution of magnesium for calcium in ordinary limestone takes place readily at ordinary temperatures until a condition of molecular equilibrium, represented by dolomite, is reached.[a]

In the Mississippi Valley, as elsewhere, dolomitization has been both local and regional. Local dolomitization is definitely related to particular fractures, and is believed to be due to the action of ordinary underground waters. Dolomite found in connection with the Joplin ore deposits affords an excellent example[b] of local dolomitization. The attempt has been made to refer the regional dolomitization of the upper Mississippi Valley to similar agencies,[c] but the necessary reduction in bulk, estimated as 10 to 1, is greater than the field evidence ndicates has occurred in this region. A much more probable explanation is that the change occurred while the rocks were still beneath the sea, after the limestone was formed, but before it was elevated above the water or completely buried by succeeding beds. It is known that both magnesium and calcium are held in solution in sea water in small but appreciable amounts, and that the magnesium may under certain conditions be deposited directly as a carbonate. Klement has shown by experiment[d] the action of solutions of magnesium salts on powdered aragonite crystals and coral by exposing these to the action of magnesium sulphate in a concentrated solution of sodium chloride. Action began at 60° C. and increased to 91°, with a maximum yield of 42 per cent of magnesium carbonate, which, in the presence of calcium carbonate, would crystallize in time as a true dolomite. It is to be noted that these conditions would all be readily reproduced in shallow sea basins, such, for example, as the inclosed lagoons or atolls. This is in line with what has been actually observed in coral atolls.[e]

In inclosed basins of sea water magnesium chloride is often in considerable excess over the sodium chloride.[f] Evaporation of the sea water tends to make the solution continually stronger, so that there is a constantly increasing tendency for the magnesia to enter into combination with the lime rock which may be believed to form the basin of the pool and to have been deposited mainly, as usual, through the action of living organisms. The actual formation of dolomite under such conditions has been observed, and it is believed that the conditions were similar in this region when the rocks were formed.

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[a] Van Hise, C. R., Treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1905, pp. 798-808.

[b] Bain, H. F., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, pp. 208–210.

[c] Hall, C. W., and Sardeson, F. W., The magnesian series of the northwestern States: Bull. Geol. Soc. America, vol. 6, 1895, pp. 167-198.

[d] Klement, Constantine, Bull. Soc. Geol. Belge, 1895, 9, 3-25; Tschermaks. Mitt., 1895, 14, 526-544; Abstract Jour. Chem. Soc., vol. 70, pt. 2, 1896, p. 116.

[e] Dana, J. D., Corals and Coral Islands, 1890, pp. 393–394.

[f] Geikie, Text-book of Geology, 3d ed., 1893, p. 412.

MAQUOKETA SHALE.

Name and thickness.—Above the Galena, in the long slopes that lead up to the mounds and the Niagara escarpment, is a body, 140 to 175 feet thick, of blue to green shale with occasional bands of limestone and dolomite. This formation was entirely overlooked by Owen and the earlier investigators, but was recognized by Hall and correlated with the "Hudson River" shale of New York.[a] There has been a great deal of discussion concerning the formation.[b] In Illinois[c] and Wisconsin[d] it has been customary to use the term Cincinnati for this body of rock. Without going into the general question of the correlation and age of the formation it will be sufficient for present purposes to adopt and use the local term Maquoketa, proposed by C. A. White[e] for the beds developed in the Iowa portion of the field.

Distribution and character.—The Maquoketa is best developed in Iowa and Illinois, in the southern part of the region. It has been very generally cut away by erosion in Wisconsin, and only around the mounds is it preserved in its full thickness. The lower portion of the formation is perhaps best exposed near Graf, Dubuque County, Iowa, where the following section was measured in 1899 by Calvin and Bain:[f]

Section of Maquoketa shale at Graf, Iowa.

	Ft.	in.
17. Drab to black, argillaceous, unfossiliferous	2	
16. Sixth Orthoceras bed; brownish, hard, granular, nonfissile shale, with numerous specimens of the minute, brad-like shells of *Coleolus iowensis*, some small gasteropods, a few specimens of *Orthoceras sociale*, together with cephalic shields and pygidia of *Calymene mamillatus*	1	2
15. Shale, drab, very fissile, somewhat sandy, no fossils	1	4
14. Fifth Orthoceras bed; light brown, earthy, nonlaminated, rather hard layer, which some writers have described as limestone; not very calcerous; crowded with shells of *Orthoceras sociale*, which are generally crushed and otherwise imperfect, some of the partially decomposed shells still retaining the original nacreous luster	1	
13. Fissile, slaty shale, dark gray in color, containing many blade-like or sheath-like impressions of *Spatiopora iowensis* Ulrich		6
12. Fourth Orthoceras bed, lithologically the same as No. 14; *Orthoceras* very numerous and crowded, more perfect than in 14		6–8
11. Shale varying in thickness, dark gray in color		1–3
10. Third Orthoceras bed, resembling 12 and 14		10
9. Thin bed of dark, fissile shale; irregular as to thickness, in some places reduced to a mere parting		1–3
8. Second Orthoceras bed, lithologically like 10, 12, and 14	1	
7. Shale, dark brown, imperfectly laminated, rather coarse grained and earthy, crowded with *Diplograptus peosta*		5
6. First Orthoceras bed, like No. 8		4–8
5. Shale, brown, fissile, fossiliferous		7
4. Shale, earthy, granular, nonlaminated, with many comminuted fossils and perfect shells of *Coleolus iowensis*, *Murchisonia gracilis*, *Liospira micula*, and other species	2	
3. Shale, dark brown, nonfissile, with a species of *Lingula* three-eighths of an inch long and one-fourth of an inch wide	2	
2. Shale, dark bluish-black, fissile or slaty, containing large numbers of *Leptobolus occidentalis* and two species of *Lingula*	2	2
1. Shale, brown or black, nonfissile, fossils rare, occasional specimens of a *Lingula* half an inch long and three-eighths of an inch wide	6	

Apparently the lowest beds of the Maquoketa are not represented in this section. These, together with much of the Graf section, are shown in the following, also measured by Calvin and Bain:[g]

[a] Foster and Whitney, Geology Lake Superior Land Dist., 1851, pt. 2, pp. 148–151.
[b] For summary and citations see Calvin and Bain, Iowa Geol. Survey, vol. 10, 1900, pp. 431–432.
[c] Geol. Survey Illinois, vol. 1, 1865, pp. 137–141.
[d] Geology of Wisconsin, vol. 1, 1883, pp. 170 et seq.
[e] Geology of Iowa, vol. 1, 1870, pp. 180–182.
[f] Ibid., vol. 10, 1900, pp. 435–436.
[g] Ibid., pp. 439–440.

Section of Maquoketa shale near Hills Mill, Dubuque County, Iowa.

	Ft.	in.
30. Blue and green plastic clay shales, concealed in slope, except at contact with No. 29; thickness not measured		
29. Shale, yellowish, weathering to plastic clay	1	
28. Indurated, stony beds, yellow		3
27. Shale, laminated, fissile, yellow	2	
26. Dark drab, nonfissile shale containing a few specimens of a small *Orthoceras*, a different species from *O. sociale* Hall		3
25. Fissile, slaty, bluish shale, weathering yellow		6
24. Yellow, stony, calcareous, nonlaminated bed, with some specimens of *Murchisonia gracilis* and numerous small lingulas	3	
23. Drab, slaty shale, equivalent to Nos. 16 and 17 of Graf section	2	
22. Shale	1	
21. Fifth Orthoceras bed; 40 feet above base of the formation	1	
20. Shale, equals No. 13 at Graf		6
19. Fourth Orthoceras bed, equals No. 12 at Graf		6
18. Thin seam of shale, equal to No. 11 at Graf		2
17. Third Orthoceras bed, equal to No. 10 at Graf		10
16. Shale, equal to No. 9 at Graf		2
15. Second Orthoceras bed, equal to No. 8 at Graf		10
14. Dark, fissile shale		3
13. Nonlaminated shale, with shells of *Murchisonia gracilis*		3
12. First Orthoceras bed, equals No. 5 of Graf section		6
11. Brown, fissile shale, equals No. 5 of Graf section	1	
10. Nonlaminated, fossiliferous bed, equal to No. 4 at Graf	2	
9. Brown, fissile shale, equal to No. 3 at Graf	2	
8. Earthy, fossiliferous shale, not represented at Graf		2
7. Blue, slaty shale, with the fossils of No. 2 at Graf	1	2
6. Hard, yellowish, barren shale		3
5. Laminated shale with the large lingulas of No. 1 at Graf	13	
4. Bluish or drab, laminated shale, with traces of graptolites and numerous specimens of *Leptobolus* and *Lingula* in the lower part; upper part barren	8	
3. Bluish, unfossiliferous, laminated shale	8	
2. Shale, variable in color and texture, but in general nonlaminated and coarse; very fossiliferous; carries a small species of *Orthoceras, Liospira micula, Pleurotomaria depauperata, Hyolithes parviusculus, Cleidophorus neglectus,* and *Ctenodonta fecunda;* the last-named species very common	2	
1. Upper beds of the Galena limestone, showing the usual thin layers which become progressively thicker from above downward; exposed in vertical walls in bank of stream	15	

The lowermost bed of shale found in this section, with its peculiar assemblage of fossils, is especially characteristic of the base of the Maquoketa, and has been found at many widely scattered points throughout the region.

Above the beds illustrated in these sections, there is a considerable thickness of very plastic blue clay, usually but not always nearly free from included limestone bands. Near the top of the formation the limestone or dolomite bands become more and more important and the shale partings less conspicuous. Along the Illinois Central Railroad between Scales Mound and Apple River there are true rock cuts in this formation.

Fossils.—The Maquoketa as a whole is very fossiliferous, but owing to the poor exposures there are few good locations for collecting. The character of the fauna of the lower beds has perhaps been sufficiently indicated.

At the top of the formation at many places fossils occur in great abundance. The thin plates of limestone and apparently also the intercalated shales at this horizon, are highly magnesian, and the fauna itself is very different from the one found at the base of the formation. The following species, collected near the tops of the mounds 2 to 4 miles south of Shullsburg and determined by Ulrich, are characteristic of the beds:

Monotrypella quadrata.
Monotrypa rectimuralis (?)
Heterotrypa singularis.
Plectambonites saxea.
Leptæna microcostata.
Plectorthis whitfieldi.
Dinorthis subquadrata.
Hebertella occidentalis.
Platystrophia acutilirata var.
Rhynchotrema capax.
Rhynchotrema perlamellosa.
Rhynchotrema (?) neenah.

This association of species leaves no doubt of the Richmond age of the bed

Relations.—The relations of the Maquoketa to the Galena, while probably those of unconformity, are not altogether clear. The Galena dolomite is considered to be of Trenton while the Maquoketa carries fossils of Richmond age. Between the two there is in the east a Utica shale, which has no certain representative in this region. It has been held by some that the Maquoketa accordingly rests unconformably on the Galena. J. F. James[a] detected, as he thought, distinct evidence of unconformity near Dubuque. Calvin and Bain[b] were unable to confirm his observations, and Sardeson,[c] arguing from paleontologic data, would disregard altogether the obvious lithologic change from dolomite to shale and join with the Maquoketa most of the Galena beds above the upper Receptaculites zone. These citations are perhaps enough to indicate in what confusion the matter stands. For present purposes it is sufficient to point out certain lines of evidence which indicate that in the particular area studied, there is no physical evidence of unconformity.

It has already been shown that the uppermost beds of the Galena formation are characterized by thinner bedding with heavier clay partings. (Pl. V, *A*.) These beds are exposed in quarries near Dubuque, and may be seen near Graf and at other points in Iowa and in Illinois. They have a thickness of approximately 30 feet, which is fairly constant. They carry a distinctive fauna, particularly a ledge in which *Lingula iowensis* is very common. Their base is approximately 30 feet above the upper Receptaculites horizon. The beds are not easily confused with the other members of the Galena section, and it is difficult to see how any process of weathering would give the lower lying beds similar characteristics.

So far as observation goes, and wherever suitable exposures are available for study, these beds form the top of the Galena section. In the Dubuque mines, where it is customary to sink through a portion of the shale into the Galena, these beds are not so well defined as in the quarries, since weathering has not accentuated the bedding. Even here, however, certain other ledges are commonly and easily recognized at the usual distance below the shale, so that there is little reason to suppose that any portion of the Galena was renewed by erosion before the Maquoketa was deposited. The base of the Maquoketa is generally equally well defined. While, as shown by the two sections given, the same bed is not always present, it usually is. The bed most characteristic of the horizon is that found in the Hills Mill section, which contains fossils determined by Professor Calvin, as *Cleidophorus neglectus*, *Liospira micula*, *Pleurotomaria depauperata*, *Hyolithes parviusculus*, and *Ctenodonta fecunda*. With these fossils are a number of small pebbles or pellets of calcerous material. These are the best evidence of unconformity. They indicate in conjunction with the lithologic change from dolomite to shale and the introduction of a new fauna, a certain readjustment of land and sea.

It is believed that they do not necessarily indicate such a period of elevation, erosion, or depression as is ordinarily connoted by the term unconformity, but rather a change in shore line in some adjacent area, by which sediment previously excluded from this particular basin was introduced. That this change was gradual rather than sudden is apparently shown by the increasingly thicker clay partings between the layers of dolomite near the top of the Galena.

SILURIAN ROCKS.

NIAGARA DOLOMITE.

Name.—Above the soft shale of the Maquoketa is a body of fine-grained dolomite, carrying more or less chert. This forms the uppermost member of the stratigraphic section in the area. The beds in the lead and zinc district form only the lower portion of the great thickness and strata which have long been known collectively as the "Niagara."

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[a] Am. Geologist, vol. 5, 1890, p. 344.
[b] Iowa Geol. Survey, vol. 10, 1900, p. 440.
[c] Am. Geologist, vol. 18, 1896, p. 356, vol. 19, 1897, p. 22.

Thickness and character.—The beds cap the mounds and the high escarpment which hems in the territory to the southwest. A thickness of 150 feet is present. The corresponding beds have been studied in some detail in Dubuque County, Iowa, where the following section has been made out:

General section of the Niagara formation in Dubuque County, Iowa.[a]

	Feet.
7. Upper quarry beds	20
6. Cerionites beds	25
5. Pentamerus beds	50
4. Syringopora beds	65
3. Chert-bearing beds	25
2. Lower quarry beds	20
1. Basal beds	15
Total	220

In general the Niagara dolomite is lighter colored, fine textured, and freer from small, irregular cavities than the Galena. It is usually not difficult to distinguish them, though in places it requires a knowledge of their fossils to do so.

Within the mining district beds 1 to 5 of the general section are present. In the bounding escarpment the higher beds are perhaps present. The Niagara is not here an ore-bearing rock, and it is of interest merely as limiting the district to the south and west.

Fossils.—The remains of organic life in this formation, as exposed within the mining district, are not very abundant, but on the top of the West Platte mound three compound corals—*Halysites catenulatus* Linnæus, *Favosites favosis* Goldfuss, and *Favosites niagarensis* Hall—occur rather plentifully. On this mound there are also many casts of the brachiopod, *Pentamerus oblongus* Sowerby. These occur in loose flint masses that probably belong to a horizon higher than the corals mentioned above, which occur in place in the dolomite.

QUATERNARY DEPOSITS.

General character.—The Quaternary deposits of the area have been treated in some detail by Chamberlin and Salisbury,[b] Calvin and Bain,[c] and Grant,[d] so that only a few words concerning them are necessary here.

The deposits include residual clays, which may represent the whole of Quaternary and possibly a portion of Tertiary time; loess, which in the main, at least, is of Pleistocene age and is to be correlated with the Iowa drift sheet; terrace gravels and silts, which are of Pleistocene age and, so far as definitely fixed, belong with the Wisconsin drift; and alluvium, which is post-Pleistocene, or Recent, in age.

These deposits lie within the Driftless Area, and although both Sardeson[e] and Squire have raised some question as to the entire absence of glacial deposits in this area, it may be safely said that there is no sustained evidence of either local glaciation or the invasion of the area by the fringing ice sheets.

Residual clay.—The deep-red sticky clay containing small pieces of chert and limestone, which may be noticed at many points below the loess, represents the residuum from the decay of limestone and dolomites. Grant has calculated[f] that 10 feet of this represent 100 feet of preexisting limestone, and it is accordingly an impressive token of the large amount of erosion which the region has undergone, even if it is nowhere very thick.

Loess.—The light-buff earthy clay which forms a thin mantle extending from the Mississippi eastward and from the edge of the drift to the river bluffs on the west represents the loess. It has not been restudied in detail, but there are no known reasons for doubting that it forms a portion of the general loess sheet of this region. It is significant in that it mantles the hills and valleys in such fashion as to indicate clearly that almost no erosion has occurred

[a] Iowa Geol. Survey, vol. 10, 1900, p. 459.
[b] The driftless area of the upper Mississippi; Sixth Ann. Rept. U. S. Geol. Survey, 1885, pp. 239–311.
[c] Geology of Dubuque County: Iowa Geol. Survey, vol. 10, 1900, pp. 459–475.
[d] Bull. Wisconsin Geol. and Nat. Hist. Survey No. 9, 1903, pp. 14–19.
[e] Sardeson, F. W., On glacial deposits in the driftless area: Am. Geologist, vol. 20, 1897, pp. 392–403.
[f] Bull. Wisconsin Geol. and Nat. Hist. Survey No. 9, 1903, p. 18.

where it lies as compared with the erosion that took place in the area before it was laid down. The dissection of the old peneplain by the present streams was almost wholly accomplished before the loess was deposited.

Terrace deposits.—Along the Mississippi there is a well-defined terrace, underlain by gravels and sands of glacial derivation. It may be traced up the river and certain of its branches connected with the Wisconsin drift sheet, and for that reason has been regarded as of Wisconsin age. It is possible that older terraces, representing earlier stages of the ice, are confused with it.

Many of the streams tributary to the Mississippi have their sources wholly within the Driftless Area. The terrace occurring along them is accordingly underlain by material of local origin, laid down in quiet, ponded waters at the time the main terrace was formed in the Mississippi Valley. This material is a fine silt or clay, closely laminated. It is shown in the city of Galena at many points, Grant Park being located on the top of the terrace. (See fig. 1, p. 12.)

Alluvium.—In time of floods the streams are now, as in the past, depositing beds of alluvium, so that irregular stretches of bottom land are found along them from their mouths well toward their sources. No attempt has been made to represent these areas on the map. In general they are irregular, and the streams have rock bottoms. Near Hanover the Galena dolomite occurs in the bottom of Apple River for nearly 2 miles below the point at which the dip carries it below the terrace. At Galena, on the other hand, Fever River, like the Mississippi, is running over a filling of Quaternary age. Opposite Dubuque the rock bottom of the Mississippi occurs at depths ranging from 405 to 452 feet above sea level[a], a fact that has been frequently interpreted as indicating a pre-Glacial or inter-Glacial elevation of the area. If this be the correct interpretation, the period of higher elevation was too short to influence the tributary streams any considerable distance from their mouths.

In view of the large importance of scour, to which J. E. Todd has called attention,[b] and the evidently large volume of the Mississippi at certain times during the Pleistocene, it is possible that the depth of the valley is not a measure of an earlier elevation of the land.

GEOLOGIC STRUCTURE.

GENERAL FEATURES.

General dip.—The rocks of the zinc and lead region have a slight dip to the southwest Near Dodgeville the base of the Galena formation touches points as high as 1,120 feet above the sea. In the southwest corner of the area shown on the Dubuque special sheet there is one local basin within which the same bed goes down to 510 above sea. Near Highland this horizon reaches 1,160 feet, while at Buncombe it drops to 660. These figures would correspond to a general dip of approximately 25 feet to the mile, measured in a southwest direction, or of 15 feet to the mile from north to south.

Local dips.—At various points the dip is much greater, and at a number of places amounts to 50 feet in a half mile. Near Meeker's Grove there is a change of elevation of 130 feet within a half mile, but this, both in amount and degree, is unusual. In a few instances very local dips of 8° to 10° have been observed, but these are by no means general. Differences of elevation of 30 to 50 feet are common and are very irregularly distributed. They result in certain depressed areas or basins, which, although irregular in form, are usually better defined than the intervening elevations.

LOCAL FEATURES.

TYPES OF BASINS AND ANTICLINES.

While it has proved impossible, with the data at hand, to detect any system in the distribution of these undulations it is possible to discriminate several types. Grant has recently studied these in connection with the making of detailed maps of the productive districts for

[a] Norton, W. H., Iowa Geol. Survey, vol. 6, 1897, p. 213.
[b] Bull. U. S. Geol. Survey No. 158, 1899, pp. 150–153.

the Wisconsin Geological and Natural History Survey. Upon these maps, supplemented by others made by the United States Geological Survey in the course of the present studies, the structure is shown by means of contours representing the base of the Galena formation. Within the area surveyed four types of structures may be recognized: (1) Broad, shallow basins; (2) flat monoclines; (3) sharply asymmetric anticlines; (4) canoe-shaped basins. These are described and illustrated below.

Shallow basins.—The basin in the Dodgeville area (fig. 41, p. 109) illustrates this type. It is a broad, shallow basin 20 to 30 feet deep, 1½ to 2 miles wide, and of rather indefinite length and outline. If more data were available it is probable that the basin might be somewhat better defined on the map, but it none the less represents with fair accuracy a type that is common in this region. Similar basins may be seen on the other special maps, particularly on the Mineral Point and Highland sheets.

Flat monoclines.—Closely related to the broad, shallow basins are the flat monoclines, an excellent example of which occurs a short distance west of Shullsburg, Wis. It is illustrated

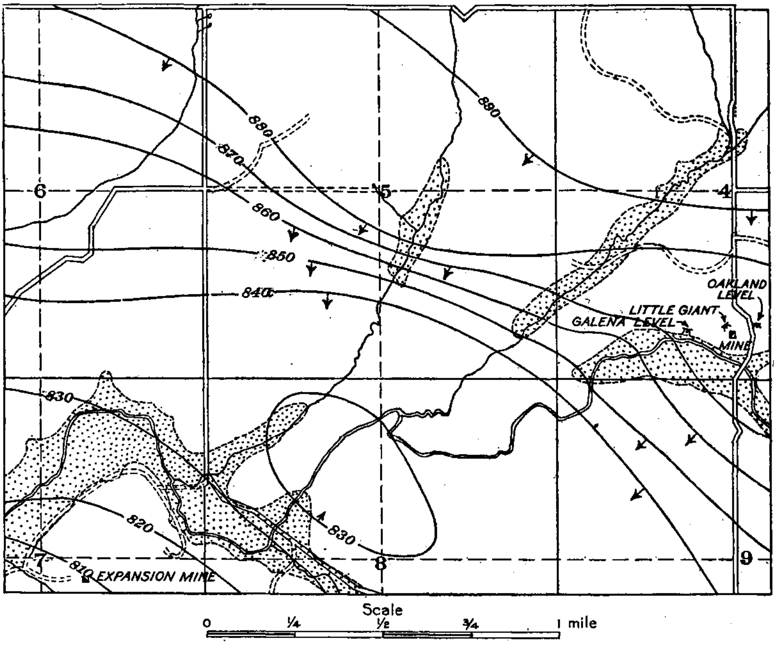

FIG. 4.—Monocline structure near Shullsburg, Wis. (After Grant.)

in fig. 4. The rocks here dip to the southwest 50 feet in a half mile, then lie nearly horizontal for approximately three-quarters of a mile, only to dip off to the southwest again 40 feet in a half mile. Only the upper portion of this latter slope is shown in the figure. The broad, flat belt between the two monoclines is not quite level, and, as is shown by the closed contour, there is one shallow depression of 10 feet or more. It is this depression that links the flat monocline to the broad basin type already discussed.

Asymmetric anticlines.—By accentuation the flat monocline becomes the asymmetric anticline of which the Meeker's Grove area affords an excellent illustration. (Fig. 24, p. 89.) This fold has a long, gently rising southern limb and a shorter northern one, of considerably steeper dip. In about 2½ miles the St. Peter sandstone rises along Fever River from 818 feet to 900 above sea level. In the next quarter of a mile to the north it descends 90 feet, and in the half mile 130 feet. The Platteville and Galena formations arch up over the sandstone, maintaining their usual thickness. This type of fold is common in the region and many illustrations of it can be found on both the special maps. The amount of deformation is so great that such folds can be recognized in the field by means of ordinary sections and do not require the close structural studies necessary to recognize the others.

Canoe-shaped basins.—True canoe-shaped basins, miniature representatives of the Appalachian type, are present in this region. These are from 20 to 60 feet deep, from a half mile

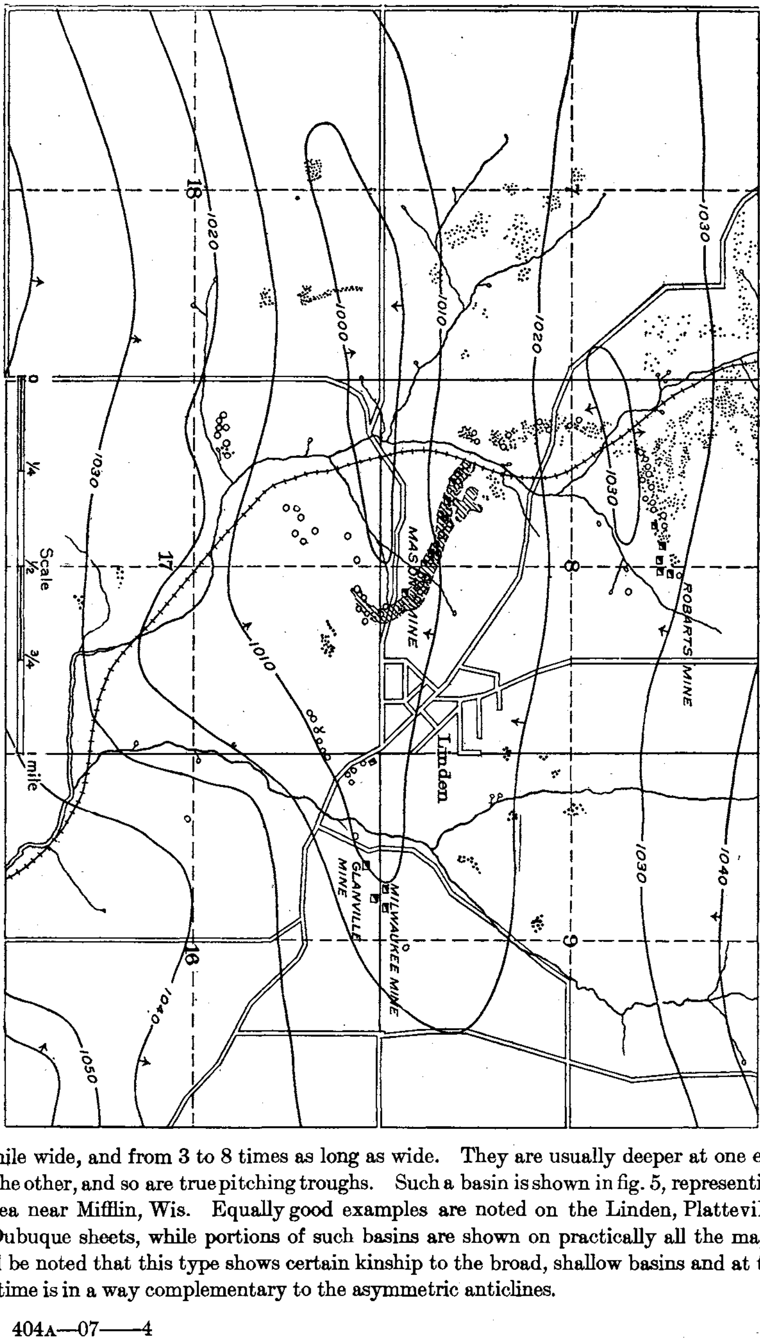

Fig. 5.—Canoe-shaped basin near Mifflin, Wis. (After Grant.)

to a mile wide, and from 3 to 8 times as long as wide. They are usually deeper at one end than the other, and so are true pitching troughs. Such a basin is shown in fig. 5, representing an area near Mifflin, Wis. Equally good examples are noted on the Linden, Platteville, and Dubuque sheets, while portions of such basins are shown on practically all the maps. It will be noted that this type shows certain kinship to the broad, shallow basins and at the same time is in a way complementary to the asymmetric anticlines.

DISTRIBUTION OF BASINS AND ANTICLINES.

Unfortunately the detailed maps are not sufficiently numerous to allow the relations of the basins in one area to those of another to be determined, and the basins themselves are so small and shallow that it is difficult to detect them except by most careful detailed mapping. The asymmetric anticlines being the more pronounced, can be to some extent located by the exposures. In the early literature of the region much was made of these anticlines, or "centers of elevation," as they were sometimes called. Both Percival[a] and Murrish[b] devoted much energy to their discovery. Chamberlin has summarized and discussed these observations,[c] and the reader is referred to his discussion for details.

It is perhaps sufficient to indicate that the major structural axis of the region is a generally NNW.-SSE. uplift, which runs a little east of the productive region, and that within the latter the most pronounced structural features have a general NEE.-SWW. trend. The individual anticlines are not known to be persistent across the whole territory, but seem to give place longitudinally to basins. For example, there is seemingly a structural ridge extending westward from Jonesdale, passing north of Mineral Point and Mifflin about to Livingston. From this point westward toward Anniston and Stitzer lies a basin with a ridge to the south. South of Mineral Point a second ridge occurs, which may be traced westward about on the line between Iowa and Layfayette counties, Wis., to Platte River. Still farther west, on Grant River, there is a basin with elevations to the north and south. The Meekers Grove anticline is possibly to be correlated with the outcrops of St. Peter sandstone, near the mouth of Platte River. At Eagle Point, near Dubuque, an anticline brings the Platteville above the river level, but this elevation does not seem to extend more than a few miles either to the west or the east.

All such tracings of uplifts and correlation of structural features over the regions as a whole rest on very meager foundation and must be received with great caution pending the completion of additional structural maps.

ORIGIN OF THE BASINS.

The origin of the anticlines and synclines of the region has been discussed in some detail by Chamberlin.[d] He reached the conclusion, with which the author fully agrees, that they were due to the conditions of deposition modified in part by deformation due to pressure. It is possible that a third factor may be worthy of consideration—namely, settling incident to the consolidation of the beds. For convenience in discussion, attention may be centered upon the basins or synclines, the ridges or anticlines being understood to stand in antithesis to these.

Basins of sedimentation.—As noted in the description of the formations, there are several unconformities in this area. At the base of the St. Peter sandstone, to go no lower, is a marked unconformity, and when deposition of the sandstone began there were local inequalities of the sea bottom of 70 to 80 feet. There is a tendency in sedimentation to perpetuate basins already formed, a phenomenon of which the permanence of the ocean basins is itself an example. Smaller basins down to the smallest show the same tendency. Whether or not it is manifested in the overlying sediments depends on many factors, including the character of the beds, their thickness, and the speed of filling. Local irregularities of the sea bottom may be completely obliterated in any given period of deposition, but, on the other hand, they may be perpetuated through a considerable thickness of overlying sediments. In the upper Mississippi Valley the basins present at the beginning of St. Peter deposition seem not to have been entirely obscured by the deposition of the sandstone, so that at the beginning of Platteville time there were numerous irregular and very shallow depressions. If there was any erosion between the close of St. Peter and the beginning of Platteville time,

[a] Percival, J. G., Ann. Rept. Geol. Survey Wisconsin, 1855, pp. 22-27.
[b] Murrish, John, Report as Commissioner for the Survey of the Lead District, 1871.
[c] Geology of Wisconsin, vol. 4, 1882, pp. 422-438.
[d] Ibid., p. 420 et seq.

these basins probably would have been deepened and the inequalities of the surface accentuated. The same principle applies with regard to the contact between the Galena and the Platteville, and it is inherently improbable that the Galena at its beginning was deposited upon an absolutely smooth and level surface. Inequalities of some sort must have been present. It remains only to inquire whether there is any evidence connecting the present structural basins with the probable original ones.

A study of the sections already given shows that there was at least some difference in the character of the sediment within and without the basins in early Galena times. The contrast between the Darlington and Platteville sections is instructive in this connection. In the Platteville area there is thick oil rock, and the sections show considerable thicknesses of shale. At Darlington there is almost no oil rock, and the shaly beds that mark the base of the Galena at Platteville are replaced by massive dolomite. The Platteville sections are within one of the structural basins. The Darlington section does not seem to be. The same contrasts may be observed between the Eagle Point and Spechts Ferry sections. This difference may be due, as has been suggested, to the fact that in one case certain beds are dolomitized, and hence not easily recognized, which at other points are unchanged. This would not, however, account for the difference in amount of argillaceous material present in the shales of the basins and absent elsewhere, so that there have been at least some differences in sedimentation. Not only is there more argillaceous matter within the basins, but it is there that the greater amount of oil rock is present, and this indicates the local accumulation of plant remains not found outside the basins. Mr. Ulrich finds corresponding faunal differences in the basal beds of the Galena.

At higher horizons, as already pointed out, the same life zones run through both the dolomitized and undolomitized portions of the Galena. This fact is not necessarily inconsistent with differences in the basal beds, since at the time the higher beds were formed the original inequalities may have largely disappeared.

These differences in amount of argillaceous material, in abundance in plant remains, and in faunal facies of the basal beds warrant the inference that deposition in early Galena time occurred in irregular, partially disconnected embayments or basins, or that there were certain shallow irregular areas on the ocean bottom in which sedimentation was peculiar. Granting that the water itself was shallow, it is likely that the showers of algæ, whose remains especially characterize the oil rock, would be swept into the slightly deeper basins by currents and would there rest. This hypothesis does not, however, offer any adequate explanation of the greater amount of shaly matter present in such places and largely absent elsewhere.

If, on the other hand, these basins be considered to represent drowned river valleys only partially filled by Platteville sediments, or embayments at the mouths of the rivers at the local beginning of Galena deposition, the presence of shale, betokening mechanical sedimentation, in the midst of limestone and dolomite due to organic and chemical deposition is easily explained. Mechanical sediment is to be expected in greater abundance at the mouths of rivers than elsewhere, since a slight change in the attitude of the land far toward the head waters of the streams would give the rivers temporary cutting power and increase their load of mechanical sediment. Through most of Platteville and Galena times the land was apparently at base level, and chemical rather than mechanical deposition was the rule. The interruption of these conditions shown by the shaly beds was temporary only, as limestone-forming conditions and clear water soon recurred and prevailed throughout Galena time.

While it is seemingly impossible to demonstrate this hypothesis, it may be pointed out that it offers also a ready explanation of the long, narrow form of most of the basins, and it is perhaps significant that the basins having most definite form have trends ranging from a little north of east to true northeast. It is in this direction that the land from which the material was derived probably lay. The breaking up of these early embayments into a series of disconnected basins is probably due to slight cross folding.

The broad, shallow basins of irregular outline mark apparently less pronounced original troughs. The fact that oil rock and the basal shaly layers of the Galena are well developed only in and around the mines has already been stated. An examination of the accompanying maps shows that practically all the mines are in the basins, and these facts seem to sufficiently connect the deposits with initial inequalities of the sea floor.

Basins of consolidation.—Sediments as deposited are rarely dense. They contain much open space and are susceptible of considerable compression. This is truer of some sorts of sediments than others, but even in glacial till it has been shown that normal consolidation is enough to lead to the resurrection of rivers blotted out by a glacier and the reexcavation of valleys buried beneath a hundred feet or more of drift.[a] Shales and coal settle even more in the process of consolidation, and the amount of this settling has been measured and its influence on succeeding formations studied in the case of coal in particular.[b] It has been found that in many coal mines where mountain-making forces have not complicated the conditions the thicker coal lies in certain irregular channels or basins bordered by thinner coal. Toward the edge of the basin the coal rises and at the same time thins, and there is a fairly constant ratio between the amount of the rise and the decrease in thickness, ranging from 1:10 to 1:16. These facts are explained as due to deposition in initially irregular

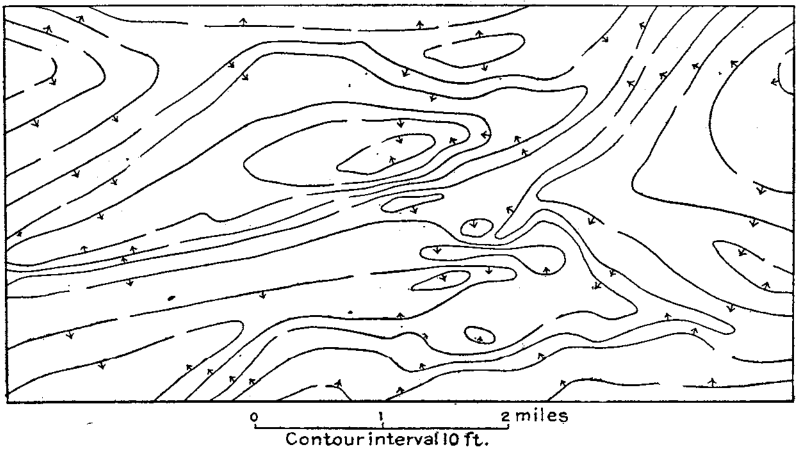

FIG. 6.—Structure-contour map of an area near Mifflin, Wis. (After Grant.)

basins coupled with unequal settling due to the greater compressibility of coal than rock. This settling produces a basin in the overlying rocks if they be soft and yielding, as is shale, or causes fractures and faults if they be hard and unyielding, as are limestone and sandstone.

These facts are significant in the present connection since it is believed that bituminous shale undergoes the same changes as does coal, though to a less degreee, the difference being due to the smaller amount of organic matter in the shale. The oil rock found in the basins of the zinc district contains now from one-third to one-half bituminous matter, and so may be assumed to have suffered compression in the process of consolidation, amounting to one-third to one-half that of coal. It may accordingly be assumed that 1 foot of oil rock was originally equivalent to a bed of mud and decomposing organic matter 3 to 8 feet thick.

It is difficult to make sure of the thickness of the oil rock itself, since the shale is often distributed in thin bands through a considerable amount of thin-bedded limestone. Bands of oil rock alone 12 to 18 inches thick are not uncommon, and a minimum thickness of 2 to 3 feet of bituminous shale would probably not be too much to assume. This would be the equivalent of 16 to 24 feet of original material, and its compression to its present thickness would be enough not only to lead to extensive fracturing in the beds above, but to accen-

[a] Iowa Geol. Survey, vol. 7, 1897, p. 280.
[b] Bain, H. F., Origin of certain features of coal basins: Jour. Geol., vol. 2, 1895, pp. 646–654.

tuate in an important degree the original basins in which the deposition took place. It must be said, however, that such thickness of oil rock is not common, and an assumption of 1 to 2 feet, with corresponding settling of 2 to 14 feet, would be much more nearly correct. While this would still be enough to fracture the beds above and accentuate the basins, it would hardly account for any but the shallower ones.

It is important to observe that the oil rock, although practically confined to the basins, is very irregularly distributed within them, and it seems much more fitting to regard this consolidation as an explanation of the minor sags which are a constant and striking feature of the mines than as an explanation of the larger basins themselves. Since, however, the patches of oil rock are practically confined to the basins, it should be noted that consolidation, so far as it might be effective, would work with rather than against the hypothesis of initial basins of sedimentation.

Basins of deformation.—It may well be doubted whether the factors so far discussed are alone adequate to form such basins as occur. The sharp definition of the basins and the amount of vertical discordance seems to necessitate a belief in at least some deformation.

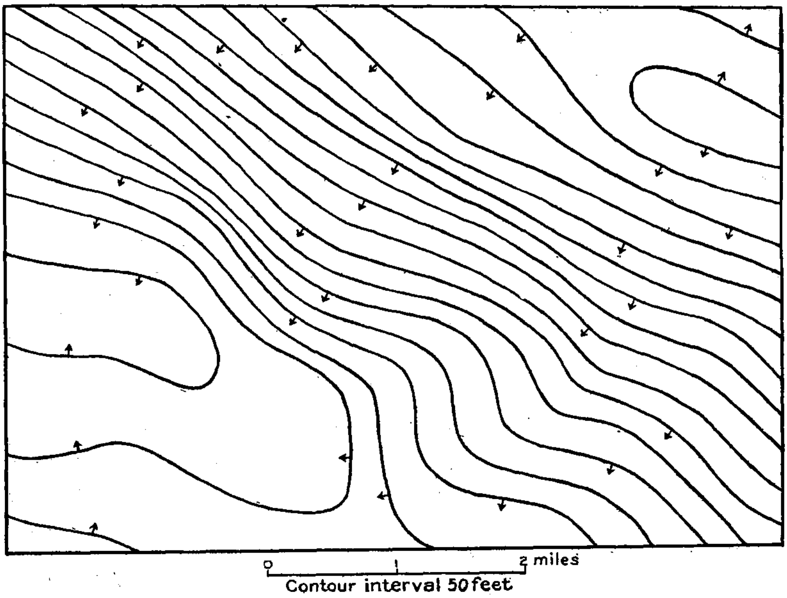

FIG. 7.—Structure-contour map of an area near Masontown, Pa. (After Campbell.)

In figs. 6 and 7 are shown structure-contour maps of two areas, one within the zinc and lead district, the other in the coal-mining district of western Pennsylvania. The two maps are on the same scale, but that of the Wisconsin area shows contour intervals 10 feet apart, while the Pennsylvania map shows 50-foot intervals. None the less there is a striking similarity in the structure of the two areas. This is heightened when, as in fig. 8, the Pennsylvania map is reduced to one-fifth its original scale to give apparently, not actually, the same interval as the Wisconsin map.

The Pennsylvania structure is explained as due to deformation produced by lateral compression, and in the absence of evidence to the contrary it seems proper to consider the Wisconsin structure an expression of the same sort of forces. Lateral compression, acting on the Galena dolomite between cushions formed by the soft Maquoketa shale above and the shaly limestone beds at the top of the Platteville, would tend to throw it into a series of gentle folds. To some extent the Platteville, cushioned by the soft St. Peter sandstone, would accommodate itself to these folds. The Platteville, however, being much less homogeneous, would be mainly deformed bed by bed rather than as a whole.

The locus of the bending in the Galena would be determined by the original inequalities of the beds, as was long ago pointed out by Chamberlin,[a] in a discussion of this region and later formulated as a general law by Willis[b] in his studies of the Appalachians. The deformation is therefore to be thought of as merely somewhat intensifying preexisting curvature in the beds. In the upper Mississippi Valley this intensification has evidently been

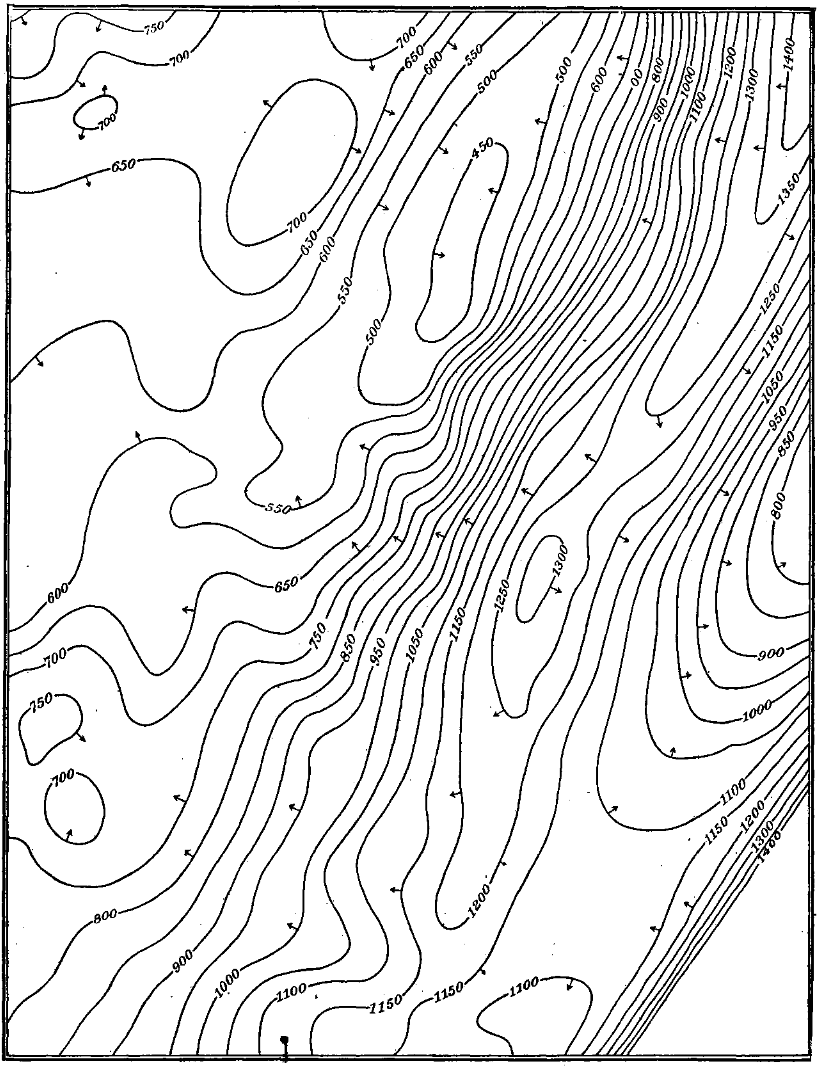

FIG. 8.—Structure-contour map of the Masontown, Pa., quadrangle. (After Campbell.)

slight, while in the Appalachians it has been so great as almost to obscure the initial inequalities. In the zinc and lead district deformation has been at a minimum. A calculation based upon a 3-mile section from north to south across the Mifflin area—the area shown in fig. 6—was made by Mr. A. W. Lewis, which indicated a total crustal shortening of 1.58 feet,

[a] Geology of Wisconsin, vol. 4, 1882, p. 431.
[b] Willis, Bailey, Mechanics of Appalachian structure: Thirteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1893, pp. 253-263.

equivalent to 0.52 foot per mile. A similar measurement of 3 miles of the Pennsylvania area, shown in fig. 7, resulted in a corresponding figure of 3.92 and 1.30 feet. In closely folded areas of the Appalachian the crustal shortening is currently estimated at 5 to 10 times this amount.

FAULTS AND FAULTING.

In the early studies of the region there was considerable discussion of faulting, but the careful explorations made first by Whitney and later by Strong and Chamberlin failed to show any important faults, so that recent opinion has settled down to a belief that they are absent. W. P. Jenney,[a] who visited the area about 1892, and W. P. Blake[b] are the only recent observers who have reported faulting to be present. In the course of the present survey careful search was made for evidence of faulting, with only negative results. Displacements of 2 or 3 inches were found at a few places, but these represent a maximum. The cases cited by Percival seem, on the basis of exposures now available, to be due rather to folding than faulting. Other apparent faults are more easily explained as the result of the unconformities already discussed. The instances cited by Blake near Shullsburg are believed to be examples of the irregular downward extension of dolomitization in the Galena formation. Massive dolomite and thin shaly limestone are found, it is true, at the same horizon within short distances of each other, but so far as observation goes there is no evidence of a fault plane between, and at higher horizons the same bed may be traced across from one point to the other. The same phenomena have been seen at so many other points where this is manifestly the correct explanation that it seems unnecessary to call in another here.

Jenney has suggested that horizontal faults are present. Such faulting is difficult to recognize, but it is believed that he was misled by the offsetting of joint planes, due to the tendency of stresses to seek relief along the crevice already present.[c] Most careful and persistent search, extending through several field seasons, has so far failed to develop any clear cases of faulting of consequence. There are certain general facts relating to the underground waters of the district which render it extremely improbable that any such faults are present, and the writer is therefore constrained to believe, with Chamberlin, that the beds are practically unfaulted.

JOINTS.

Both vertical and pitching joints occur within the region. The best developed vertical joints trend approximately, but rarely exactly, east and west. A less prominent set of joints runs at right angles to them, and these are locally called "north-souths." Quartering crevices also occur and in individual areas may be more prominent than the main sets.

Pitching crevices cross the beds at angles of 45° to 60° and strike at all angles. In the mines, just as the east-west vertical crevices are most often open so the pitching crevices parallel to them are apt to be conspicuous. In individual mines, however, the pitching crevices may be traced completely around three-quarters of a circle.

Both the vertical and pitching joints are excellently developed in the bluff at the east end of the Dubuque bridge and are illustrated in Pl. V, *B*, from a photograph by Grant. The fine lines running diagonally from right to left represent the inclined joints. The vertical joints are here more widely spaced and less regularly developed. The wide spacing is characteristic throughout the district, but the irregular development is not. It may be noted that in this view, contrary to the ordinary rule, no set of joints is developed at right angles to the inclined joints. Such a set is, however, present in the area and is well displayed about 150 feet north of the spot shown in the view. So far as observation goes these two sets are developed normally in proximity, but not in immediate juxtaposition. Between the two here, as in the mines, there are two or three well-defined vertical joints.

The pitching joints are best developed in the lower portion of the Galena formation and are relatively rare above. There are some reasons for thinking the pitching joints are older

[a] Trans. Am. Inst. Min. Eng., vol. 22, 1894, pp. 208-212.
[b] Ibid., pp. 558-574.
[c] Iowa Geol. Survey, vol. 10, 1900, pp. 519-520.

than the vertical, but the evidence on this point is not conclusive. Both sets of joints are excellently displayed in the Mississippi River bluff in the southern part of Dubuque. At one or two places here it was observed that vertical crevices were deflected where they crossed pitching crevices. This is interpreted as indicating that the pitching crevice, being present when the vertical was formed, partially relieved the strain.

The origin of the joints is not altogether certain. The vertical joints can be best explained as due to the deformation which produced the folding, since the more important ones show a general relation to the folds, running either parallel or at a right angle to them. The most prominent joints in the vertical series at any one point are apt to be those best situated to serve as trunk channels to underground circulation. At Potosi the main crevices have a northwest-southeast course, while the larger structural basins run in an opposite direction. It is believed that this is due to the crevices having been rendered prominent by circulation of ground water. Minor crevices parallel to the structure are present.

Chamberlin[a] was disposed to refer the formation of the pitching joints to the same agency. They do not, however, seem to show that close relation to the folds which such a reference requires. In considering their origin account must be taken of the fact that there are evidently two different sorts of such joints present in the region. In the vicinity of Potosi there is a very small but very sharp little thrust fold, illustrated in fig. 45. Parallel to the crest of this anticline are several well-developed joint planes or crevices which pitch outward from the fold. These occupy the position, with reference to stresses, of the crevices developed by G. F. Becker in his experiments on schistosity and slaty cleavage,[b] and the explanation offered by him is entirely adequate for them. Similar crevices on a small scale have been noticed in the mines by C. K. Leith, and it is not improbable that they are present throughout the region. These crevices are different in several particulars from the ordinary pitches of the mines. The most striking and important difference is that the inclination of the crevice at Potosi is toward the basin, while it is a universal rule that the pitches of the mines incline outward from the basin or sag in the mine. In the second place, these crevices parallel a thrust anticline, while in the mines the thrust phenomena are at least unrecognized, and the pitches strike in all directions. In this connection it is interesting to study the map of the area adjacent to the Hoskin and Kennedy mines at Hazel Green, shown in Pl. X. On this map Ellis has traced the underground workings and the pitching joints. To this has been added the structural contours as located by Grant. It is difficult to see here any relation between the pitching crevices and the structure. A similar map of the Potosi district and studies of other areas confirm the conclusion that there is no relation between the two.

On the other hand, the relations of the pitching crevices to the minor sag, seen continually in the mines, is very definite. It is a rule having a few exceptions that the floor of the mine rises to the pitch and that on either side of the sag the crevices pitch outward. This would, it seems, warrant the reference of the pitches to the same agency that caused the sag, and they are, in fact, believed to be an expression of the settling of the rocks due to decrease in bulk of the oil rock. Anyone examining the ordinary cross section of a typical sag and pitches will notice the resemblance of the fractures to those produced in a brick wall, where, for example, a window frame has failed to support its load. The pitching fractures in this case arch upward over the settled portion, following in part the mortar joints between the brick in a manner strictly analogous to the flats and pitches in these mines. Fractures of of the same sort may be found in the roof shales of coal mines where the load is not fully supported, and are, in fact, characteristic of such situations everywhere.

Fractures formed after this manner should follow in strike the outline of the settled mass. They should approach as they ascend and should finally form an arch whose height is dependent upon the strength of the materials, the width of the area affected, and the amount of the settling. They do not require the formation of a corresponding set of fractures diverging upward, as they would if they were formed by vertical pressure affecting the whole thickness

[a] Geology of Wisconsin, vol. 4, 1882, pp. 482–488.
[b] Becker, G. F., Experiments on schistosity and slaty cleavage: Bull. U. S. Geol. Survey No. 241, 1904, fig. 13.

of the rocks. They may have been formed any time after the rock became firm enough to fracture, and they may continue to form as long as the oil rock gives off gas and oil. The settling required to produce the fractures is not greater than the amount that is theoretically possible as a result of decrease in the bulk of the oil rock—indeed, it is not so great as this amount. The many peculiar and close relations of pitches, flats, sag, and oil rock are all explained by this hypothesis, and the explanation is so complete that it is believed to be a true and important one.

AGE OF STRUCTURAL FEATURES.

That the general deformation of the region occurred after the deposition of the Maquoketa shale is shown by the fact that contours drawn on the base of the Maquoketa, as in the Dubuque special map, show the same sort of structure as when drawn on the base of the Galena. Presumably this is due to the Maquoketa participating in the folding. That it took place before the peneplain was cut is shown by the fact that the folds are beveled by that plain. Between these two periods there was a long time during which in adjacent areas deformation occurred. At La Salle there is evidence of folding, both before and after the Carboniferous,[a] and it is not unlikely that the zinc and lead region came under pressure more than once. Since, however, the crevices were not opened and the chain of operations which produced the ore deposits set in motion until the peneplain was cut, the exact date of the deformation is for present purposes unimportant.

GEOLOGIC HISTORY.

The geologic history of the region has, in the main, been given in the discussion of the formations and the structure. A short résumé may, however, be helpful. The strata in this area record a number of long periods of sedimentation. These periods included portions, at least, of Cambrian, Ordovician, and Silurian time. The history of the district in pre-Cambrian time is not very definitely known, and it can only be said that at some time in it the area became land and remained above the sea for a very long time before the first sediments of the Cambrian were laid over it. At some time in the Cambrian, probably in the middle, this land sank beneath the ocean waters and sedimentation began. Except during certain intervals, the sea then retained possession of the area until the close of the Niagara epoch, and possibly longer. At different times parts, at least, of the area were lifted above the sea and and deposition temporarily ceased. Of these intervals of nondeposition the most significant from the present point of view are those which preceded and followed the deposition of the Galena dolomite. The evidence of these periods of nondeposition has already been stated. The first prepared the way for the original deposition of the zinc by forming shallow basins adapted to peculiar sedimentation. As these basins became filled the sea spread in a thin sheet over a shallow semiinclosed offshore area to which the sediments did not penetrate and in which evaporation was unusually active. Organic remains slowly accumulated, and as fast as they were formed were altered by the action of the magnesia in the overlying sea water. Eventually the basin may have become entirely filled or cut off from connection with the ocean and the whole of the remaining waters evaporated. On the other hand, the basin may have become very shallow only before the influx of the muddy water from which were deposited the lowest beds of the Maquoketa. With that incursion the dominance of the sea was reestablished.

Whether this area was ever covered by the sea after the Niagara dolomite was deposited is not certain. In the adjacent regions there are small outliers which have been found to be of Devonian, Carboniferous, Cretaceous, and possibly Tertiary age, and it is not impossible that beds representing some of these periods may have once covered the Driftless Area. The next period, however, of which there is definite record was one of erosion, as is made evident by the peneplain already described as occupying much of the district. This plain,

[a] Udden, J. A., Geological section across the northern part of Illinois: Rept. Illinois Board World's Fair Commissioners, 1893, pp. 144-146.

which cuts across soft Maquoketa shale and hard Galena dolomite alike, marks a time during which the land was stable sufficiently long for the streams to reduce to a fairly even plain all the territory extending from the mounds far to the north.

The age of this peneplain is not definitely fixed, but there are reasons for believing that it represents the closing stage of the Tertiary. The epoch in which it was formed was terminated by an uplift, accompanied by a tilting to the south, and the wide meandering streams began to cut their channels down into the peneplain. They are still engaged in this task, and, so far as the evidence of this immediate territory shows, the work has been uninterrupted. At times during the occupation of the surrounding region by ice the Mississippi carried an unusual amount of water, which caused it to widen its valley and to truncate the salients between the tributary streams. With the return of normal conditions of volume it was unable to carry the material with which it was loaded, and so constructed the terrace upon which parts of Dubuque and many other river towns are built. At the same time, in the ponded lower portions of the tributary streams, silts were deposited to an equivalent level. The upper portions of the streams were unaffected, and to all appearances nothing has disturbed them since the uplift of the peneplain. If, during Pleistocene time, there were elevations and depressions of the area, they were so slight or of such short duration as to leave no mark on the courses of the streams.

ORE DEPOSITS.

GENERAL CHARACTER.

The ores of the upper Mississippi Valley are zinc ores, made up largely of blende and subordinately of smithsonite, with nonargentiferous soft lead and iron sulphides. They are distinguished for the simplicity of their mineralogic composition and for their occurrence in unaltered, flat-lying dolomites and limestones far from any known igneous rocks. In form the ores occur in vertical crevices with openings, in honeycomb runs, in pitches and flats, and in thin, flat-lying, disseminated bodies. Most of the ore shows crustification and crystallization in open cavities, but metasomatic replacement also has occurred. The ore bodies are closely related to certain very shallow structural basins, believed to be depositional in origin, and to certain shale beds known locally as oil rock, which contain a large percentage of fossil gum formed from minute unicellular algæ. The present ore bodies are believed to represent metallic sulphides that were originally disseminated through local areas of the Galena dolomite and concentrated, probably in late Tertiary or post-Tertiary time, by the action of descending surface waters. The ores are typically sedigenetic.[a]

COMPOSITION.

VEIN MATERIAL.

The ores of the upper Mississippi Valley are relatively simple in composition. The complex sulphides and many of the gangue minerals found in the zinc-lead ores of the Rocky Mountain region are practically absent, and instead of a wide variety of country rock, only dolomite, shale, and limestone need be taken into account. Despite these facts the vein material as mined and sent to the concentrating mill or picking table is far from consisting only of the ore minerals. Four elements must be distinguished:

(1) Pieces of country rock intimately mixed with the ore in nature or broken off in the process of mining. These include fragments of dolomite, limestone, and shale.

(2) The original metallic minerals, consisting of galena, blende, iron sulphides, and chalcopyrite. These are the most important ore minerals and it is customary to speak of lead ores, zinc ores, sulphur ores, and copper ores according as the one or the other is the preponderant mineral. The first three are now being mined. Copper is not now shipped and the copper formerly sent out from the district seems in the main to have been derived from alteration

[a] Bain, H. F., Sedigenetic and igneogenetic ores: Economic Geology, vol. 1, 1906, pp. 331–339.

products of the chalcopyrite. The minerals of this group are called the original metallic minerals because they represent the oldest form in which the metals are believed to have been combined. Much of the galena and blende in its present position is doubtless younger than other bodies of alteration minerals and may have been several times altered and redeposited.

(3) Alteration minerals. The original metallic minerals have been changed in the process of weathering from sulphides to sulphates, carbonates, and oxides. Some of these have probably in turn been changed back to sulphide but others remain in their altered form. The most important minerals in this group consist of smithsonite, cerussite, limonite, hematite, malachite, and azurite.

(4) Gangue minerals. Aside from the metallic minerals and their alteration products there are certain earthy minerals in ores which it is customary to distinguish as gangue minerals. In the upper Mississippi Valley the important gangue minerals are calcite, dolomite, barite, and gypsum. It may be noted in passing that aside from calcite none of these are abundant, and the small amount and simple composition of the gangue is a striking feature of the ore deposits of this region.

COUNTRY ROCK.

Galena dolomite forms the most common country rock for the ores. Its usual facies is a granular dolomite, blue where unweathered, and brown where oxidized. It is coarse textured, and where fresh shows small, irregular cavities, which are believed to represent the shrinkage incident to the change from limestone to dolomite. Where weathered it is rough surfaced and sandy in appearance. It breaks down into a loose sand consisting of individual dolomite crystals and fragments. In the upper workings this sand is so abundant as to be easily picked or shoveled aside and in places shows true cross-bedding due to rearrangement in the crevices and openings by moving water. There is often not enough clay in the material to make it plastic when wet.

Analyses of the rock have already been given. They show it to be a normal dolomite. It contains a small amount of organic matter, as much as 1 per cent being found even in rock relatively light-colored.[a] In the lower darker layers much more is present.

According to Whitney[b] the rock also shows traces of the alkalies, of chlorine, and of sulphuric acid. Since much of the rock near the mines contains small quantities of minutely distributed galena and blende, it is possible that the trace of acid is derived from them.

It is customary, particularly in the vicinity of Linden and Mineral Point, to recognize certain beds near the base of the dolomite as the "green rock" and "brown rock." These where examined were found to be the normal sandy dolomite, the color being probably due in the main to the particular form in which the iron is present. It is not improbable that some of the brown rock is colored by organic matter similar in origin to that of the oil rock.

In the middle portion of the formation flint is abundant, and in the ore bodies found in these beds it accordingly enters into their composition. In the lowermost beds, shale and oil rock occur, and these in turn become elements of the ore bodies. In certain places the beds of the galena consist of limestone rather than dolomite.

In dolomite the ore minerals occur freely crystallized in solution cavities, cementing the fractures of the rock either in place or in tumbled heaps, and as metasomatic replacements later to be described. Where the dolomite containing metasomatic-ore minerals weathers down, the clusters of crystals and crystalline masses are found in the resulting loose sand. In the shales the ore occurs in small, irregular individuals and clusters of crystals. In the limestone the fractures are usually small and irregular. The ore minerals here act as fillers.

In the Platteville formation the ore occurs either in shale or in limestone of the peculiar type already described as "glass rock." In the northeastern portion of the area the glass-rock beds are magnesian and in places have been converted into dolomite.

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[a] Weems, J. B., Analyses Eagle Point lime rock: Iowa Geol. Survey, vol. 10, 1900, p. 602.
[b] Geol. Survey Illinois, vol. 1, 1866, p. 170.

The ore found in the Prairie du Chien is confined to the dolomite layers and occurs in part in disseminated form.

In the Maquoketa blende has been found at one point in small scattered druses in certain dolomite layers.

THE ORES.

The minerals which enter into the composition of the ores or which are associated with them have been described in some detail by Chamberlin.[a] Interesting additional details have been given by Leonard[b] and a crystallographic study of the more common ones has been made by Hobbs.[c] From these sources, from standard text-books and from field observations, the following brief descriptions have been prepared. It is to be regretted that no complete mineralogical study of the ores of this region has ever been made.

ORIGINAL METALLIC MINERALS.

Galena.—(PbS; lead, 86.6 per cent; sulphur, 34.4 per cent; specific gravity, 7.4 to 7.6.) Galena is the only important lead ore of the district. It is also known as galenite or lead sulphide, and the miners usually term it "mineral" or "lead." It commonly occurs in crystals or clusters of crystals, which usually show the form of cubes and less commonly of octahedrons. Sometimes a combination of these two forms is seen, and Hobbs has noted modifications due to the presence of the rhombic dodecahedron. Skeleton growths occur and are known as "reticulated galena."

Hobbs has noted,[d] in specimens from Galena, Ill., two generations of growth separated by a layer of marcasite. The earlier generation showed the cube with only the corners minutely truncated by the octahedron, while the later showed the relations reversed. In general throughout the region large cubes of galena seem to represent a very late stage of deposition. Crystals of galena several inches or a foot across have been found. The miners call such large crystals "cog mineral." Small crystals, especially when disseminated through the rock, are known as "dice mineral." Where galena fills a narrow fissure it rarely shows individual crystal form and is known as "sheet mineral." This form is common in the narrow north-south crevices, and experienced miners and smelters can tell such mineral from that found in the east-west or larger crevices. The peculiar striations which such mineral shows are explained by Hobbs as due to an unusual form of twinning, and he aptly suggests that in the narrow crevices, the space being limited, the orientation of the mineral particles or crystals may be uniform from wall to wall.

The galena seldom shows bright metallic surfaces except on fracture planes. The faces of the crystals are dull and, in the upper workings, are frequently coated with cerussite. Occasionally they have been acted upon by solution until each face has been hollowed into a cup-shaped cavity. When broken the cleavage faces frequently show inclusions of dolomite and other foreign material. The strong crystallizing force of the galena is shown by the very perfect cubes developed where it has grown metasomatically in the dolomite.

Galena formed the original lead-ore mineral of the district and from it have been formed others, none of which are important. Unlike the galena of most mining districts, the mineral found in the upper Mississippi Valley contains practically no silver. It accordingly yields in the furnace a high grade "soft lead."

Sphalerite.—(ZnS; zinc, 67.15 per cent; sulphur, 32.85 per cent; specific gravity, 3.9 to 4.1.) Sphalerite is also known as zinc blende or zinc sulphide. The miners commonly refer to it as "black jack" or simply as "jack." This, by far the most important ore of the region, is the original zinc mineral. It is found commonly below the level of ground water, and so, although discovered early, was not mined until later. It varies in color from a light straw yellow through brown to jet black; this black color being due to impurities,

[a] Chamberlin, T. C., Geology of Wisconsin, vol. 4, 1882, pp. 380–398.
[b] Leonard, A. G., Iowa Geol. Survey, vol. 6, 1897, pp. 9–65.
[c] Hobbs, W. H., Bull. Univ. Wisconsin, sci. ser., vol. 1, No. 4, 1895, pp. 109–156; Zeitschr. für Kryst., vol. 25, 1895, pp. 257–275.
[d] Bull. Univ. Wisconsin, sci. ser., vol. 1, No. 4, 1895, p. 127.

particularly iron. While enough iron is present in the blende to give it color, the amount is really small, a fraction of 1 per cent. In this particular it differs from the blende of the Rocky Mountain States, in which the chemically combined iron amounts to several per cent. The iron found in the upper Mississippi Valley mines is mainly in the form of crystals of marcasite and pyrite mechanically mixed or intergrown with the blende. It can therefore be almost entirely separated in dressing the ore, and concentrates running 58 to 59 per cent in zinc are regularly prepared, some lots running as high as 61 per cent.

Cadmium, a frequent element in zinc ores and a deleterious substance, has not been recognized in the district and is believed to be entirely absent. When properly dressed therefore, the blende of the region is excellently adapted to the manufacture of spelter.

Sphalerite occurs most commonly in sheets lining the crevices and openings. On free surfaces there are small and rather poorly formed crystals. Ordinarily it forms solid sheets along the wall of a cavity, ranging in thickness from a fraction of an inch to 8 or 9 inches. Where it has crystallized in large, open cavities, such as the caves of the region, it sometimes forms mushroom-shaped clusters 6 inches across. Small nodules of sphalerite, some of which have a diameter of an inch or more, are embedded in the clays, especially in the clay bed that marks the base of the Galena formation. This form of sphalerite is frequently spoken of as "strawberry jack." It is seen at the Penitentiary mine near Mifflin, at the Capitola mine west of Platteville, and at the Eberle mine near Highland, where individual masses reach diameters of 3 inches. From the alteration of sphalerite the other zinc minerals of the district have been formed.

Marcasite and pyrite.—(FeS_2; iron, 46.67 per cent; sulphur, 53.33 per cent; specific gravity—pyrite, 4.67 to 5.20; marcasite, 4.65 to 4.88.) These two minerals are intimately associated with galena and sphalerite, especially the latter. Marcasite crystallizes in the orthorhombic system, while pyrite crystallizes in the isometric system. It commonly takes the form of cubes and octahedrons. Marcasite is by far the more common form of the iron sulphide in this region, and in the following descriptions it is assumed that all of the iron sulphide is in the form of marcasite unless it is otherwise stated. Marcasite is important economically from its association with the sphalerite and from the fact that in milling it is separated with some difficulty from the zinc ore. Above the level of ground water marcasite is commonly altered to limonite. Marcasite occurs as a cryptocrystalline coating on galena and blende, and also in well-formed crystals, but most commonly as thin sheets underlying as well as coating the other minerals. In cross sections these sheets appear to have a radiate structure, and they build up until they present a general mamillary surface. Hobbs has discriminated five crystallographic types.

Pyrite has not been widely recognized but when present is abundant. Leonard[a] found it in perfect octahedrons at the mine of the Dubuque Lead Mining Company. In the old shaft on the hill above the Hoskin mine pyrite was found in great cubical crystals with edges 1½ inches long. The faces are distorted and in general appearance the crystals greatly resemble the large cubes of galena frequently found in this region. At a number of places pyrite was found to be of secondary origin. The pyrite of the Rowley mine is a possible exception. Here it forms a thin sheet separating the blende from the country rock, usurping the place ordinarily occupied by the marcasite.

Iron sulphide as well as blende and galena has been found in the form of stalactites in the upper workings of the mines.

Chalcopyrite.—($CuFeS_2$; sulphur, 34.9 per cent; copper, 34.6 per cent; iron, 30.5 per cent; specific gravity, 4.1 to 4.3.) This mineral closely resembles pyrite, but is softer, being easily scratched with a knife. It is inclined to tarnish and become iridescent on weathering, from which fact it is quickly recognized. It is not abundant in the lead and zinc mines, but has been found at several points in the region. Where present it is mainly massive. It has largely been altered to malachite and azurite.

[a] Iowa Geol. Survey, vol. 6, 1895, p. 28.

ALTERATION MINERALS.

Smithsonite.—($ZnCO_3$; carbon dioxide, 35.2 per cent; zinc oxide, 64.8 per cent; metallic zinc, 52.06 per cent; specific gravity, 4.3 to 4.4.) Smithsonite is known by the miners as carbonate, or more commonly as "dry bone." Hobbs distinguished two sorts, one a massive semivitreous white to gray variety, which has frequently been mistaken for calamine, and the other the porous variety known as dry bone. The latter is usually brownish or yellowish in color, and has a decidedly earthy appearance. A great many local varieties are recognized, these being due to variations in the texture and amount of zinc present. Apparently there is considerable intergradation between the dry bone and the dolomite, since the commercial grades range from 20 to 40 per cent in zinc. Smithsonite is, next to sphalerite, the most important zinc mineral in the region. It occurs commonly above the level of ground water, but in places extends a short distance below. In the early mining it was neglected, and it is now produced in considerably less amounts than a few years ago and in decidedly smaller amounts than the sphalerite. Formerly it was about the only zinc ore mined. At the present time most of the smithsonite is burned to zinc white at Mineral Point, and very little of it is used in the production of spelter.

The smithsonite exhibits a strong tendency to replace other minerals, and occurs in pseudomorphs of calcite, galena, and blende. It also completely replaces fossils [a] and commonly extends into the wall rock some feet from an ore body, gradually becoming less abundant as the distance increases.

Hydrozincite.—This is a basic hydrous carbonate of zinc (specific gravity, 3.58 to 3.8) known also as zinc bloom. When pure it contains 60 per cent of metallic zinc. Hydrozincite is frequently associated with smithsonite and it is usually difficult to distinguish one from the other. It is reported from this district [b] but was not recognized in the course of the present investigations.

Calamine.—(H_2ZnSiO_5; silica, 25 per cent; zinc oxide, 67.5 per cent; water, 7.5 per cent; metallic zinc, 54.23 per cent; specific gravity, 3.4 to 3.5.) This ore of zinc is common in Missouri and Virginia, but it has not been certainly recognized in the upper Mississippi Valley. Because of its close resemblance in some forms to the massive nonporous variety of smithsonite it may possibly have been overlooked.

Cerussite.—($PbCO_3$; carbon dioxide, 16.5 per cent; lead oxide, 83.5 per cent; metallic lead, 77.5 per cent; specific gravity, 6.46 to 6.57.) Lead carbonate is locally called white lead ore. It occurs at some places in minute colorless crystals on the surface of the larger crystals of galena, as at the Robarts mine, near Linden. More commonly, however, it occurs as a white to yellowish powder-like coating on altered galena crystals. It is a secondary mineral derived from the alteration of the galena in the zone of weathering. It does not occur in large amount and was never an important ore in this region.

Anglesite.—($PbSO_4$; sulphur trioxide, 26.4 per cent; lead oxide, 73.6 per cent; metallic lead, 68.3 per cent; specific gravity, 6.3.) This mineral has been reported from this district, but it is of rare occurrence, and examination of some of the so-called anglesite from Mineral Point by Hobbs showed that selenite or gypsum had been mistaken for it.

Sulphur.—(S; specific gravity, 2.) Native sulphur, though not abundant, is occasionally found in the lead region in a pulverulent or minutely crystalline form in crevices or small cavities in the mines. It is undoubtedly due to decomposition of the sulphides, probably mainly the marcasite and pyrite. It is never found in sufficient abundance to be of any importance.

Wad.—This mineral, a hydrous oxide of manganese (specific gravity 3 to 4.7), occurs as an amorphous black substance. It is widely distributed in small quantities, and commonly takes the form of a fine black powder. It is not certain from what mineral it has been derived, though Chamberlin has suggested the possible presence of the sulphide alabandite.

Limonite.—The hydrated oxide of iron is found in large quantities in the ore-bearing crevices, where it was formed by the oxidation of the pyrite and marcasite. This alteration

[a] Leonard, op. cit., p. 27.

[b] Chamberlin, op. cit., p. 396.

process has gone on so extensively that a large part of the original minerals has been changed into iron oxide. It is usually impure and earthy, imparting to the clay and other crevice material a brown color. West of Dubuque it is so abundant in certain crevices as to have been mined for iron ore and shipped to Chicago and Milwaukee.[a]

Melanterite.—Iron sulphate has been occasionally detected and marks a step in the process of the alteration of the pyrite and marcasite. Similarly sulphate of zinc is occasionally present. As these sulphates are very soluble they are rarely found.

GANGUE MINERALS.

Calcite.—($CaCO_3$; carbon dioxide, 44 per cent; lime, 56 per cent; specific gravity, 2.7.) This is known commonly as calcspar, or simply as spar, and the miners refer to it as "tiff." It is the most common gangue mineral in the district. It is almost everywhere associated with lead and zinc ores and occurs in the middle of the cavities, being deposited after the metallic sulphides. It also commonly occurs in veins or in any kind of cavity throughout the limestones and dolomites of the district, especially in the Galena and Platteville formations.

Hobbs has discriminated six crystallographic types, and Leonard has studied and illustrated some very interesting varieties of both calcite and aragonite,[b] found in caves south of Dubuque. The abundance of crystallized calcite in these ores and the relative scarcity of dolomite, despite the fact that the latter constitutes almost the whole of the country rock, is a striking feature of the ores. It is, however, not peculiar to this district, but the same phenomenon is found in the southern Appalachians and in southeastern and central Missouri. In southwestern Missouri, where limestone and not dolomite forms the country rock, the reverse is true; dolomite being more abundant in the ores.

Probably the explanation of these facts lies in the principles pointed out by Van Hise[c] as controlling the replacement of calcium by magnesium and the reverse. Where solid calcium carbonate forms the more abundant compound, as in southwestern Missouri, and is in contact with calcium and magnesium-bearing solutions, the law of mass action requires that a part of the calcium be replaced by magnesium. At first the substitution goes forward rapidly, but as the process continues toward the point of equilibrium it becomes slower. Since calcium is the more energetic base and also the more abundant, when the stage of molecular equilibrium is reached, corresponding to the composition of dolomite, calcium in turn becomes able to replace magnesium. In the upper Mississippi Valley the country rock being itself dolomite the two elements are in molecular equilibrium to begin with. If, now, solutions of calcium and magnesium carbonate be introduced, the calcium as the more energetic base tends to replace magnesium and calcite crystallizes out as a result. Since in the southwestern district the balance is evidently favorable to solution rather than to deposition of calcite, as is shown by the formation of cavities, there is opportunity for the dolomite to crystallize. In the Wisconsin deposits the balance is in the opposite direction, and calcite crystallizes out, while dolomite goes into solution. Presumably the magnesium solutions travel on, in this case downward, until in the Platteville limestone, finding rock in which magnesium is below the normal, they replace calcite and become fixed.

Dolomite.—($MgCaCO_3$; carbon dioxide, 47.9 per cent; lime, 30.4 per cent; magnesia, 21.7 per cent; specific gravity, 2.8 to 2.9.) While this mineral is the most important constituent of the Galena and Prairie du Chien formations, it almost never occurs in crystals of any size, and it does not seem to have been deposited in the veins, for reasons already discussed. It may, however, be found in very small crystals lining druses in the country rock, both in the mining districts and away from them.

Selenite.—($CaSO_4$, 2 H_2O; sulphur trioxide, 46.6 per cent; lime, 32.5 per cent; water, 20.9 per cent; specific gravity, 2.3.) This occurs in small crystals, but it is not very common. It undoubtedly owes its origin to certain chemical reactions taking place between

[a] Iowa Geol. Survey, vol. 10, 1900, pp. 597-600.
[b] Iowa Geol. Survey, vol. 6, 1897, pp. 29-36
[c] Treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, pp. 804-806.

the calcium carbonate of the rocks and sulphuric acid formed by the breaking down of the marcasite. Its scarcity is doubtless due to its great solubility.

Barite.—($BaSO_4$; sulphur trioxide, 34.3 per cent; baryta, 65.7 per cent; specific gravity, 4.3 to 4.6.) This is commonly known as heavy spar. Grant has noticed that barite appears in the main in the vicinity of the oil rock when occurs at all. Although usually it is not common, in certain of the mines it is abundant. Aside from occurring with the oil rock, it also lines cavities in the veins, being the last mineral deposited.

Quartz.—(SiO_2; oxygen, 53.3 per cent; silicon, 46.7 per cent; specific gravity, 2.6.) This occurs chiefly in the form of flint, which is abundant in certain parts of the Galena formation. Notwithstanding the large amounts of silica in the ore-bearing rocks, it is rarely found in crystalline form, except in cavities in the Prairie du Chien limestone, and here the crystals are commonly very small.

PARAGENESIS.

The association of the minerals with one another is interesting and instructive. Chamberlin devoted some time to a careful study of their order of deposition.[a] Van Hise[b] summarizes these observations as follows:

> The full succession at various openings from the wall to the druse is (1) marcasite; (2) ferriferous sphalerite; (3) galena in cubic crystals; (4) ferriferous sphalerite subordinate in quantity; (5) marcasite; (6) galena in octahedral crystals, very subordinate in quantity. Some of the elements of this succession are lacking at various veins. A very common order is (1) sphalerite, (2) galena, and (3) marcasite.

It is doubtful whether much significance should be attached to so complex an order. So far as present observations go the most common order is (1) marcasite; (2) blende, either free or containing some galena; (3) galena or marcasite, or both, and occasionally pyrite; and (4) calcite. The marcasite first deposited forms a thin sheet, not usually more than 1 millimeter in thickness, lining the solution cavities and fractures in the dolomite. It is rarely absent. The blende formed over it varies in thickness from a few millimeters to 3 or 4 inches. On the blende are scattered crystals of galena and pyrite and occasionally an incrustation of marcasite.

Probably more significant, however, is a grouping corresponding to the vertical order of succession of the dominant ore minerals. According to this grouping the ores may be classed as (1) galena or lead ores; (2) smithsonite or zinc-carbonate ores; (3) blende or zinc-sulphide ores; (4) "sulphur" ores.

Galena or lead ores.—These are the characteristic ores of the upper horizons and are the ones which attracted attention in the early history of the region. In them galena is the dominant mineral and zinc minerals are very subordinate. These ores range in general from the surface down to the level of underground water, and much the largest quantity of galena so far obtained has been found as loose masses in dolomite sand, which is residual from the decomposition of the country rock. Iron and manganese oxides are commonly found in these ores in small quantity, though sufficient to give a rusty brown or black color to the mass. Despite the many years of careful prospecting since the district was first opened these ores are still found and mined, and at Elizabeth, Ill., a large body of such ore was found in the summer of 1903. These ores formed the basis of the early mining of the region, and the working of them calls for only the simplest machinery and methods.

Smithsonite or zinc-carbonate ores.—Somewhat below the lead ores proper, beginning, however, above the actual level of underground water and extending a little below it, is the zone from which, in the years 1860 to 1890, the main ores of the region were obtained. In this zone the amount of galena present is much less than in that above; the dominant mineral is zinc carbonate. With it are minor amounts of galena and toward the bottom increasing amounts of zinc sulphide and iron sulphide.

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[a] Geology of Wisconsin, vol. 4, 1882, pp. 491–497.
[b] Trans. Am. Inst. Min. Eng., vol. 30, 1901, p. 104.

The relations of the zinc carbonate to the zinc sulphide are such as to make it clear that the carbonate is an alteration product from the sulphide. The oxides of manganese and iron are present in this zone, as in that above. The ores carry from 20 to 40 per cent of metallic zinc as usually prepared. They are mined and dressed ordinarily with only the simplest machinery.

Blende or zinc-sulphide ores.—Below the zone of zinc-carbonate ores is that in which blende becomes in turn dominant. It extends from near the level of underground water down to the "oil rock" and in a few cases a short distance below. Associated with the blende are galena and the sulphides of iron. The latter occur in considerable quantity, and the various sulphides are so intimately mixed as to preclude any successful attempt at determining an invariable order of deposition. The order (1) iron sulphide; (2) blende; (3) minor amounts of galena, is most common, but the reverse order and various permutations of it also occur. Clear well-defined crystals of calcite frequently occur in this zone. The dominance of the blende and the absence of alteration products are apparently the significant features of this zone.

The zinc-sulphide ores are the ones now being worked at most mines. Their mining and dressing require usually the erection of much more elaborate plants than are necessary in the case of the other ores and necessitate good pumping and milling equipment. This requires more capital and results in the concentration of effort upon a smaller number of veins. It is this stage of mining that is becoming more and more important in the district.

"Sulphur" ores.—At the horizon of the blende or zinc-sulphide ores the amount of pyrite and marcasite becomes at places so abundant that the ore is more valuable for its sulphur than its zinc content. These mixed ores have in recent years been largely shipped to Mineral Point, Wis., where they are roasted, to manufacture sulphuric acid. At a few points in the region marcasite and pyrite occur in such abundance and so free from the other sulphides as to be in demand at other acid works. They have accordingly been mined and shipped from time to time.

CAUSE OF THE VERTICAL ORDER.

Chamberlin discussed the vertical order of the ores and arrived at the conclusion[a] that "selective chemical affinity" was the most important cause. This cause is the one cited by Van Hise to explain the process of secondary enrichment of the sulphides developed by his studies in this same region.[b] It is undoubtedly a true and the most important cause of the present order of superposition of the ores. There are, however, some reasons for thinking that there may have been originally a greater abundance of galena in the upper beds and of blende below. As these reasons are largely founded on theory they will be discussed in connection with the general topic of the genesis of ores.

MODE OF OCCURRENCE.

There are four general forms of ore bodies recognized in this region: (1) Crevices and openings; (2) honeycomb or sprangle runs; (3) pitches and flats; (4) disseminated ores. The ores are made up in large part of minerals which have crystallized in open spaces. To a subordinate degree they include metallic sulphides, metasomatically replacing dolomite, limestone, and shale. In the first three classes of ore bodies metasomatic replacement has been strictly subordinate. In the disseminated ores it has been the most important process in the formation.

CREVICE DEPOSITS.

Definition.—The ores first worked in this region occur largely in "crevices," as they have long been locally called, for which Whitney[c] coined the term "gash veins." These he con-

[a] Chamberlin, op. cit., p. 552.
[b] Trans. Am. Inst. Min. Eng., vol. 30, 1901, pp. 104-109.
[c] Metallic Wealth U. S., 1854, p. 48.

sidered to be intermediate in character between segregated and true veins. They occupy preexisting fissures, but are of limited extent, being usually restricted to a particular formation and not connected with any extensive movement of the rocky mass. As developed in this region, these veins occupy joint cracks. Usually, instead of a simple continuous fissure, there are a number of parallel fissures occupying en échelon positions. Collectively they are known as a "range." Two systems of joints are commonly developed in this area—vertical and pitching joints. The crevices are developed along the vertical-joint planes. The vertical joints, and hence the crevices, are best developed in the upper strata and within the first hundred feet of the surface. In general, the vertical joints are notable for their extent and regularity.

Openings.—The joint planes are simple cracks through the rock. They are not planes of any appreciable faulting and, though the vertical joints are very persistent, would not in themselves afford space for much ore. They have, however, been materially enlarged by the dissolving action of underground waters. Locally this action has been fairly uniform along the plane, and space has been cut out in which a simple sheet of mineral from a quarter of an inch to as much as 4 inches in thickness has been deposited. This form of ore body seems to be especially characteristic of the crevices occupying north-south and quartering joints. Along the main crevices, which over most of the area are approximately east-west in direction, solution has been more active, and irregular cavities and chambers have been excavated. There is a tendency for these to form at certain stratigraphic horizons, which differ from camp to camp, but are fairly constant within the limits of small areas. At the intersection of these planes and the joint planes the crevice either widens

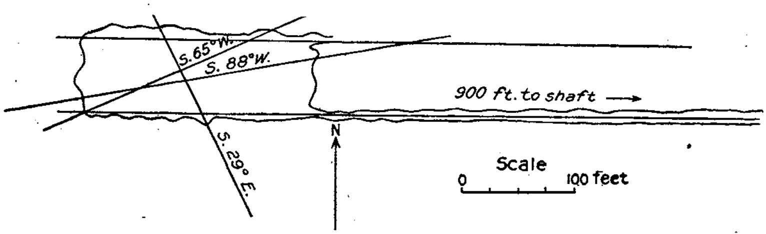

FIG. 9.—Sketch map showing location of Stewart's cave.

out abruptly and an open space is formed, or the rock becomes soft and thoroughly disintegrated. In either case the term "opening" is applied.

The openings are usually from 1 to 4 feet wide and from 4 to 6 feet high. Occasionally the rock between two crevices has been cut out by solution and broad chambers 25 to 30 feet wide and 30 to 40 feet high have been formed. The walls of the opening usually show firm dolomite, not especially disintegrated. Frequently they exhibit a pitted surface very similar to that which the same dolomite takes on exposure to weathering agencies at the surface. The roof of the opening may either be a flat "cap rock" through which the crevice can be traced only by a line of water seepage (Pl. VI, *A*) or be irregular as a result of the presence of "chimneys," which often extend as pipes from one opening to another. In many mines three distinct openings, one below another, are present. Two such openings are illustrated in Pl. VI, *B*, from a photograph taken in Dunleith or East Dubuque by Grant. Occasionally openings have been found 500 feet long, while lengths of 1,000 feet are not uncommon for the smaller openings. In certain cases, as a result of this softening of the rock, connections have been made by very little digging, so that an individual crevice may be followed underground for a mile or more.

Light on the method of the formation of such openings may be derived from a study of Stewart's cave near Dubuque. This cave is located at the intersection of several crevices, as indicated on the accompanying sketch map (fig. 9). It is reached by means of a shaft on an east-west crevice, whose south wall forms the south wall of the cave proper. The crevice itself is now open for 900 feet from the shaft to the cave. Along this distance it is open to a width of from 14 inches to 3 feet and to a height of 25 to 50 feet, above which it narrows to a mere crack. Winzes at several points have been put down 45 feet in soft dolomite sand without any sign of hard rock, but show galena near the water level. This mineral is in large cubes—"cog mineral"—and is more abundant near the cave than farther east. Rust or ocher is prominent near the shaft. The sands in the bottom of the crevice show cross-bedding and indicate actual movement of material along the crevice. Prospecting seems to have developed ore mainly at crevice intersections. The crevice forming the north side of the cave is, so far as known, barren.

The walls of the main crevice are weathered, as on an exposed cliff face—that is, so as to bring out very sharply the bedding planes. These correspond from side to side, and there is no indication whatever of faulting, either vertical or horizontal. The main crevice is cut by occasional cross crevices, running north-south, northeast-southwest, and northwest-southeast. Occasionally two of these cross in the main crevice. These cross crevices are usually marked by vertical cracks in the wall rock as much as 3 inches across and filled with dolomite sand.

The cave itself is an irregular rectangle about 80 by 200 feet, and if it were cleared of fallen rock it would be between 40 and 50 feet high. The fallen rock, however, fills it nearly to the roof, which is flat and unbroken. Along this roof the great east-west crevices are plainly marked but the "north-souths" are less well defined. The bearings as given in the sketch were taken in the summer of 1899 and are magnetic.

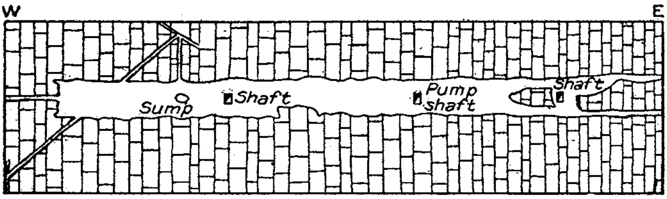

FIG. 10.—Levens cave, Dubuque, Iowa.

The bottom of the cave can not be reached, as water stands in it. The crevice and the cave proper are, however, quite dry. There is no drip and no calcite crystals line the roof and walls. The cave was discovered through a chimney on the main "east-west," and considerable galena was taken from the crevice, though not from the cave. The galena occurred in bunches high in the top of the crevice and in loose fallen masses in the sand. No systematic work has been done here for many years, though a little prospecting has been carried on.

Another well-known and characteristic cave in the Dubuque district is the Levens. Fortunately it is possible to give a somewhat exact account of this cave as it was when first discovered and as it now appears. The Levens range has been worked at intervals for nearly 3 miles. The eastern portion, lying within the city limits, was developed between 1830 and 1850. It was worked farther west in 1852–53, and still farther west, on mineral lot 371, Thomas Levens, in 1855, made one of the big strikes of the region. It is estimated that he raised about 2,500 tons of galena from this lot. Some blende was also discovered, but as it was at that time valueless, no attention was paid to it. It is estimated that in all 7,500 tons of galena have been taken from this crevice.

Its general course is S. 83½° W., and it is said to vary but little from this course. The only portion of the work open in recent years is the old Levens cave, which was visited in 1899 and again in 1900. This cave is in the SW. ¼ SE. ¼ sec. 15, T. 89 N., R. 11 E. The discovery is said to have been made by crawling into the cave from the east, but later three shafts were sunk on the cave. The middle shaft (fig. 10) is the one from which the main mineral was hoisted. About 50 yards east of it is a shaft sunk in 1860 by Anderson & Co., and used later for a pump shaft, a 40-horsepower engine and pump being used. The work was, however, never carried much, if any, below the levels now free from water.

The main portion of the cave is 25 to 35 feet wide, and 30 to 40 feet high. Except for the key rock west of the pump shaft it is open for nearly 500 feet. There are two well-marked crevices and the cave has been formed by solution of the rock between them. At the intersection of a "north-south" a prospect shaft showed blende at a depth of about 40 feet. Not far beyond the crevice narrows from 40 feet to 2 feet or less. On the Stout land, one-half to three-fourths of a mile farther west, the crevice opens out into a second cave from which mineral has been taken.

The following description of the cave when first found may be read with interest:[a]

For a description of this very interesting locality as it appeared when first discovered we are indebted to C. Whittlesey, who visited it immediately after its discovery by Mr. Levens and before it had been at all disturbed. This was in October, 1850; it was first visited by one of us two years later, after about 2,000,000 pounds of ore had been removed from it. The locality, as at first seen by Mr. Whittlesey, presented a narrow cave or crevice entering from the side of the hill, and capable of admitting, although in some places with great difficulty, the passage of a man. The crevice had a nearly east and west direction in general, with small deflections from a straight course. We annex Mr. Whittlesey's description of his visit to the locality in question. After speaking of the difficulty of squeezing between the walls of the narrow and winding crevice, he goes on as follows:

"We had not gone far in this uncomfortable manner when a handsome cave appeared before us, illuminated by the lights in front. It was a square room, with a mud floor and a rock ceiling, along the middle of which was a seam, or vertical crevice containing galena. This crevice was about 2 feet broad, the sides covered with mineral 6 to 8 inches thick, leaving a space between the inner faces of the mineral, up which we could see several feet. There was about this ercvice an entirely new feature, so far as I know. The solid mineral projected from this crevice downward, a foot to a foot and a half in a 'sheet,' as they call it, 8 to 10 inches thick, and 25 to 30 feet long, spreading fan like as it descended. A part of the way there were three sheets, two thick and heavy ones, with coarse irregular surfaces, composed of aggregated cubes from 2 to 10 inches on a side, and one long, thin sheet, the whole covered with oxide (carbonate?) of lead and having, in consequence, a pure-white color. This depending mass was wholly clear, except where it was attached to the rock above and projected downward in space—the most rich and beautiful object I ever saw of a mineral kind. About 200 feet more of twisting and squirming brought us to the leaden temple where lay the fortune of our bold explorer. It is a cave, or pocket, some 130 feet long, 20 feet high in the dome, or cavern part, and 20 to 30 feet wide, the sides and roof arched in an irregular manner. Probably it extends in this oval shape to a depth equal to the clear space above. The whole appears to have been ceiled with lead; and although its size is not as great as that of many (?) other mineral caves, the amount of galena in view at one time is said to exceed that of any 'pocket' yet opened. Much of the lead lining the roof and sides had fallen down in immense blocks, some of them very recently. This mineral incrustation was, in places, 2 feet thick, and one of the fallen masses was estimated to weigh 23,000 pounds. In the mud and clay that formed the bottom, or floor, of this spacious room, they said that mineral would be found buried, or inclosed in large lumps, to the bottom, probably 15 feet deeper."

Such was the appearance of things at this most interesting locality, certainly one of the most remarkable ever discovered, in 1850. In October, 1852, about 2,000,000 pounds of ore, worth, at the then current price of lead, about $50,000, had been removed, and there was still left in the mines about 1,500,000 pounds of ore, which was taken out in 1853 and 1854. A shaft had been sunk from the surface to strike the rich cave spoken of above, the top of which was reached at a depth of about 90 feet, and the bottom of the excavation was about 45 feet deeper. The length to which the crevice had been traced was about 1,200 feet; and the cave-like expansion extended for nearly 300 feet, widening out in some places to 25 feet. The galena at this time could be seen, in some places, occupying a fissure extending upward into the cap rock; it also formed flat sheets running into the sides of the opening, in some places, with a thickness of 3 to 4 inches of solid ore; but by far the greater portion lay in loose masses of partially disintegrated limestone, called "tumbling rock." Besides the shell-like deposit of ore which lined the walls of this cave, as described by Mr. Whittlesey, there seem to have been horizontal layers which once extended through the opening. These had been broken up, and the rock surrounding them removed by the action of currents of water, of which the evidence could be seen in every part of the crevice, especially in the waterworn and grooved lower surface of the cap rock and in the rounded edges and angles of the projecting strata of the sides of the opening.

From such workings as these came the great bulk of the galena shipped from the region in earlier years. The workings are now mainly of historical interest, though a similar cave, containing blende rather than galena, was opened in the California mine south of Galena, Ill., in 1903. This is described on page 78.

The openings ordinarily seen in the mines are much smaller, and the combination of horizontal openings and vertical chimneys makes a system of ore bodies quite deceptive to those

[a] Whitney, J. D., Iowa Geol. Survey (Hall), vol. 1, 1858, p. 450.

not acquainted with the peculiarities of the district. In fig. 11, a plan in the vein, a portion of the Avenue Top workings at Dubuque is illustrated. At first glance a considerable amount of unstoped ore would seem to be blocked out. As a matter of fact, only a thin coating of lean ore remains on the walls, and the blende which occurs at intervals along the bottom of the lower level is probably as patchy in distribution as the irregular, worked-out stopes above the level show the "dry bone" to have been. One of the chimneys, it will be noticed, lengthened into a small stope and similar stopes 50 to 80 feet long are not unknown, though they are rare.

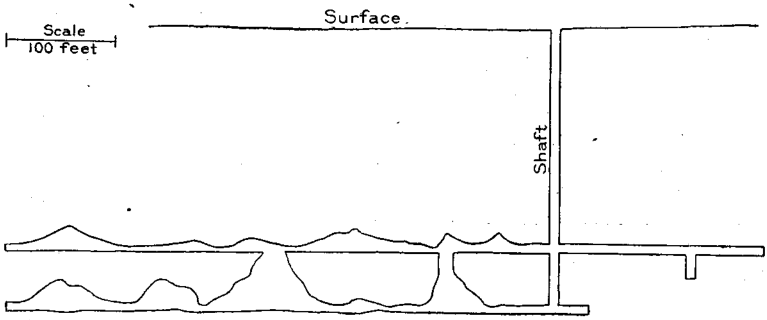

FIG. 11.—Vertical east-west section along the McNulty crevice, Avenue Top mine, Dubuque, Iowa.

Ores of the crevices.—In the crevices and openings the characteristic ore is the galena. This occurs as (1) thin sheets completely filling the smaller crevices; (2) crystals and crystalline aggregates clustered on the walls (fig. 12); (3) fallen and broken masses in the loose dolomite sand mixed with broken pieces of rock. The sheets have yielded relatively little mineral. In 1839 Owen estimated[a] that a regular sheet one-half inch thick could be worked profitably in solid rock that required blasting, while in loose ground a vein one-fourth

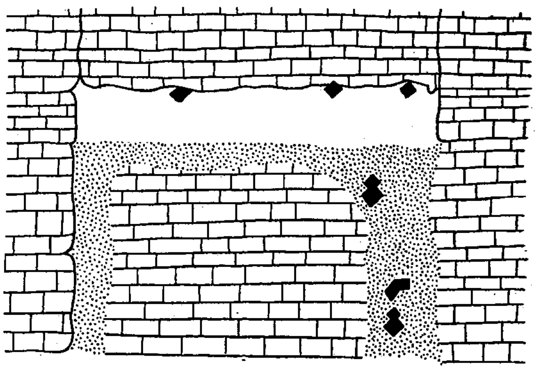

FIG. 12.—Typical occurrence of ore in roof of flat opening and in fallen masses, Kane Brothers' mine, Dubuque, Iowa.

of an inch thick would pay. Such thin sheets have not been worked for some years, except in the hope that they would lead the prospector to a cave or pocket of mineral. The open chambers have yielded the great bulk of the lead ore. From 1,000 to 2,000 tons of clean galena have in a number of cases been taken from individual openings.

Not only the galena ore, but the bulk of the zinc-carbonate ore, has come from the crevices and openings in which the smithsonite occurs as loose fragments mixed with the broken rock and sand, as incrustations lining the solution pits of the walls and covering the blocks

[a] Senate Doc. No. 407, 28th Cong., 1st sess., 1844, p. 38.

of tumbled rock and as a replacement of the dolomite. To a variable but nowhere great extent the smithsonite metasomatically replaces the dolomite of the walls, forming a low-grade carbonate ore. In a few cases blende has been found in quantity in the crevices and openings, but such zinc ore as is present is ordinarily in the form of carbonate.

The crevice ores in the main represent crystallization in open spaces, but subordinate amounts of ore originating through metasomatic processes are present. An interesting example is illustrated in fig. 13, from a specimen obtained at the Etna mine, near Benton. The rock here is a light-brown dolomite of rather coarse texture and shows numerous open druses one-half to three-fourths of an inch in diameter, lined with clear calcite crystals. The galena crystals are sharp angled, cubical in habit, and have clear lustrous cleavage faces where broken. Where they have been dug out of the rock, the resulting cavity is the exact form of the galena crystal and shows no evidence of a preexisting cavity. It may be noted that in places the crystal outline is incomplete, the galena and dolomite meeting in a rough, irregular line. In certain cases small amounts of dolomite occur entirely surrounded, so far as can be determined, by galena.

This specimen is believed to illustrate excellently the conditions under which galena replaces dolomite. It is from a horizon about at water level and the rock contains a small amount, less than 1 per cent, of organic matter, as determined by Mr. F. F. Grout. This amount is, however, ample to precipitate sulphate of lead, the form in which it is believed the lead was brought to its present position. It is clear that both the dolomite and the galena or its elements were in solution at the same time. The galena replaced the dolomite little by little. In doing so, however, there was no tendency toward pseudomorphism, the galena maintaining its own form throughout. The reason for this is believed to lie in the following facts: If the galena had crystallized in a simple aqueous solution, it would have grown freely and formed perfect crystals. Since at any one time and place along the border of the crystal growing in the rock there was an aqueous solution, the galena took its own proper form as it crystallized, and it seems likely that it was able to build out the complete crystal, because here, as in ordinary solutions, there was a considerable difference in density between the material on either side of the border. The tendency by virtue of which large crystals grow at the expense of small ones in order to decrease the amount of surface proportional to the bulk, apparently operated as between the dense galena and the less dense dolomite. Within the galena crystal there were more molecules in a given space than outside it. It is possible that this points to a general law explanatory of the fact that the metallic minerals commonly replace the lighter, nonmetallic. It may be noted that in this region it is characteristic of the minerals occurring metasomatically that they are well crystallized and idiomorphic.

FIG. 13.—Galena metasomatically replacing dolomite, Etna mine, Benton, Wis.

Distribution of the crevices.—Mineral-bearing crevices have been found throughout the mining area and exactly similar crevices, except for the absence of the ores, are found throughout a much wider region. On the maps accompanying Whitney's reports to the State geologists of Iowa, Wisconsin, and Illinois many of these old crevices are laid down. On the atlas sheets of the later Wisconsin Geological Survey the mineral-bearing crevices of the most productive portions of the area are shown in great detail. The general distribution of such crevices is shown in Pl. VII of this report. On the special map of the Dubuque district forming Pl. VIII the location and direction of the best known crevices is shown, and in fig. 14 are shown on a larger scale the details for a single quarter section of land (SE. ¼, sec.

33, T. 89 N., R. 3 E.), known locally as the Pikes Peak area. In this figure are shown the crevices, the principal shafts, and the approximate production of galena in pounds from data furnished in 1899 by W. H. Guilford. If it be remembered that only those crevices are indicated which have yielded considerable ore, some idea of their abundance will be obtained. Perhaps an even better notion of the extent of the old workings in areas where considerable lead mining was carried on may be gained from fig. 15, representing the Stacey diggings north of Galena. Each small pit represents a shaft sunk for galena, and their number is not only indicative of the difficulties of early mining, which prevented crosscutting and the driving of long drifts, but also tells something of the abundance of the ore and its nearness to the surface.

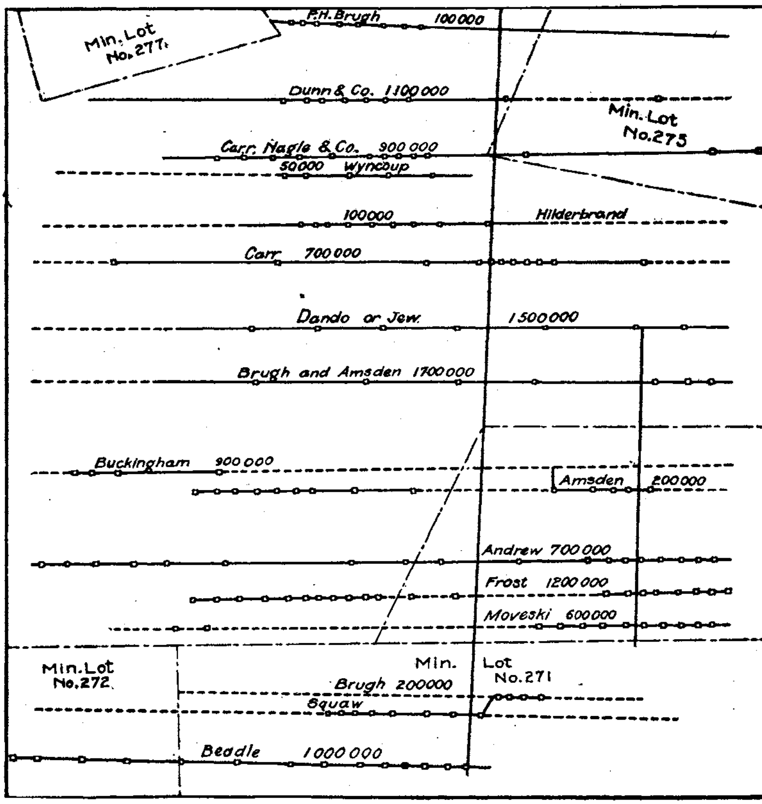

FIG. 14.—Typical crevice area near Dubuque, Iowa (SE. ¼ sec. 33, T. 89 N., R. 3 E.), showing direction of known crevices and approximate production in pounds of galena.

Origin of the crevices.—As already indicated, the crevices represent joint cracks enlarged by solution due to underground waters.

Whitney,[a] in his anxiety to distinguish these "gash veins" from true "fissure veins," stated that "the origin of this class of fissures must in all probability be referred to the contraction of the rock caused by shrinkage either while gradually undergoing consolidation or from the effect of long exposure to somewhat elevated temperature." It seems probable, however, that the difference between gash and fissure veins is one of degree of development rather than of genesis. Even a slight study shows that it is out of the question to assume that the rocks here have been subjected to "elevated temperature." A study of the crevices also affords convincing evidence that they can not be referred to shrinkage as that term

[a] Metallic Wealth U. S., 1854, pp. 48-49.

is now applied to rocks. Shrinkage could probably produce such fissures as are commonly known as mud cracks, but this cause is not to be lightly assumed for other cracks in sedimentary rocks. Mud cracks are most frequently formed in unconsolidated rocks and have rarely any continuity of direction over wide areas.

The crevices of this region were evidently formed after the rock was dolomitized and had become essentially as firm as now. The great shrinkage, 12 per cent, which took place in the change of the limestone to dolomite apparently does not express itself in these cracks, but in the large number of small cavities which distinguish even hand specimens of the Galena dolomite from limestone.

The crevices bear definite relationships to each other. The major ones run very nearly east and west. They are crossed by a second set at almost exactly a right angle, which is significant, as is also the fact that the major crevices are nearly parallel to the low, broad folds which cross the region.

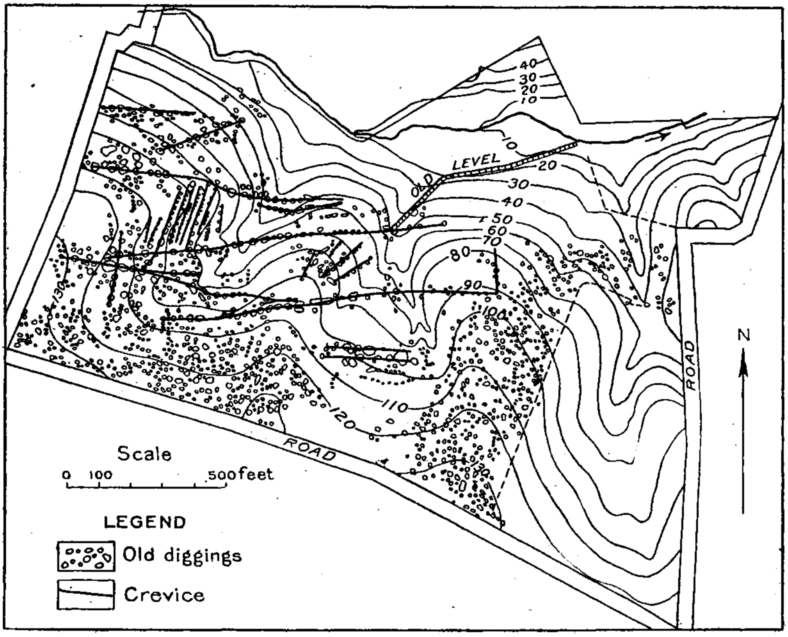

FIG. 15.—Map showing crevices and old workings of an area north of Galena, Ill. From map furnished by Newman and Smith.

When Whitney worked in the region joints, fissures, and folds were considered to be radically different sorts of things. They are now believed to be but diverse results of one general phenomenon—deformation. The parallelism between the major crevices of the region and the most pronounced folds strongly supports this theory. All the phenomena indicate that at some time later than the consolidation of the beds the strata were subjected to a certain amount of strain and that in their effort to accommodate themselves to this strain they were in part slightly folded and in part cracked. When a rock or body of rock is subjected to stress it tends to obtain relief by a change of form or of dimensions. All rocks are under more or less strain, and even relatively strong rocks tend to accommodate themselves to the various stresses to which they are subjected, though the strain may be no greater than that resulting from unequal support. If a rock be homogeneous, it acts as a unit; but if there be differences in density or strength, the various stresses are deflected from point to point. If the rock be soft and plastic, as is true of much the larger portion of the Maquoketa shale, the strain is accommodated by flow rather than by fracture—that is, the individual particles of the rock move rather than great masses of rock itself. If the rock be thin bedded, and if, furthermore, its character change from bed to bed, as is true of the Platteville limestone, particularly when interbedded with shale, the stresses act on smaller blocks of rock and deformation takes the form of numerous small fractures. It is very common to find the Platteville broken up into a large number of small blocks rather than in solid ledges. When, however, the rock is homogeneous, firm, and of low elasticity, stresses are resisted for a longer time and are ultimately relieved by great cracks extending, perhaps, for miles. The same amount of deformation may thus be accommodated in different ways in the different rocks of the same section. Van Hise has shown that one rock may be so squeezed as actually to flow under pressure, while another under the same conditions is merely broken.[a]

The Galena is a very massive formation of considerable extent and of fair thickness. It is thick bedded, and the bedding planes themselves are not marked by any notable amount of shale or other foreign matter. The rock is of low elasticity and has been subjected to certain stresses, which have been relieved by cracking. Apparently there has been very little displacement, either vertical or horizontal. The ore-bearing rocks of the region are essentially undisturbed. The low folds found here are simply the expression of such slight earth movements as have probably taken place in all areas. The exceptional development of the crevices is due to the inelastic and homogeneous character of the rock, which has allowed the formation of single crevices or bunches of closely parallel crevices extending in a fairly constant direction for some miles. Careful estimates of the amount of possible crustal shortening resulting from such deformation as the rocks have suffered indicate that while it might be sufficient to produce tension joints, the displacement along any single plane would be so slight as to permit no measurable faulting.

HONEYCOMB RUNS.

Definition and form.—The term "run" has been defined by Jenney[b] as "an irregular ore body found at the intersection of an ore horizon with a vertical fissure." The openings found in connection with the crevices might properly be spoken of, therefore, as runs; but since their essential feature is the open ground or a cavity only partly closed by fallen and usually oxidized rock, it seems desirable to retain the older local name. Below water level, where a considerable thickness of the Galena formation is present, there are typical runs. These correspond in position to the openings found above water level and are believed to represent merely an earlier stage in the formation of the ore bodies. At certain favorable horizons the ore penetrates the rock for a variable distance on either side of the crevice. In such cases the ore body consists of a porous dolomite with the interstices lined or partially filled with metallic sulphides. Locally the open spaces, which are half an inch to 2 inches in diameter, equal half the original bulk of the rock. Where the ore is very coarse and the fragments of rock are sharp angled, it is often spoken of as sprangle. Where the material is less cavernous and there is less distinct evidence of brecciation the term honeycomb is more commonly used.

Origin.—In some cases the brecciation is very evident, but in others it seems that the cavities are due mainly to solution. The two sorts of ore, corresponding roughly to honeycomb and sprangle, pass into each other in the same deposits. In most cases it seems probable that originally the rock was brecciated or partially brecciated, allowing free access to circulating waters, and that these waters have enlarged the cavities by solution of the semibrecciated or strained limestone. These honeycomb deposits occur in some places as small openings or enlargements of a crevice. They also make extensive deposits along vertical fissures and along flats.

Ores of the honeycomb runs.—The open spaces in the honeycomb rock are ordinarily lined with a thin sheet of marcasite. On this, completely closing the smaller fractures and spaces

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[a] Van Hise, C. R., Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 601.
[b] Trans. Am. Inst. Min. Eng., vol. 22, 1894, p. 189.

and partially filling the larger ones, both galena and blende occur. In the Hazel Green mine there is typical honeycomb ore, a specimen of which is illustrated in fig. 16. The gray dolomite here shows small irregular cavities that are almost all lined with marcasite. This seems to penetrate the dolomite slightly, becoming less and less abundant as distance from the cavity increases. The sheet of marcasite covering the surface of the cavity is 0.5 to 1 mm. thick. On it both galena and blende occur. In the smaller fractures and cavities the galena when present is apt to occupy the entire space and to show a uniform crystallographic orientation. Large spaces show the free crystallographic surfaces of the galena. Brown blende occurs in the same relations, but there is a notable tendency for each mineral to be segregated and to occupy different cavities or different portions of the same cavity rather than to be intergrown. This is not, however, an absolute rule.

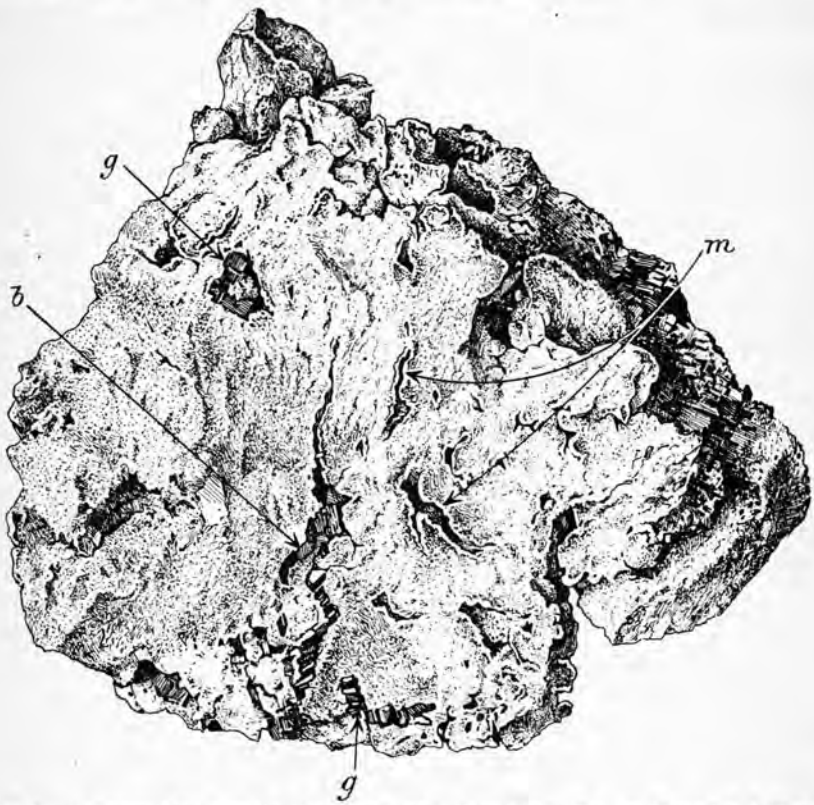

FIG. 16.—Honeycomb ore from the Hazel Green mine, Hazel Green, Wis. *m*, Marcasite; *b*, blende; *g*, galena.

In some places the fractures are so closely spaced and the cavities form so large a portion of the mass that the ore seems to be a breccia of dolomite, partially cemented by the sulphides. This ore is the typical sprangle ore.

When water level has sunk below the honeycomb deposits, they are partially or wholly oxidized, and zinc carbonate accordingly becomes the most important ore mineral. In such situations, as at the Fitzpatrick mine, no sharp line can be drawn between honeycomb runs and ordinary openings.

Among typical honeycomb deposits may be mentioned the Hazel Green mine, described in some detail on pages 86–88; the Pikes Peak mine, at Dubuque; the Oldenburg, at Galena; the Strawberry Blonde, at Strawbridge, and the upper workings of the Enterprise, at Platteville.

PITCHES AND FLATS.

Definition.—The most interesting and unique forms of ore bodies in the district are the flats and pitches. In these the ores follow in part the vertical joint planes, in part the bedding planes, and in part the dipping joint planes. The result is an ore body occupying a series of horizontal sheets called "flats" connected by a series of dipping sheets or "pitches." Many of these pitches are parallel to a main vertical crevice and pitch outward from it on both sides. The ore spreads out along the bedding planes both toward the main vertical crevice and away from it. It also descends from bedding plane to bedding plane by a number of parallel pitches. The deposition of the ore in the cavities formed by the combination of joints and bedding has usually been accompanied by some metasomatic replacement of the country rock, particularly that of the core between the two sets of pitches and the vertical crevice. Chamberlin was the first to recognize the peculiar character of these ore bodies and to describe them adequately. While a number of the mines now working afford excellent examples of the pitches and flats and are described on later pages, it may be conducive to clearness if Chamberlin's original description be quoted here:[a]

The most curious and significant form of deposit is beyond question that of the flats and pitches. Among the numerous examples a few must suffice for special description. In some respects the Roberts mine, near Linden, though not the most important, furnishes our best initial example. The following typical section was made under the direction of Capt. John Poad and verified by personal observation so far as the accessibility of the mine would permit. These crevices descend from above, one near the center and one each on the north and south margins of the upper flat, the trend of the range being east and west. These crevices terminate in a fine flat opening about 40 feet wide and 1 foot in depth. On either side this descends by slopes and steps through the lower bed of the Galena limestone till the stratum known locally as the "blue bed" is reached, at which point the divergent sheets are found to be 75 feet apart. On the pitches the ore is from 2 to 8 inches thick. It usually follows one main crevice, but sometimes branches into minor seams, reuniting below. Through the "blue bed" and what is here termed "quarry rock" (not to be confounded with the "Buff limestone" below, also known as "quarry rock"), a narrowed seam descends nearly vertically. On reaching the "brown rock" the crevice reverses its pitch, and on entering the "glass rock" forms an extensive flat, 2 feet in maximum thickness, having a central sag of 3 feet. Below this point the disposition seems to be toward impregnation of the rock rather than the formation of well-defined veins. The depth from the upper to the lower flat is about 50 feet.

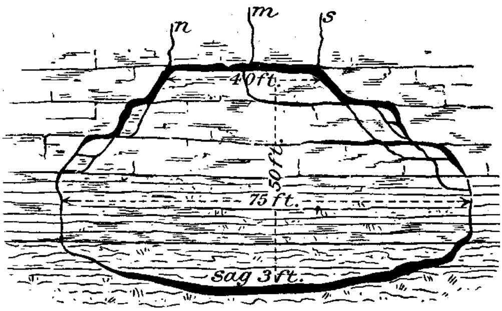

FIG. 17.—Section of flats and pitches of Roberts mine, Linden, Wis. *n*, *m*, *s*, North, middle, and south crevices. (After Chamberlin.)

The cross section given by Chamberlin and reproduced in fig. 17 has been widely republished and has come to be considered typical for this form of ore body. It has materially influenced the conception of the genesis of these peculiar ore bodies and to some extent has served to direct exploration.

Strike of the pitching crevices.—While Chamberlin's section is entirely accurate, it is believed that certain misconceptions have grown out of neglect to remember that such cross sections measure an ore body in only one plane. It is important to inquire more particularly regarding other planes, especially those at right angles to the one taken above.

As presented in this cross section and in those of the Marsden lode,[b] Mills lode,[c] and

[a] Chamberlin, T. C., Geology of Wisconsin, vol. 4, 1882, pp. 469–470.
[b] Ibid., p. 478.
[c] Ibid., p. 476.

others, the presence of two outward-pitching ore bodies parallel to the trend of the main crevice is emphasized. In the description of the Mills lode the fact is brought out that to the north there is a third equivalent pitch in the course of the old vertical crevice, or, to quote: "The form of this summit flat is not unlike that of a domestic flatiron, the sides gradually approaching each other and uniting in a point directed northward. On the east, west, and north—i. e., on the sides and point—this flat breaks down into pitches that decline about 45°, that on the west being somewhat the steepest."[a] The accompanying figures leave no doubt as to the north pitch being exactly similar in all particulars to that on the east and west. The occurrence was treated, however, as wholly exceptional, and the general notion of the parallelism of the vertical and pitching crevices became in time firmly fixed. Grant, in 1903, called attention to the presence in the Enterprise mine of pitches to the east and west as well as to the south,[b] and in the description of the mine given on page 93 of this report it is shown that at the southwest end of the upper workings the pitch is in fact continuous around a half circle, uniting the north and the south pitches in one outward-dipping plane, similar to that in the Mills diggings described by Chamberlin. Similar phenomena in a number of other workings are described and it is believed that they represent normal rather than exceptional conditions.

In the course of the present work Mr. Ellis made a detailed survey of typical sections near both Potosi and Hazel Green, mapping the pitching joints with great care in order to discover any apparent relation between them and the dip of the rocks or the vertical joints in the area. The results were so unpromising that it was not deemed necessary to extend the observations. In Pl. X Mr. Ellis's map of the area adjacent to the Hoskin and Kennedy mines is given. The extreme diversity of strike of the pitching joints is the most notable feature. If the reader will examine the various mine maps accompanying this report he can not fail to be impressed with a similar diversity, which appears the more striking when the general regularity and great continuity of the vertical crevices is recalled. This discordance would probably be even more evident if all the pitches could be illustrated.

Despite these facts, it is entirely true that a visitor to many mines in the region would be impressed mainly with the presence of those pitches which are parallel or approximately parallel to the main vertical crevices. It is believed that this is due to the emphasis of such parallel pitches by secondary factors rather than to their real predominance. Stresses which find relief along an east-west vertical crevice would be apt to emphasize a parallel pitching crevice, and underground waters flowing in a given direction, whether enlarging their channels or depositing ore, would be as likely to seek out and emphasize the pitching as the vertical crevices. It is believed that the verticals or crevices and the dipping joints or pitches represent two different phenomena.

The tendency of the pitches is to conform in strike to oblong or elliptical areas, with an outward dip in all directions.

Origin of the pitches.—These peculiar joints it is believed originated in the settling due to the consolidation of thicker patches of the oil rock. The reasons for this belief have been already discussed (pp. 43–44).

Position.—The flats and pitches are best developed in the lower part of the Galena formation. They reach their maximum size and importance in the beds between the flint and the top of the Platteville limestone. They occur, however, as high as the top of the flint beds and as low as the "glass rock" of the Platteville.

Ores of the pitches and flats.—The characteristic ore of the flats and pitches is the zinc-sulphide ore. It is in them that blende and its associated minerals are most commonly found, though this may be due to the fact that they are rarely developed above water level, as well as to their position low in the formation. Well-developed pitches were found above

[a] Chamberlin, op. cit., p. 476.
[b] Grant, U. S., Lead and zinc deposits of Wisconsin: Bull. Wisconsin Geol. and Nat. Hist. Survey No. 9, 1903, fig. 6, p. 68.

water level in the Stewart and Bartlett mine at Dubuque,[a] and yielded large quantities of galena ore. A similar body of galena was found in a well-developed pitch at Elizabeth in 1903, and is described on page 80.

The ores found in the pitches and flats bear evidence of having been formed mainly in open spaces. Crustification is common and the various fracture planes and druses are lined or filled with the sulphides. In the great core of rock between the pitches there is a certain amount of disseminated ore, which is due to metasomatic replacement; but even here the rule seems to be that of deposition in open spaces.

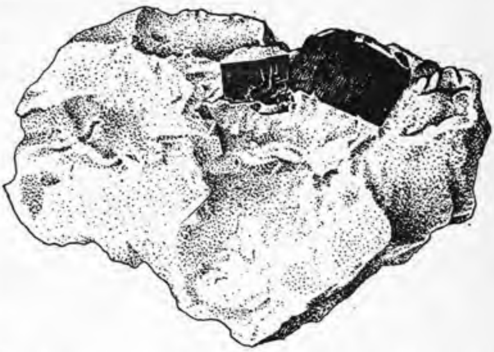

FIG. 18.—Disseminated galena in oil rock from the Enterprise mine, Platteville, Wis.

DISSEMINATED DEPOSITS.

Definition.—In certain of the mines, particularly those in which the country rock includes a considerable amount of clay or shale, both blende and galena occur in small, scattered crystals, which do not apparently fill previously existing cavities. Such ore is known as disseminated ore, or frequently as "strawberry jack" when the crystals are of blende and of about the size of strawberries.

The ore forms flats, usually of slight vertical but considerable horizontal extent. These flats in ground plan form long, irregular runs, and often show definite relations to vertical or pitching joints which come down through the roof.

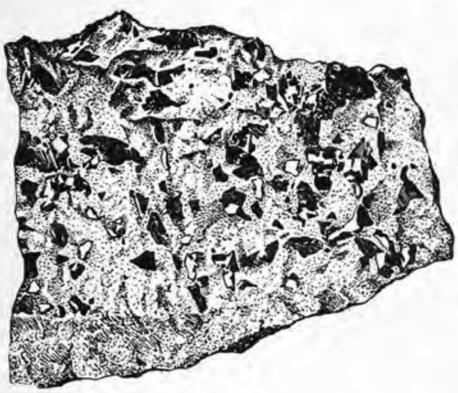

FIG. 19.—Disseminated blende in oil rock from the Gruno mine, Mifflin, Wis.

Ores of the disseminated ore bodies.—Blende is more common in such ore bodies than galena, and as compared with its occurrence in other forms of ore bodies iron sulphide is rare. The crystals or crystalline masses of both blende and galena are usually sharp angled and idiomorphic. They vary from a sixteenth to three-fourths of an inch in diameter, and occur in certain mines in great abundance. This sort of ore is illustrated in figs. 18 and 19, drawn from specimens of disseminated galena at the Enterprise mine and of blende at the Gruno. In both cases the ore occurs in a brown, fine-grained limestone, such as is typical of the beds in and near the oil-rock horizons. In a similar specimen from the Tippecanoe mine, where soft shaly layers of oil rock contain blebs and lenses of dolomite, it was noticed that the mineral showed a distinct tendency to replace the dolomite portions of the rock rather than the shale.

[a] Whitney, J. D., Iowa Geol. Survey (Hall), vol. 1, 1858, p. 450.

Position.—Disseminated ore is found mainly in the lowermost beds of the Galena and the upper portion of the Platteville formation. It is most abundant in and near the oil-rock horizon. In the sag within the pitches disseminated ore is very common in the oil-rock flat.

Origin.—The disseminated ores represent metasomatic replacement of the rock by ore-bearing solutions. Their close association with the oil-rock horizon is believed to be due to its relative imperviousness and to its high content of organic matter suitable for the reduction of sulphate solutions.

RELATIONS OF THE ORE DEPOSITS.

GEOGRAPHIC DISTRIBUTION.

The location of the working mines and of old crevices within the region is perhaps sufficiently indicated on the accompanying maps (Pls. VII–XV). The patchy distribution of the ores and the presence of barren ground between the various camps has been alluded to. In the area east of the region shown in these maps small amounts of galena have been found at various points. The eastern border may therefore be regarded as being to some extent indefinite and marked by a fading out of the producing territory and an increase in the relative extent of the barren interdistrict areas. Viewed in a large way, however, the eastern boundary is rather more definite, and coincides with the Wisconsin protaxis, which separates the Galena-Platteville of southwestern Wisconsin from that of the eastern part of the State. To the southeast the apparent limit of the district coincides approximately with the border of the Driftless Area, and there are reasons founded in the geologic history of the region which lead to the belief that this is a real border as well.

To the south and west the boundary of the district is marked by thickening Maquoketa shale and Niagara dolomite, which not only prevent the exploration of the ground, but probably control the course of underground circulation. In Illinois and Iowa a number of wells have been sunk through the deeply buried rocks of the horizons productive in the mining districts. In only one case is there any record of the finding of galena or blende in these wells. At Carbon Cliff, Ill.,[a] small pieces of zinc blende were found at the Galena horizon.

To the north the various sulphides occur in small scattered bodies in the area covered by the Prairie du Chien formation. The deposits of Allamakee County, Iowa, are the northernmost which have proved workable.

Looked at in a larger way, there is possible significance in the distribution of zinc and lead throughout the Mississippi Valley. In southern Illinois and western Kentucky small deposits are found in the Mississippian limestone, which are, in the writer's judgment, probably derived from lower horizons. In southeastern Missouri the equivalents of the Galena and Platteville are barren. Some ore is found in the equivalents of the Prairie du Chien, and the big lead deposits occur in Cambrian beds. In northern Arkansas the ores are found in Mississippian limestone and in beds approximately equivalent in age to the Prairie du Chien. In southwestern Missouri they are in the Mississippian, but are believed to have been derived from lower beds. In central Missouri the ore beds seem to be mainly equivalent to the Prairie du Chien. In eastern Tennessee and southwestern Virginia they are probably older. In southwestern Arkansas, except the fact that the country rock is made up of altered Paleozoic beds, there is little that is certain.

RELATIONS TO STRATIGRAPHY.

Ore deposits in the Niagara dolomite.—Galena has been found in the dolomites of the Niagara formation at a few points in the upper Mississippi Valley, although always in small quantity and never in amounts sufficient to warrant mining. Specimens are said to have been found at Sherrill Mound, north of Dubuque, and unsuccessful attempts have been made to develop such deposits near Clinton and Anamosa, Iowa. Both these areas are

[a] Udden, J. A., Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 836.

without the region discussed here. Within it only small, isolated specimens of galena have been found in this formation, and so far as known no blende has been found, so that for all practical purposes the formation is considered to be barren.

Ore deposits in the Maquoketa formation.—Crystals of blende and of galena are occasionally found in the Maquoketa. The only place in the region, however, at which blende has been found in quantity is at the Glanville prospect near Scales Mound, Ill. (NE. ¼ NW. ¼, sec. 24, T. 29 N., R. 2 E.). At this point there are certain thin bands of dolomite about the middle of the formation in which some blende and baryta occur. The rock is dark colored, earthy and of the type commonly found near the top of the Maquoketa, and is well exposed along the Illinois Central Railroad between Apple River and Scales Mound. The blende is brown to black in color, and occurs with small crystals of baryta lining druses in both the weathered and the unweathered rock. The individual masses are one-half to three-fourths of an inch in diameter, but are not sufficiently numerous to warrant much hope of finding a workable ore body. A short drift was run in on the bed in the winter of 1903–4, but did not reveal any considerable amount of ore.

It is believed that the Maquoketa as well as the Niagara is for all practical purposes barren.

Ore deposits in the Galena formation.—The great majority of occurrences of ore in this region are confined to the Galena formation. It is found at all horizons from top to bottom, though locally particular beds seem to be more favorable than others. In the Dubuque district three measurably constant horizons favorable for openings are recognized above the flint beds. In Wisconsin certain lower horizons are recognized by such names as green-rock opening, brown-rock opening, etc. These do not seem to be equivalent in the different districts and are best discussed in connection with the individual mines.

Strong[a] gives the following general section of the beds and openings in the lower portion of the Galena:

Generalized section showing openings in the Galena formation.

	Feet.
Green rock	4
Green-rock opening	3
Green rock	12
Brown rock	12
Brown-rock opening	5
Brown rock	8

These openings are both in the sandy dolomite below the flint beds. Below them is the oil rock or "upper pipe-clay openings," which Strong placed in the lower formation. The large ore bodies now worked are found mainly in the beds below the flints. The character of these beds has already been sufficiently described.

Ore deposits in the Platteville formation.—In the eastern part of the region, where the Galena formation has been largely cut away by erosion, considerable amounts of ore are found in the Platteville. This is mainly in the glass rock, at the base of which in many places is a thin shale bed that corresponds in character to certain phases of the oil rock and that is often confused with it. Below the glass rock is a gray limestone, magnesian but rarely a dolomite, which is also reported to carry ore here and there. In the midst of the quarry beds below it is not uncommon to find a thin shale band, which the miners know as the "lower pipe clay." It is reported to carry some ore, but this has not been verified. Still lower, between the quarry rock and the St. Peter, is a well-developed bed of clay or shale that is referred to occasionally as the "big pipe clay." It is said that drill holes near Dodgeville have shown blende at this horizon, but wherever seen in the field it was barren.

Ore deposits in the St. Peter sandstone.—The St. Peter is a barren formation, though a small amount of ore has been reported from its top in a few places. The old Crow Branch diggings have in particular been cited in this connection. Chamberlin[b] described and figured an

[a] Geology of Wisconsin, vol. 2, 1877, p. 695. [b] Geology of Wisconsin, vol. 2, 1877, p. 510.

occurrence of galena here, but saw no reason for considering the formation as properly ore bearing. All the exploration of recent years has only the more closely confirmed his conclusion.

Ore deposits in the Prairie du Chien formation.—The Prairie du Chien, or "Lower Magnesian limestone," as it was long called, is a dolomite similar in many respects to the Galena and apparently well suited to be the locus of ore deposition. Galena has been found in it at a number of points, and in the aggregate a not inconsiderable amount of lead has been won from this formation. The particular occurrences and the possibility that more of such ores may be found in the future are discussed on later pages, in connection with the description of the mines. It will be sufficient here to point out that all the known occurrences are in areas where the Galena and Platteville have been carried away by erosion and where the topographic situation is favorable for the secondary lodgment of such ore as existed in them.

Ore deposits in structural basins.—The presence within the region of certain broad, low anticlines and synclines was early recognized. They were elaborately discussed by Chamberlin,[a] who reached the conclusion that the irregularities were primarily depositional in character and secondarily deformational. He also made the generalization that the ore deposits were, in the main, at least, confined to the synclines. All of these conclusions have been confirmed in the course of the recent survey.

The general shape and depth of the basins have already been discussed and illustrated. Most of them are believed to have suffered deformation so slight as to be almost negligible. It is preferred, therefore, to use the noncommittal term basin rather than syncline. The slope of the sides of these basins is in most cases so gentle as to be recognized only by means of instrumental surveys. If the bottoms of the basins were exposed, they would, with few exceptions, have so little slope as to be thoroughly practicable railway grades. It is difficult to conceive of beds being laid down much more evenly and equally difficult to think of lateral pressure or tension buckling the beds so slightly.

Grant, who has especially studied these basins and to whose painstaking care their actual delimitation on the accompanying maps is due, has discussed the relations of the ore deposits to them,[b] with the following conclusion:

> It is not intended to imply that all of the deposits of the Wisconsin zinc and lead region are confined to these synclinal basins, but it is very evident that a large number of the important deposits are so located, and there can be no question as to the causal relation of these structural forms to the ore deposits.

Chamberlin, in his discussion of the phenomena, considered both the major lines of deformation, such as the Meeker's Grove anticline, and the small, shallow sag almost invariably found between the pitches in the mines. The pitches were correlated with the basin structure and held to be an expression of the tendency of cracks to diverge toward the convex side when beds are bent. On this basis the sag in the mine must be considered as a minor basin within the larger one and, if related to it as a secondary, tertiary, or *n*th order expression of the bending, should be either parallel to the axis of the major basin or at a right angle to it. Actually there is no constant relation between the two, and in the cases where the facts are best known—the Enterprise pitches, the Doll, the Mason, the Coker, and others—the sag and the pitches run at an angling course down the structural slope. The correlation of the minor sag and the pitches as seen in the mine is undoubtedly correct, as the relation may everywhere be seen to be close. As already indicated, however, the strike of the pitches bears no constant relation to the dip of the rocks, which reflects the structural basins shown on the maps. It is believed, therefore, that the sag and the pitches represent a different sort of phenomena from the larger basins and that beyond the fact that they occur within the basins there is no direct relation.

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[a] Geology of Wisconsin, vol. 4, 1882, pp. 419–438, 482–488.

[b] Structural relations of the Wisconsin zinc and lead deposits: Economic Geology, vol. 1, 1906, pp 233–242.

The fact that the crevice and opening deposits show close relations to the vertical joints, while the pitches and flats are related to the dipping joints and minor sags, has already been stated. The disseminated ores occur usually within the broader, shallower basins, and at least in part are less directly related to pitches than to vertical joints.

RELATIONS OF THE ORES TO TOPOGRAPHY.

The fact that the deposits of the region have so far been found under topographic slopes rather than in uplands or bottom lands has long been recognized. Chamberlin quotes with approval Wilson's observations regarding the crevice deposits as follows: [a]

> First, where the crevice passes directly under the ridge, at right angles, it usually encounters close or barred ground and is lean under the steep face of the ridge, but develops its greatest openness and richness under the more receding brow, while as it approaches the summit it usually pinches up and becomes unproductive; second, where the crevice passes obliquely under the face of a ridge, it is usually meagerly productive; and third, where it pursues a course nearly parallel to the surface contour, but neither near the summit nor under the steep face of the ridge, its situation is favorable to productiveness.

These observations seem well founded and accord with what is known of the occurrences of ore in the old ranges. Such occurrences are at present relatively unimportant, however, as compared with the lower pitches and flats. The honeycomb ore, originating in the same way as the crevice ore, might be expected to bear the same relations to topography. If so, the Hazel Green mine affords an exception, since the main deposit, recently worked, occurred under the bottom land, though, it is true, in a minor valley.

The pitches and flats have so far been found mainly under topographic slopes. The Rowley mine furnishes an exception in a deposit developed under bottom land. It is possible that if the drill be more used in the location of deposits and less attention be paid to the old workings, an increasing number of exceptions may be found.

Regarding the topographic relations of the disseminated deposits Grant has recorded the following observations: [b]

> All such deposits that have been seen occur along the sides of valleys which have been cut down into the Trenton [Platteville] limestone or even lower. In other words, the oil rock and the shales that separate the Trenton from the Galena are in all cases above the present drainage level of the vicinity. Moreover, as far as seen these deposits occur near the bottom of small valleys tributary to the main river valleys. Of course the occurrence of ore in such positions would be the first to be recognized in prospecting, and it may be that this ore will be found not only under these valleys, but also under the higher land which separates them. At the present time, however, mining has gone only far enough to show that along these small valleys the ore does occur.

The explanation of these various relations is doubtless to be found in the control which topographic form exercises over underground circulation and the exceptions are due to structural or other features which outweigh the ordinary agencies.

With regard to the relations of the region as a whole it may be noted that the deposits are found in a nonglaciated area having a mature erosion topography marking a period of peneplanation which has been succeeded by a relatively short epoch of stream cutting. This physiographic history is strikingly similar to that of the zinc-lead districts of the Ozark region and of the southern Appalachians..

RELATIONS OF THE ORES TO UNDERGROUND-WATER LEVEL.

The lead ores in this region have been found mainly above underground-water level. The zinc ores have been found mainly below it. The zinc-carbonate ores are found slightly above and slightly below the water table, while the zinc-sulphide ores are found almost entirely below. The iron sulphides are found with the blende, as is also a certain amount of galena.

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[a] Geology of Wisconsin, vol. 4, 1882, p. 447.
[b] Bull. Wisconsin Geol. and Nat. Hist. Survey No. 9, 1903, pp. 65-66.

While the level of underground water is an irregular surface reflecting the inequalities of the present topography, as a whole it bevels the beds from southwest to northeast. It follows the present surface, which, as already noted, is a dissected peneplain. Owing to the general dip of the rocks to the southwest, there is accordingly a greater distance between the oil-rock horizon and underground-water level south of Galena and Dubuque than farther northeast. Indeed, locally over the central portion of the area and rather generally in the northeastern portion the oil rock is above water level.

In the mines now being worked the largest and richest bodies of ore are found below the water level, but within a short distance of it.

In several of the basins in which the mines occur local artesian conditions are present and a generous flow of water is found when a drill hole penetrates the glass rock. General artesian conditions extend under the district as a whole, and water may be found in the Cambrian sandstone almost everywhere, though owing to the topography flowing wells are not to be expected.

RELATIONS OF THE ORES TO THE OIL-ROCK HORIZON.

In the discussion of the stratigraphy attention was called to certain beds known locally as the oil rock. As ordinarily found in the mine this material is a brown or black shale, between the layers of which are thin lenses or blebs of magnesian limestone or dolomite. The limestone and dolomite are also usually brown and often fine grained and brittle, breaking with a clean, conchoidal fracture. These beds vary in thickness from a few inches to 6 or 8 feet, though the shaly matter itself does not usually form any single band more than 1 foot thick. Beds of shale 2 or more feet thick do, however, occur.

The most striking peculiarity of this rock is the presence in it of organic matter in the form of fossil gum, which is abundant not only in the apparent shale but also in the limestone lenses. This is not carbonaceous in the usual sense, but contains so much of the hydrocarbons that it may usually be readily ignited, at times even with a match, and burns with a clear, luminous flame and a petroleum odor.

Disseminated ore is frequently found in the oil rock, and pitches and flats are developed above it. The oil rock is seldom seen in any considerable thickness outside the mines, though it is not of such a nature as to be especially destroyed by weathering. In quarry and natural sections where the oil-rock horizon occurs, it is usually very thin and much less characteristic than in underground workings. It is believed that there is some significance in these facts, and the generalization is proposed that the ore bodies are, in the main, confined to those areas in which the oil rock is thick. There are doubtless exceptions due to special causes. Apparently the thick oil rock, the sag, and the well-developed pitches go together and the whole set of coordinate phenomena are confined mainly to the structural basins already discussed.

It is believed that the sag and pitching crevices are due to the settling down of the beds coincident with the consolidation of the oil rock resulting from decrease in bulk as the more volatile portion of the organic matter was given off. In this explanation, account is taken of the shaly bands, similar in composition to the oil rock, that are occasionally found below the glass rock. The areas of thick oil rock are believed to represent irregular accumulations of the remains of unicellular algæ within the depositional basins, which, being later in part deformed, are now the structural basins in which the ore bodies are found. This hypothesis is further discussed in connection with the genesis of the ores (pp. 134–136).

AGE OF THE ORE DEPOSITS.

The ore bodies now being exploited are doubtless due to concentration or reconcentration, through the action of ordinary underground waters. It is difficult to suppose that much concentration was effected until the heavy Maquoketa shale was removed by erosion. If the physiographic interpretation outlined in an earlier part of this paper (pp. 15–16) be correct, the concentration occurred when the Lancaster peneplain was cut, and the best evidence available assigns this to the late Tertiary. According to this view the present ore bodies were therefore formed not earlier than the late Tertiary and it is probable that concentration is still going on.

The period during which a peneplain is being completed seems especially adapted to the concentration of such ores, since the underground waters have then a particularly short vertical range as compared with the horizontal component of their courses. Solution becomes unusually active relative to abrasion, and the gentle slopes lead to a slow movement of the waters whereby each portion has time to do its full share in chemical denudation and transportation. These ore bodies, it is believed, were concentrated mainly under such conditions, and it is probably significant that the ores of the Joplin area, the southern Illinois-Kentucky area, and a portion at least of the Virginia fields sustain similar relations to a peneplain of nearly the same age. Whether there were before this epoch ore bodies from which the present deposits were developed is less certain and is mainly of theoretical importance.

After the peneplain was elevated and while the present stream channels were being cut the water level sank and, pari passu, much of the ore was carried down a short distance. It is believed that to this relatively recent action is due mainly, though not wholly, the present vertical arrangement of the ores.

DESCRIPTION OF MINES AND DISTRICTS.

GENERAL RELATIONS.

The grouping of the mines into districts and subdistricts is one of the striking features of the region. This grouping has long been recognized and indeed, as pointed out by Chamberlin,[a] practically all the centers of mining were located within the first few years after the region was opened for settlement. Certain of these districts, as that of Elizabeth, are sharply defined and are separated from their nearest neighbors by considerable areas of barren ground. Others, as the Hazel Green and Benton, are more or less well connected with each other. These differences are believed to be not wholly due to the extent to which the intervening territory has been prospected, but to be in part original and genetic. In describing the individual mines, therefore, the attempt will be made to define, as closely as may be, the separate districts and to discriminate the subgroups of mines. It will be convenient to describe the mines in a general way from the southwest to the northeast, since thereby those in the upper portion of the formation, the first to be worked and the simplest in form and genesis, are first taken up.

In the following pages no attempt has been made to describe and locate all the mines in the region. Many of the old mines have long since been abandoned, and the material for such descriptions is either lacking or already in print and available to anyone caring to look it up. Pl. VII shows, with such accuracy as the small scale of the map permits, the general distribution of the old workings and crevices. The data for this map are taken from the publications of the older Wisconsin Geological Survey, to which the reader is referred for additional details.[b] The present significance of these old workings lies in the fact that recent prospecting has very commonly shown blende deposits to be present below the old lead workings. This is not a universal rule, and there are good reasons for anticipating many exceptions. It is, however, so frequently true that the old lead diggings become the most important factor in the selection of ground in prospecting for zinc.

Pl. VII also shows the areas covered by certain large-scale detailed topographic and geologic maps, which, with the exception of the Dubuque and Potosi sheets, were made under the direction of Doctor Grant for the Wisconsin Geological and Natural History Survey. The Potosi map was made by the United States Geological Survey, but was published with the others by the Wisconsin Survey.[c] The Dubuque map (Pl. VIII) was made by the United

[a] Geology of Wisconsin, vol. 4, 1882, p. 399.
[b] Atlas Wisconsin Geol. Survey.
[c] Grant, U. S., Rept. on lead and zinc deposits of Wisconsin, with an atlas of detailed maps: Bull. Wisconsin Geol. and Nat. Hist. Survey No. 14 (Economic ser. No. 9), 1906.

States Geological Survey, and has not yet been published on the large scale. Reduced copies of some of these maps and parts of the others form plates accompanying the mine descriptions. On them the geology and topography is shown by the usual conventions. In addition, structural contours are shown by heavy dark-green lines. These structural contours are drawn on the oil rock at the base of the Galena dolomite and by subtracting from the elevation of the surface, as shown by the topographic contours printed in brown, the elevation of the oil rock, as shown by the structural contours printed in dark green, the distance from the surface to the productive horizon can be determined. In the case of the Dubuque map it is not certain that the contours exactly represent the facts. The base of the Galena is practically unknown in this district, so the contours have been located by subtracting a uniform distance of 250 feet from the base of the Maquoketa. This is on the assumption that locally any unconformity between the Maquoketa and the Galena is negligible and that the Galena is of uniform thickness. It is not certain that either assumption is entirely correct, though both seem to be. The map should be used with caution until drilling either substantiates or disproves these assumptions. In the following descriptions there is much repetition, but this is inevitable when any considerable number of mines are described, and serves a useful purpose in indicating roughly the relative frequency of occurrence of certain features in the deposits. Only those mines are described which were visited by some member of the Survey in the course of the work.

The writer's observations have been supplemented mainly by those of Mr. E. E. Ellis, who assisted him, and of Dr. U. S. Grant, who studied the Wisconsin mines, first for the State independently and later in the course of cooperative work carried on by the State and national surveys. His notes, as well as published observations, have been fully drawn on in preparing the following descriptions, as have those of Mr. Ellis. In addition the writer has used material and notes that were collected some years ago while he was connected with the Iowa Geological Survey and that have been courteously placed at his disposal by the present director. Since the work was completed a large number of old mines have been reopened and additional deposits have been located. Most of these are mentioned in the list on pages 9–10, but even this is not entirely complete, since only those properties in active operation at the time the region was last visited are noted.

Certain districts have been treated in greater fullness than others economically more important, because the material available permitted it and for the further reason that they particularly well exemplify certain features of the deposits. The Dubuque district, for example, which at present produces very little ore, affords excellent examples of the crevice and opening type of deposits. The Dodgeville district, on the other hand, illustrates equally well the occurrences of flats of ore in the glass rock of the Platteville. Probably the best type of the disseminated deposits is to be found along Little Platte River, west of Platteville, while the honeycomb and sprangle ores are excellently developed at Hazel Green.

Only the mines in the Galena and Platteville formations are described by districts. The ore found in the Prairie du Chien and lower formations is described separately.

MINES IN IOWA.

DUBUQUE DISTRICT.

History.—The Dubuque mines were the first in the upper Mississippi Valley to be opened and among the first in America to be developed. In earlier years they were the most important source of lead in the world, aside from the mines of northern England and Spain. At one time they were considered far more valuable than the "lower Mississippi" or Missouri mines, but for nearly half a century the lead production of this district has been relatively unimportant. The early mining was altogether for lead. Zinc ore has been known to occur for nearly a century, but has been produced only since 1880. While both blende and smithsonite are present, the principal production has so far been of the latter. Aside from a few attempts at deeper mining made when galena was the mineral sought, very little pumping has been done, and the ore so far won has come mainly from above water level. At present little mining is being carried on, and in describing the district it is necessary to rely mainly on existing reports.

In connection with the first Geological Survey of Iowa, J. D. Whitney studied the Dubuque mines at a time when lead mining was being actively carried on. His wide experience and excellent judgment give his descriptions[a] unusual value. In 1896 A. G. Leonard gave a concise description of the mines and mining industry.[b] In 1899 and 1900 the writer, then connected with the Iowa Geological Survey, made a restudy of the district in cooperation with Prof. Samuel Calvin. The report made at that time[c] has been very fully drawn on in preparing the following pages. The mining industry of the Dubuque district has made but little progress from 1900 to 1905, so there is little to add to the other report.

The map accompanying this report (Pl. VIII) was prepared from field surveys made by E. E. Ellis, assisted by J. R. Bannister, G. H. Cox, and W. J. Read. The distribution of the crevices is taken from a map prepared in 1899 by the writer, with the assistance of W. H. Guilford, of Dubuque.

Geographic limits.—The mines of the Dubuque district proper are all within the limits of the area shown in the special map (Pl. VIII). Most of them are within the city of Dubuque. A few bodies of galena have been found in Table Mound and Mosalem townships, to the south; considerable mining has been done at Durango, immediately to the northwest, and some lead ore has been found near Sherrill Mound and Rickardsville, in Jefferson Township. In 1903–4 a mine was being opened in the northern part of the county south of Buena Vista, and in Clayton County mines were formerly open near Buena Vista and Guttenberg. These outlying mines, except at Durango, have never been heavy producers.

Geologic position.—All these mines are in the Galena dolomite and, except the Guttenberg mines, all are in its upper portion. Although the entire thickness of the Galena formation is exposed within the city of Dubuque, the ores have so far been won almost entirely from the upper 100 feet. By far the largest amount of ore so far discovered has come from within 50 feet of the top of the formation. Most of the Dubuque mines are situated on the sides of long finger-like ridges reaching over toward the river, and a considerable thickness of the overlying Maquoketa shale is commonly passed through in sinking. There is no record of any mining at Dubuque within a hundred feet of the base of the Galena.

Character of the ores.—The early mining at Dubuque was directed altogether toward the winning of lead ores. Galena was the principal mineral mined, though minor amounts of cerussite were also found. Pockets of lead ore are still encountered and individual deposits containing over 500 to 1,000 tons have been discovered within recent years. Since 1880 zinc carbonate or "dry bone" has been mined more extensively than galena. This, as well as the galena, has so far been mined only above water level. In the Alpine mine, in 1898–1900, considerable bodies of mixed carbonate and sulphide of zinc were worked, and in other properties similar ores are known to occur at about the water level. From the Pikes Peak mine in 1899–1900 several carloads of a mixed blende-galena-marcasite ore were shipped, taken from just below water level. The prevailing low price of zinc and the impracticability at that time of cleaning such ores led to the abandonment of the enterprise. In 1895 a mixed galena-pyrite honeycomb ore was worked below water level by the Dubuque Lead Mining Company, as described by Leonard.[d] This kind of ore body is unusual, both for the district and for the region.

Form and size of the ore bodies.—The ores at Dubuque occur almost entirely in crevices and openings. Pitches and flats have been found in only one or two instances and are nowhere well developed in the beds so far investigated. The crevices are vertical, and while north-south and quartering crevices occur the main ore bodies have so far been

[a] Whitney, J. D., Geology of Iowa (Hall), vol. 1, 1858, pp. 417–471.
[b] Leonard, A. G., Lead and zinc deposits of Iowa: Iowa Geol. Survey, vol. 6, 1896, pp. 9–66.
[c] Calvin, Samuel, and Bain, H. F., Geology of Dubuque County: Iowa Geol. Survey, vol. 10, 1900, pp. 379–622.
[d] Iowa Geol. Survey, vol. 6, 1896, p. 48.

found in east-west crevices. The richest deposits have been found at crossings. The main crevices are usually in closely spaced parallel groups known as ranges, and individual ranges may be identified with fair degree of certainty for as much as 2 miles. Development is generally confined to a quarter or a half mile along a range. The ore occurs in horizontal shoots or runs, locally called openings, from the circumstance that such runs are usually in soft or open ground. Between openings the crevice is normally very narrow or entirely closed, though in places the ore extends in vertical shoots or chimneys from one opening to the other. It is customary to recognize three such openings in the district, and these are numbered from the top downward. While it is not probable that these can be widely correlated, they have a certain local significance. They are known as the "top," "middle," and "third" openings.

The top opening is the one more commonly worked in West Dubuque. It may be seen in the quarries on Eighth street and is represented in Pl. VI, A. It occurs in the heavy-bedded dolomite lying between the upper thin beds and the Receptaculites zone. It is about 20 feet above the latter and 40 feet below the base of the shale. At this horizon there is a firm, heavy layer of dolomite about 2½ feet thick, known to the miners as the cap rock. Below it is usually another firm bed 8 to 9 inches thick, under which come certain thinner beds, which disintegrate easily and produce enlargements or openings where the formation is crossed by the crevices. These openings may be entirely clear or may be partially occupied by weathered dolomite or dolomite sand. The opening is ordinarily about 4 feet high; but by caving in of the roof and solution of the fragments chimneys are formed, which in places extend up to the overlying shale. This opening is not always found at the same horizon, but is generally present at or above the horizon indicated.

The middle or second opening occurs in the heavy-bedded dolomite between the Receptaculites zone and the flint beds. In West Dubuque it is ordinarily 40 to 50 feet below the cap rock of the top opening.

The third opening is found about 26 feet below the cap of the second and is the one worked in many of the West Dubuque mines. It is a short distance above the flint beds as developed in this vicinity. In the top of the flint beds a fourth opening is sometimes found.

Not all the openings are everywhere developed, though it is common to find two or even three in a single shaft. In cross section they do not differ much, and chimneys often extend from one to another. Pitches and flats have not been worked extensively in the Dubuque mines, though a north pitch was found in the Alpine mine leading down from the third opening, and Whitney [a] figures well-developed pitches in the Stewart and Bartlett mine at a level possibly higher.

Working mines.—At the time of this survey comparatively little mining was being carried on at Dubuque. A little galena and smithsonite were being raised, the principal output being from the Avenue Top, the Fourteenth Street, and the Greenhouse mines, which were operated, respectively, by John Alexander, Hird & Dolan, and George Frost. These are all typical crevice and opening mines, such as are described above. In the Iowa report[b] the details regarding individual crevices are given so fully that it seems hardly necessary to repeat the description. Certain of the mines have already been described in discussing the form of the ore bodies and the main centers of production are shown on the crevice map (Pl.VIII) accompanying this report. In general, it may be said that practically all the crevices shown on the map have been important producers of galena, and many have yielded zinc carbonate. The largest tonnage of zinc ore so far shipped probably came from the Durango mines, to the northwest, just outside the area of the special map. The aggregate production of the mines in secs. 25 and 26, known collectively as the West Dubuque mines, has, however, been considerable. These and the other mines in the district have been worked only down to water level and in several areas, notably the Pikes Peak in secs. 33 and 34, considerable blende is known to occur below.

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[a] Geology of Iowa (Hall), vol. 1, 1858, fig. 49, p. 450.

[b] Iowa Geol. Survey, vol. 10, 1900, pp. 529-566.

Away from the immediate vicinity of Dubuque the galena dolomite has not afforded much ore in Iowa. In Clayton County, near Guttenberg and Buena Vista, lead ore was formerly mined, and the old diggings have been described by Leonard.[a] Recently an effort has been made to reopen certain of the old lead mines south of Buena Vista in Dubuque County.

The Fitzpatrick Mining Company, of which J. N. Britt is superintendent, has opened a mine in sec. 3, T. 90 N., R. 1 W. The Maquoketa shale here caps a long ridge running out to the east, and parallel to the ridge is an old lead range, trending N. 85° W., along which the present workings are located. No. 4 shaft begins about at the top of the Galena formation, and at a depth of 110 feet is connected with the main level of the mine. In the pump shaft, located about 1,000 feet to the west and on lower ground, lower horizons are penetrated to a depth of 50 feet. The lowest workings are accordingly in the flint beds of the Galena formation, approximately 100 feet above the oil rock. The present workings show the crevice and opening type of ore body. No drilling has been done to determine whether pitches and flats are present. Both lead and zinc ores are found and in the past important amounts of lead ore have been shipped. At present "cog mineral," to the extent of only a few tons yearly, is found in the loose dolomite sand of the upper levels.

The zinc ore consists mainly of blende, though there is a little carbonate. Very little galena is found in the blende. The ore below water level shows a dark-colored blende occurring in a cavernous dolomite with a thin sheet of iron sulphide between the blende and the rock. It is very similar to that described as found at the Pikes Peak workings, southwest of Dubuque, and is of the type called "honeycomb" or sprangle in Wisconsin. Above water level the iron sulphide has been largely altered to limonite, and the blende is minutely porous. About 50 feet east of No. 4 shaft on the main level a face of such ore 10 feet wide was exposed when the mine was visited. Similar ore was reported approximately 100 feet in advance along the course of the opening, having been located by a winze from a higher level.

The topographic location of the range parallel to a ridge and part way down the slope is very favorable to the concentration of the ores. The present ore body doubtless represents, in the main, concentration at or about an old water level. The top of the Platteville may be seen near North Buena Vista station, at about 650 feet above sea level. It shows there no oil rock and only a little shale. At the mine it is too deeply buried to allow anything to be determined except by drilling.

The mine is well equipped with crosshead pumps, steam boiler, and Sampson engine. A mill was reported to be in process of building in the winter of 1905-6.

MINES IN ILLINOIS.

GENERAL STATEMENT.

The Illinois portion of the upper Mississippi Valley region was made the subject of special study in the summer of 1903 by the writer, assisted by Messrs. E. E. Ellis and A. F. Crider. The results of that study have been published in a bulletin, accompanied by a special map on the scale of 2 miles to the inch.[b] From this report the following mine descriptions are taken, with a few minor changes and additions.

In the summer of 1903 there were in northern Illinois about fifteen places at which mining or prospecting was being carried on vigorously. A much larger number of old diggings were found in the district, and some of these not improbably are prospected more or less during the winter season. No attempt will be made here to systematically describe these old workings, but the following brief description of the mines visited will illustrate what may now be learned about the district and suggest something of what continued prospecting may be expected to show. The location of each of the mines is indicated on the accompanying map (Pl. II). For the locations of the crevices, so far as they were known

[a] Iowa Geol. Survey, vol. 6, 1896, pp. 51-53.
[b] Bain, H. F., Zinc and lead deposits of northwestern Illinois: Bull. U. S. Geol. Survey No. 246, 1905.

at the time when lead mining was most active, the reader is referred to Pl. VII and to Whitney's map,[a] accompanying his report to the State geologist of Illinois, together with the map of the crevices of the entire district in his later report.[b]

The altitudes given in the following descriptions were all determined by aneroid, checked as carefully as possible on railway levels. They should be regarded as approximate only. In addition to the occurrences described here, which belong mainly to the Galena, Sand Prairie, and Elizabeth districts, some lead has been found near Warren and at various other points in eastern Jo Daviess County, extending, in fact, as far east as Freeport, Stephenson County. These eastern workings have never been extensive and nothing was being done in that area when these investigations were made.

GALENA DISTRICT.

Waters mine.—This mine is located on the hill within the limits of the city of Galena. It was for some time under bond to the Grant Reduction Works, which sunk several shafts, put up a concentrating mill, and shipped about 80 tons of zinc ore before forfeiting the bond. The main output has been of zinc ore, and about 500 tons of mixed sulphide and carbonate ores are reported to have been shipped. Approximately as much more was in the stock piles at the time the mine was visited. In earlier years galena was taken from the crevice, but the amount is not known. Drilling for deeper ore bodies is now under way.

The mine is located on an east-west crevice, which has been traced a mile or more along its course. The elevation of the curb of the pump shaft is 762 feet, as determined by aneroid. This shaft starts some feet below the base of the shales, and the present workings are in the beds of the Galena dolomite lying above the flint. A drill hole on the property is reported to have encountered the oil rock at a depth of 228 feet, corresponding to an altitude of 534 feet above sea level.

The main shaft follows a narrow crevice through solid dolomite into an opening the base of which, as developed in the summer of 1903, was approximately 100 feet below the surface. The opening is covered with a firm cap rock which marks the upper Receptaculites zone. Below the cap rock the opening, as first found and as yet shown in the west end of the property, is about 18 inches to 2 feet wide and 3 to 4 feet high. The sides show coarsely ribbed sandy dolomite, marked by solution cavities. The bottom of the opening is occupied by dolomite sand containing broken pieces of rock. Farther east along the crevice this loose material has been excavated to a depth of 35 feet, the crevice in that depth widening until it reaches an average of 10 to 12 feet from wall to wall, with a maximum width of 20 feet. This open cavity is several hundred feet long The ore was found in the lower 4 to 5 feet of the loose material and similar ore may yet be seen at the west end of the stope. Both blende and zinc carbonate occur, though the latter is the more common. Minor amounts of galena and a little iron sulphide are present. These minerals are found in broken pieces mixed with the sand as coating on the fragments of rock and the walls, and in small flat sheets running into the walls along the bedding planes. Usually there is between the blende and the rock a thin film, 1 or 2 mm. thick, of iron sulphide. Not infrequently this has been altered to limonite, an alteration proceeding from the wall rock toward the blende. The blende itself shows, on weathering, that it represents thin sheets deposited concentrically over the rough surfaces of the dolomite. It is often completely altered to smithsonite, though retaining its original form. There are a number of small crevices intersecting the main ore, and at such crossings the amount of galena is said to increase.

Nothing certain is known as to the occurrence of lower ore horizons. The present work extends to only a few feet below water level and not to the horizon at which pitches and flats, if present, should be expected.

Little Corporal mine.—This mine is located on a well-developed east-west crevice (N. 89½° E.) upon which for one-half to three-fourths of a mile old workings are indicated by dumps. The present workings are connected with the surface by means of a shaft 110 feet

[a] Geol. Survey Illinois, vol. 1, 1866, opp. p. 154.
[b] Rept. Geol. Survey Upper Mississippi Lead Region, Albany, 1862.

deep. The curb of this shaft is at an altitude of 763 feet, slightly below the base of the Maquoketa shale. The oil rock is reported from a neighboring drill hole at 506 feet above tide. The workings are accordingly in the beds above the flints, which seem here not to extend as high in the formation as usual by a few feet. The workings are now along what is locally known as the first pipe-clay opening. Some work has been done 20 feet above this opening, but in general the upper ground showed very little ore, and this mine is exceptional in that considerable bodies of zinc ore are found where no large body of galena was taken from the upper ground.

At the time the mine was visited the lower drift was approximately 400 feet long. The opening varies from 8 to 12 feet in height, being closed usually by a firm cap rock in which the crevice is marked by a mere line. In places it could be seen that above the timbering there were chimneys connected with the opening. The drift varied in width from 6 to 16 feet. East of the shaft there seem to be two parallel crevices, one of which is not well marked to the west. The ore makes on first one and then the other, and east of the shaft is cut off by a bar of hard rock coincident with the crossings of a north-south crevice. The walls show the normal cavernous dolomite. The pipe clay, from which the opening is named, is a thin parting of clay, not usually more than half an inch thick, but sufficiently impervious to have localized the flow of underground water and so to have caused the formation of the opening. Apparently water flowed along both its upper and lower surfaces.

The predominant ore mineral is blende, very little galena or carbonate being present. This is one of the cases of blende forming in quantity above the flats and pitches. The present work is 20 feet below the plane of permanent water, but is within the zone of oxidation, as shown by the brown color of the rock and sand. The flow of water is steady, but the amount is not known.

The usual thin film of iron sulphide occurs between the blende and the rock, and there are occasional large crystals of pyrite. For this region, however, the ore is unusually free from iron sulphide. As a rule the tailings are clean, and the ore does not need roasting and cleaning. As much as 14 tons of concentrates is said to have been produced in a single mill shift. The concentrates are said to run from 50 to 60 per cent in zinc and 2 to 4 per cent in iron. When visited the plant consisted of an 80-ton concentrating mill, a cross-head pump, hoist, air compressor, and two drills, the whole driven by gasoline power. The mill started in July, 1903, but closed down soon after.

Weber and Cring mine.—This mine includes several shafts along a crevice running N. 85° E. The top of the central working shaft is at an altitude of 813 feet. Galena is the only mineral shipped. The Dunkel and Link, a similar lead prospect, is located near by.

Vinegar Hill mine.—In Vinegar Hill Township there are many old workings and the area has produced a large amount of lead. Efforts were made in 1903 to reopen several of these mines, among which was the Vinegar Hill mine. This is located in a small ravine running toward Fever River, the top of the shaft being 33 feet below the base of the Maquoketa shale. The crevice runs east and west and has yielded galena at a depth of 29 feet. A new shaft was sunk, and a drift run to the east 10 feet below the old workings. A very neat and effective equipment, with a gasoline engine for power, was in operation when the plant was visited.

Fox River Valley mine.—At this mine there are two shafts on an east-west crevice, one more than 95 feet and the other 65 feet deep. The shafts begin a few feet below the base of the shale. Both galena and blende have been found in small quantity.

Oldenburg mine.—This, probably the best known of the mines near Galena, was not open in the summer of 1903. There are two shafts, the lower 100 feet and the upper 140 feet deep. The altitude of the lower is 800 feet and of the upper 830 feet, the nearest exposure of the base of the Maquoketa shale being 832 feet. This mine has been described by Chamberlin and by Grant. The latter visited it in the summer of 1902, and his description is as follows:[a]

This mine is along an east and west crevice, or rather along two nearly parallel crevices which unite toward the eastern part of the mine. The ore body is in a vertical sheet and is an example of the honeycomb deposits. The thickness of the sheet varies from almost nothing up to about 30 feet, and it has

[a] Bull. Wisconsin Geol. and Nat. Hist. Survey No. 9, 1903, p. 73.

been mined for about 800 feet in an east and west direction. A small amount of lead is present. Where small north and south crevices cross the main crevice there are usually larger and richer deposits of ore. The customary order of deposition in the cavities in this honeycomb deposit is a thin coating of marcasite followed by blende. Mr. Richard Kennedy informs me that the bottom of the mine, which is now about 100 feet under the top of the hill, is still 100 to 125 feet above the oil-rock horizon. Further work here will quite probably develop series of flats and pitches above the oil rock.

Northwestern mine.—The mine of the Northwestern Lead and Zinc Company is located near the Wisconsin boundary, not far from the Chicago and Northwestern Railway. It was visited in the summer of 1904, having been developed in the preceding winter. The shaft, which is 92 feet deep, is located at the base of the slope at the head of a small tributary of Fever River. The workings, which extend east and west for nearly 200 feet, are mainly in the top of the Platteville, immediately below the brown dolomite of the Galena. The oil rock proper is not well developed, but the upper beds of the Platteville show as a thin-bedded, nonmagnesian, fine-grained limestone, with many thin partings of carbonaceous material. It has a thickness of 15 feet and is said to rest on an 18-inch bed of blue clay, below which is the glass rock. A hole drilled through the latter yielded a flow of artesian water under considerable pressure.

The ore consists of thin sheets of blende, developed along the partings of the rock and minor amounts of breccia found in connection with some northward-pitching fractures. The southward pitches have not been found. At the east end of the drift a quartering crevice brings into the main vein an unusual amount of galena, which makes in a rich flat. Very little iron pyrite shows in the mine. The workings are below water level, though oxidation extends almost down to them. There is a new and well-equipped mill on the property.

Stacy mine.—The Stacy mine is located in sec. 21, T. 29 N., R. 1 E., where there are numerous old lead diggings. The property has been recently drilled and found to contain at lower horizons a considerable body of blende, which is now being developed by sinking. A sketch of the old crevices and shallow pits is shown in fig. 15 (p 60), as illustrating peculiarly well the great number of these pits in areas worked over by the old lead miners.

SAND PRAIRIE DISTRICT.

California mine.—This property was reopened in 1903 by the Royal Mining Company. It is located near Mississippi River, at the extreme southern edge of the district, in a small ravine cutting back into the Niagara escarpment. In the vicinity are a number of old lead diggings, which were formerly worked by long adits driven in from the edge of the bluff. These mines were the scene of great activity from 1849 to 1855, and at that time acquired the name "California diggings."

The Royal Mining Company located three shafts on an east-west crevice about halfway up the slope of the ravine which parallels the vein. No. 1, the shallowest, was not visited. No. 2 starts in the Maquoketa shale and was sunk through 8 feet of that and then 147 feet of galena. There are two drifts from this shaft; the main drift, at 105 feet, corresponding to a horizon slightly above the flint beds, extends eastward under No. 3 shaft. For a distance of 600 feet along this drift more or less galena and blende were won by both overhead and underhand stoping. The most interesting portion of this drift is immediately under the No. 3 shaft, which was being sunk at the time the mine was visited. At this point the drift was 6 to 8 feet wide and to the east opened out into a large cave similar in all respects to those in which in early days the large finds of galena were made. This cave was full of water when first encountered, but at the time of visit the level had been somewhat reduced by pumping. At the east end it is about 12 feet wide and equally high. It narrows above to a mere crevice. Below, it was filled with loose rock, sand, and chunks of ore. On the walls were patches of a thin coating of iron sulphide, over which both blende and galena had formed as a crust and in the form of irregular crystal aggregates resembling nothing so much as toadstools. These were commonly 3 to 6 inches in diameter and projected

2 to 4 inches from the wall. They seem to represent the free growth of crystals in a saturated solution. Many individual crystals of galena were of considerable size, as much as 2½ inches being measured on an edge. Apparently, after their formation, the conditions of the solution changed, since many of the galena crystals showed faces hollowed out to a true cup form as if by solution, and such surfaces were coated with a white material, doubtless lead carbonate. There was also a small development of zinc carbonate by alteration from the blende, and a very general oxidation of iron in the rock, as shown by the red color of the walls and the sand.

The significance of these facts lies in the circumstance that this whole cave and its contents underlie nearly the entire thickness of the Maquoketa shale, as was shown in the section of No. 3 shaft then being sunk, following a drill hole, to facilitate the excavation of the ore. In the shale there was no sign of either crevice or ore, but in the dolomite overlying the cave a small crevice showing a very little blende and galena was found. These relations make it clear that under favorable circumstances large and important bodies may be found under even a very thick cover of the impervious shale, and also that under present conditions surface oxidizing waters occur in quantity in the same situation. The bearing of these facts is discussed elsewhere in this report (pp.138–141).

Below the main drift a second was seen, 147 feet below the top of the Galena dolomite. This drift, after being driven to the east 100 feet in a bar, was when visited headed in soft ground underlying one of the underhand stopes of the main drift. From the behavior of the water it was inferred that there was a connection between the two. No flats or pitches had been encountered, though the lower level was at a horizon at which they occasionally occur, and a diamond-drill hole was later put down in the bottom of the drift in search of them.

Peru or Black Jack mine.—This is a well-equipped property not now in operation. Between 1876 and 1882 it was a steady producer, shipping ore regularly to the Illinois Zinc Company, with which its owners were affiliated. About 1903 a new mill was erected and the mine pumped out and examined preparatory to resuming work, but apparently the ore reserves were unsatisfactory, as the plant was closed down. It is understood that a second attempt to work the property is to be made. While the former examination was being made for the owners the writer visited the mine in company with the superintendent, Mr. Henry Ragge, who courteously supplied the accompanying record of a drill hole sunk some years before on the property.

The shaft curb is at an altitude of 660 feet, corresponding to a horizon about 40 feet below the base of the Maquoketa. The workings examined down to 135 feet in depth are in the flint beds and show a complicated system of pitches, beginning at about the top of those beds and extending down to the lowest horizon accessible. These pitches have a general northwest-southeast course, the pitch being to the northeast and southwest. They begin with the "second pipe-clay opening." The pipe clay, which defines an ore horizon, is the common clay parting along a bedding plane in the dolomite, and is barely 2 inches thick.

The ore is blende, occurring intimately mixed with iron sulphide. The latter, within the limits open to observation, is more abundant in depth at the north end of the property, though it is reported to be less abundant in the inaccessible lower levels. Near the top of the workings, 45 feet below the surface, cubes of galena three-eighths of an inch in size were found plentifully sprinkled over the blende. Additional cube lead was reported, though not seen, at least 60 feet below the original underground water level. The ore occurs in thin sheets in the pitches and in flats along bedding planes. Sheets 6 inches thick were observed at a few points.

The occurrence of well-defined pitches and flats so high in the formation is somewhat unusual, and their evident former richness is very encouraging to prospectors working at still higher horizons in the crevices and openings.

The following drill record is of interest and value as showing the persistence of the zones recognized farther north. The shale near the base (No. 12) represents, probably, the oil rock.

Drill record at the Peru mine, Illinois.

	Ft.	in.
28. Clay and rock	20	
27. Galena limestone, "sand rock"	37	
26. Clay, called "second pipe clay," corresponding to the adit tunnel level		2
25. Galena limestone, "sand rock"	7	
24. Clay, "third pipe clay"		5
23. Galena limestone	80	7
22. Brown rock, "dead opening"	10	
21. Clay, water level		2
20. Galena limestone	11	
19. Clay, "real pipe clay"		2
18. Blue limestone opening, ore	4	
17. Blue limestone, ore	12	
16. Cap over clay bed	2	
15. Clay	2	6
14. Blue to gray limestone		4
13. Blue to gray limestone	1	
12. Shale with blende	1	2
11. Clay	1	
10. Blue to gray limestone		3
9. Limestone, hard, brown	1	2
8. Glass rock proper		10
7. Carbonaceous shale		6
6. Blue limestone	2	
5. Carbonaceous shale		3
4. Blue limestone	2	10
3. Blue limestone, found in drill hole	10	6
2. Shale		1
1. Limestone, extending to St. Peter sandstone	?	?

ELIZABETH DISTRICT.

Wishon mine.—The Wishon mine, located a short distance north of Elizabeth, was an important producer of lead about 1865. In 1902 the old workings were reopened in a search for zinc, and a new shaft was sunk 145 to 150 feet in depth. This was closed at the time the place was visited, but the former lead workings were reached by means of a near-by shaft.

The workings are developed along an important crevice marked by old shafts for a distance of a mile. The opening visited is in the Galena dolomite, just above the flint beds. The ground shows thorough oxidation, and galena was the only mineral seen. It occurs in small pieces in tight crevices, the bulk of the ore evidently having been removed. There is a large amount of open ground with well-defined pitches, both to the north and the south, running down into the flint beds. Apparently a considerable amount of ore has been taken from this ground.

Apple River mine.—This mine is located north of Elizabeth, on a crevice which has been an important producer of lead. In the summer of 1903 an old shaft was being pumped out, but the workings were not sufficiently advanced to permit any examination. The curb of the shaft is 75 feet below the base of the Maquoketa shale, and the crevice runs N. 71° E.

Skene mine.—This mine in 1904 was being reopened by the Elizabeth Mining and Milling Company. It is located on a crevice running N. 83° E., the curb being at an altitude of 673 feet, corresponding to 40 feet below the base of the shales. It shows well-defined pitches to the north and south at a depth of 96 feet. The mine has been developed about 1,200 feet along the south pitch, with crosscuts to the north. The work is below present water level, but is entirely in oxidized ground. The ore consists of nearly clean galena. Minor amounts of pyrite are found, both as the usual film separating the galena from the rock and in distinct balls and crystals. No carbonate of zinc occurs and only a very few small pieces of blende. The ore is mainly in the south pitch, but numerous small flats and verticals run off into the core between the pitches, and possibly the whole of the core may be milled. There is no evidence that the galena in this case is a secondary concentration, and the amount of it, if it be original, is notable. Between May and August over 600,000 pounds were shipped without any cleaning facilities other than hand jigs. The mine has since been a large and steady producer.

Queen mine.—This property is located near the city of Elizabeth, with the curb of the shaft at 677 feet above the sea, corresponding to 34 feet below the shales.

SCATTERED MINES IN ILLINOIS.

Vista Grande mine.—This is a small lead mine near Scales Mound and almost on the State line. The curb of the shaft is 40 feet below the top of the Galena, and the shaft is 115 feet deep.

Glanville prospect.—This is a small prospect about a mile east of the Vista Grande mine, and is unique in being in the Maquoketa shale. It is described on page 67.

MINES IN WISCONSIN.

HAZEL GREEN-BENTON DISTRICT.

General.—The Hazel Green-Benton district includes a large, poorly-defined area separated from the Galena, Meekers Grove, Shullsburg, and Fairplay districts by only semibarren stretches. The area is traversed by Fever River, which with its tributaries has cut down to the Platteville, while the Maquoketa shale underlies the ridge upon which the town of Hazel Green is located. The entire thickness of the Galena formation is therefore present and available for mining. The mines now working are mainly below the water table, but even those above it are below the natural water level, which was lowered some years since by an important tunnel driven in from Scrabble Creek.

The geology and topography of the most important portion of the area are shown in Pl. IX, reduced from the Hazel Green-Benton special map of the Wisconsin Survey.[a] The area is one in which there are many small structural basins that do not fall into any readily intelligible system. A general east-west structure is apparent, but the essentially local character of the basins present and their irregular distribution make it unsafe to generalize. In the western half of the territory the data available are not yet sufficiently complete to allow the structure to be made out. The very large number of crevices formerly worked and the complex distribution are shown in atlas sheets 31 and 39 of the older Geological Survey of Wisconsin.[b] A characteristic section of the beds near the oil rock was measured in the Kennedy mine by Mr. Grant. It is as follows:

Section at Kennedy mine, near Hazel Green.

	Ft.	in.
7. Blue dolomite, Galena.		
6. Bands of highly fossiliferous limestone, some of which is typical glass rock, with narrow bands of typical oil rock	8	
5. The main oil rock	2	
4. Blue shale, rather soft and almost like clay in places		10
3. Oil rock		10
2. Shale similar to No. 4		10
1. Typical glass rock	2	

The thickness of the oil rock in this section, as also in the adjacent Hoskin mine, is striking. Specimens show the normal chocolate-colored material of light weight and with occasional crystals of galena, blende, or iron sulphide. At the Hoskin mine the oil rock shows distinct brecciation, small fragments or blebs of broken, twisted, and distorted material being distributed through a matrix of normal oil rock.

[a] Grant, U. S., Burchard, E. F., Hancock, E. T., Ellis, E. E., and Perdue, M. J., Hazel Green-Benton sheet: Bull. Wisconsin Geol. and Nat. Hist. Survey No. 14, 1906, pl. 12.
[b] Atlas Geol. Survey Wisconsin.

Hoskin and Kennedy mines.—These are among the best known and most productive mines in the region. They are located on Bull Branch, about 1½ miles east of Hazel Green and immediately south of the old Mills diggings. A special map of the vicinity, made by Mr. Ellis, is shown in Pl. X. The underground workings, reduced and generalized, including a portion of the old Mills diggings, were taken from a map courteously furnished by Mr. Ralph Root, late superintendent of the Hoskin mine.

The workings extend from the oil rock up to the flint beds of the Galena, and the upper flat in the Kennedy mine is about at water level. The Hoskin, or New Deal mine, as it was formerly called, is mainly developed along two pitches having trends approximately N. 50° W. and N. 70° W. The former is known as the north pitch and dips to the northeast. The latter is the south pitch and dips to the southwest. Across their end is a third pitch having a general east-west course and dipping south, and another with a north-south course and an easterly dip, so that the zone of pitching crevices swings around and connects the main north and south pitches. To the northwest the two pitches trend farther and farther apart, so far as shown by present development. In the Mills diggings, which are presumed to be connected with the north pitch of the Hoskin, the pitches again swing round an acute angle and close in the end of a basin. Chamberlin has described the phenomena in the Mills diggings so carefully that his statement as to their relations, as well as his observations on the ores, may be quoted entire:[a]

Along the central line of the mining ground there runs a fissure descending from the surface through the cap rock of the mine proper. The fissure has an average width of only about 2 inches and carries a little lead ore, with considerable iron rust. On passing through the cap rock, the fissure terminates in the main upper flat of the mine, the ore sheet of which is somewhat thickest beneath it, so that the crevice is said to act as a "feeder" to the flat sheet. The form of this summit flat is not unlike that of a domestic flatiron, the sides gradually approaching each other and uniting in a point directed northward. The sheet is said to have reached a maximum thickness of 3½ feet of solid galena—a bonanza of its kind It dips moderately to the north, discharging its drainage in that direction. On the east, west, and north—i. e., on the sides and point—this flat breaks down into pitches that decline about 45 degrees—that on the west being somewhat the steepest.

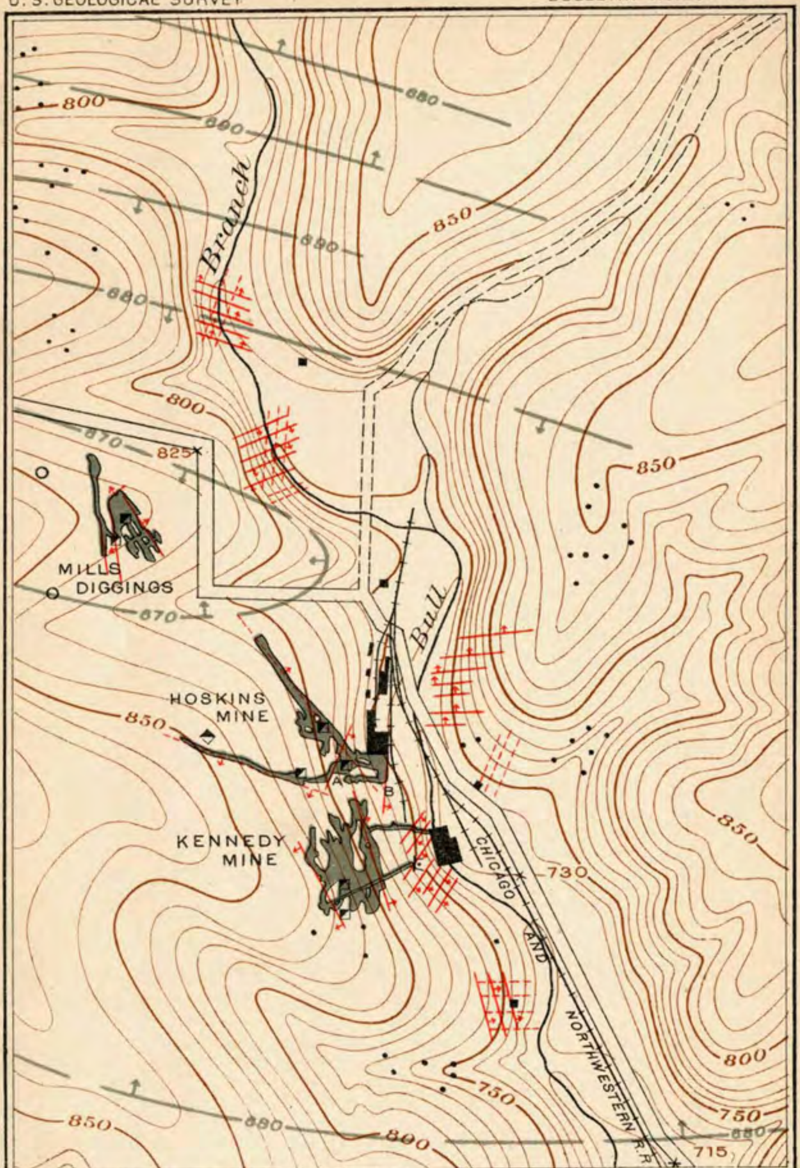
These pitching sheets sometimes consist of a single large vein, and at others divide into several smaller ones united by oblique cross veins or by parallel pitches and flats, forming a plexus of veins. As a general rule these minor veins confine themselves discreetly to about the width that would necessarily be mined out, so that they are usually easily wrought as a gang. In their descent the pitching sheets are interrupted by frequent short flats, giving the characteristic zigzag descent already sufficiently described. The ore is accustomed to make heaviest on the "roll," i. e., on the turn from the flat to the pitch or the pitch to the flat. At the angle where the sheet turns from the bedding joint into the transverse fracture, a little ore is apt to lead onward along the bedding joint. Ofttimes this connects with an oblique seam farther on and joins the main sheet below, but perhaps oftener it wedges out within a foot or two. There is frequently a reentering projection opposite this. Sometimes they develop into considerable flats. This deposit, as thus far mined, is wholly within the Galena limestone and the product has been mainly galenite. In accordance with the general rule, however, zinc ore gains on the lead as the mining is carried down. The horizons in which the main zinc deposits elsewhere occur have not yet been reached, and the further progress of mining here will be a matter of much interest, if it shall determine whether the pitching sheets join a great flat stretching under the whole series, and predominantly zinc bearing, as is the case in the mines above described and others of this type.

Iron sulphide, or its decomposition product, the oxide, lines the wall of the mine generally and at some points forms a notable deposit. Next this, for the greater part, lies zinc sulphide or carbonate, and the lead ore rests upon this and constitutes the main filling of the fissure in the upper part of the mine. But this general order is subject to local modification.

If, as surmised, the west pitch of the Mills extends down to a connection with the south pitch of the Hoskin, there should be a third "nose" somewhere to the west, and the combined system of pitches would include a large, triangular area.

A unique structural feature is the presence of an upward bend or anticline between the two main pitches of the Hoskin. This was exposed in driving the drift marked A–B in Pl. X, to connect the two parts of the mine. The oil rock here rises above the floor of the drift, though under the main workings to the east it is at least 10 feet lower. The beds above the oil rock rise with it and pass over the anticline in a gentle bow. The significance of this feature is

[a] Chamberlin, T. C., Geology of Wisconsin, vol. 4, 1882, pp. 476–477.



SPECIAL MAP SHOWING RELATIONS OF THE HOSKIN, KENNEDY, AND MILLS DIGGINGS

Scale

0 500 1000 1500 feet

1906

LEGEND

Shaft | Abandoned shaft | Old diggings | Crevices | Underground workings | Topographic contours | Structural contours

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not understood. So far as observation goes it is wholly exceptional in the Wisconsin mines. In other parts of the same mine the normal sag of the beds away from the pitches may be observed, and the true explanation lies possibly in the relations of the beds to other pitches, of which, as shown by Mr. Ellis's map, there are a great number in the mines.

The Kennedy mine, which is immediately south of the Hoskin, shows a well-developed system of pitches and flats with a general course of N. 20° W. These, as in the Hoskin, are converging rather than parallel, but their exact relations have not been so well worked out.

The general relations of these pitches to the structure of the region and to other pitches exposed at the surface is shown in Pl. X. This map is interesting chiefly as showing that there is no consistent relation between the pitching crevices and geologic structure. While the mines are located in a well-defined basin, the pitches strike at all angles and are neither parallel nor at right angles to its axis.

The ore in both mines occurs almost entirely in the pitches and flats, there being practically no true disseminated ore present. The rock between the main pitches has, however, been so crossed and recrossed by fracture planes that it is sufficiently mineralized to warrant milling and is often referred to as disseminated ore.

Both blende and galena are produced and marcasite and pyrite are abundant. Grant has made some interesting observations on the order of deposition of the minerals. His notes are summarized below:

The first flat in the Kennedy mine is some 60 feet above the oil rock and is near the water level. It contains a little smithsonite and much clay and limonite; marcasite is also very common. Below the water level the flats and pitches are seen in greater perfection and here the order of deposition is marcasite, blende, and galena. Thick masses of marcasite are seen along the bottom of some of the flats. Along the pitches are occasionally large cubes of galena, and this galena seems to be more abundant near the upper flat, where it is altering to lead carbonate. There are some stalactite-like masses in these flats, and in the upper flats the marcasite of these masses has commonly altered to limonite. One such mass which was fresh showed the following from within outward: First, a cavity of about one-half inch in diameter, then a layer of marcasite one-half inch thick; then a layer of blende one-quarter inch thick, and outside of this was a layer of marcasite 1 inch in thickness. Considerable of the marcasite in this mine is later than the blende, although the main part of this iron sulphide seems to have been the first mineral deposited. In a number of cases it is found that the order of crustification has changed several times from marcasite to blende.

The usual order of deposition in the Hoskin mine is marcasite, blende, galena, and calcite. It is estimated that at least three-fourths of the marcasite seen here is earlier than the blende. A common feature of this mine is the round, stalactite-shaped masses which are made up largely of blende. The common order in these stalactite masses is, in the center marcasite, next yellow blende, then dark, almost black blende in a thick layer, and finally a thin layer of yellow blende. Occasionally just outside of the thick layer of black blende is a thin layer of marcasite. The radiating nature of both the blende and the marcasite is very finely shown in most of these specimens. Not infrequently the core of these stalactites is of galena. In some cases these stalactite-like masses have the outer surface of marcasite, and it is not uncommon to find both of these side by side. The main part of the stalactite-like masses is of blende, with only a subordinate amount of marcasite.

The presence of a thin band of marcasite between the blende and the porous dolomite which forms the wall rock is common here as elsewhere in the district. The repeated banding of the iron sulphide and marcasite is, however, more common than usual. In one sheet two bands of blende with alternating layers of iron sulphide were well developed and coarse botryoidal layers of marcasite both above and below bands of blende are common.

Galena occurs both intimately intergrown with the blende and in well-developed crystals showing cubical and octahedral surfaces scattered over the normal blende sheets. Pyrite occurs in the same situation, and at the dumps on top of the hill a number of excellent specimens of clustered cubes were found developed over a sheet of brown blende which in turn rested upon radiating masses of marcasite. So far as observation goes the pyrite in this area is a recent, secondary mineral. The marcasite, on the other hand, is in part older than the blende.

In the Kennedy mine a number of specimens were obtained showing coatings of unaltered sulphides on walls of deeply oxidized dolomite, indicating that the oxidizing waters were reaching the mine through the wall rock rather than down the crevices. Both the Kennedy and Hoskin mines are well-equipped properties, with steam hoists, air drills, concentrating mills, roasters, and magnetic separators. The Mills mine when visited was just being reopened and had not been equipped.

Rowley mine.—The Rowley mine is located a short distance east of the Hoskin, at Buncombe, under the bottom land of Coon Branch. It is developed along an east-west range which, in the land immediately to the east, is said to have yielded considerable galena. The workings are in the beds just above the oil rock which shows in the mine sump. In fig. 20 the mine workings as developed in 1903 are shown from a map made by Mr. E. T. Hancock. The main crevice is followed by a long drift from which at the east crosscuts have been run out to the boundary pitches. A flat is developed in this part of the mine, and both roof and floor have a very perceptible sag toward the central crevice and away from the pitches. The ore is dominantly blende, though some galena is present. This is much more abundant at certain points where quartering crevices come in from the northeast. The bulk of the ore shows crustification in open spaces, but the lining of iron sulphide appears here to be commonly pyrite instead of marcasite. This is, so far as observation goes, very unusual.

The mine is located in a small structural basin at the foot of a long structural slope. It is equipped with a concentrating mill and roaster which run part of the time on custom work.

Ida and Blende mines.—These mines together work one of the largest sets of pitches seen in Wisconsin. The Ida covers all of the south pitch and the western portion of the north;

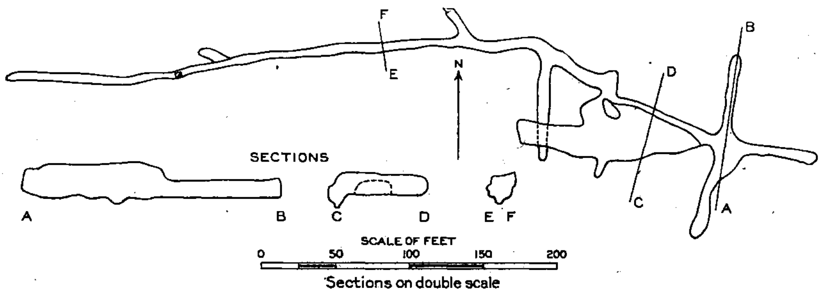

FIG. 20.—Plan and cross section of Rowley mine, Buncombe, Wis.

the Blende has the eastern portion. The mines are located about 1½ miles southeast of Benton, on a high tongue of land reaching out into a big bend of Fever River, at about 870 feet above sea level. They are near the east end of a small but well-defined structural basin and the workings extend from the oil rock upward for 70 feet. The range has a general east-west course parallel to the trend of the basin. On the north there are several parallel pitches, the major ones being about 30 feet apart. The south pitch is simple and remarkably well developed. Both pitches have a general dip of 45°, but in their descent to the oil rock are interrupted by flats. It is said that the pitches are as much as 200 feet apart at the horizon of the upper flat.

In the upper ground the ore now consists almost entirely of zinc carbonate, which occurs as sheets 6 to 24 inches thick in the pitches and to a subordinate extent in flats developed along bedding planes and making back into the core between the two pitches. In the zinc carbonate are crystals and patches of galena, and the wall rock is heavily stained with iron as well as much leached and oxidized. At lower levels corresponding bodies of blende are found with small crystals, and masses of galena intergrown and with the usual marcasite separating the blende from the wall rock. At a few points small masses of marcasite were found intergrown with the blende. At several places the bordering marcasite had disappeared and the wall rock was leached and oxidized. An unusual feature was the fact that the alteration of blende to carbonate had begun to occur from the center of the flats outward toward the walls of the cavity.

In the eastern portion of the mines iron sulphide is said to be more abundant, but it seems likely that its increase is relative rather than actual, the amount of blende and galena being less. The lower oil-rock horizon was not accessible when the property was visited. No serious attempt has been made to look for ore in the glass rock or at lower levels. A drill hole shows that under the clay bed water under artesian pressure is present.

These mines have been worked for a long period, the main production having been made in the last fifteen years. The ore is cobbed and hand jigged and the underground work is all done by hand. At present pillars in the upper ground are being robbed.

Empress mine.—In the Empress mine, located east of Shullsburg Branch, in sec. 13, the oil rock and beds immediately above are worked. The mine shows the flats and pitches in a simple and characteristic development. The ground plan of the mine is shown in fig. 21, from surveys by Mr. E. T. Hancock, with cross sections and crevices added. It is essentially a flat with the outward pitches developed along an east-west range. In the roof a vertical crevice, corresponding in direction to the major axis of the ore body, shows through much of the workings. There are, however, other crossing and quartering crevices which correspond to the crooks and turns of the workings. The vertical was formerly opened by shaft from the surface and is said to have produced considerable galena in ordinary openings above. The present workings are opened by tunnel and the ore shows comparatively little galena.

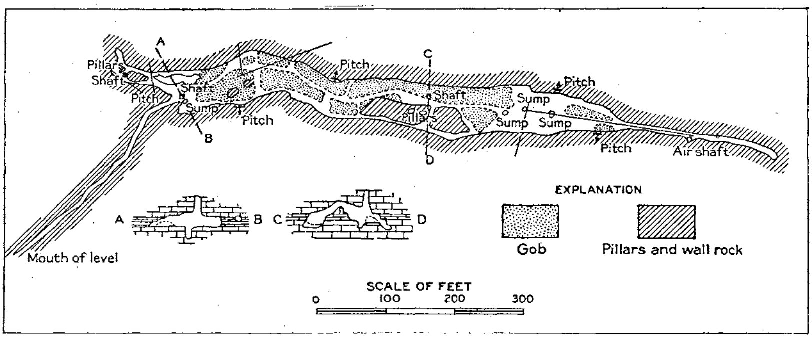

FIG. 21.—Ground plan and cross section of Empress mine, Benton, Wis.

A representative section of the north wall is given below:

Section in Empress mine.

	Inches.
9. Dolomite, earthy, brown; some finely disseminated iron sulphide and a very little blend	8
8. Main flat, generally regular in thickness and with very clean blende; the iron sulphide is apparently not much intergrown with the blende. Detailed measurements: Iron sulphide, $\frac{1}{2}$ inch; blende, $1\frac{1}{4}$ inches; calcite, 1 inch; blende, $1\frac{1}{4}$ inches; iron sulphide, $\frac{1}{2}$ inch	$4\frac{1}{2}$
7. Dark, earthy dolomite with some iron sulphide	$1\frac{1}{2}$
6. Dark, earthy, bituminous dolomite	12
5. Minor flat; an irregular open cavity with $\frac{1}{8}$-inch lining of bright, clear iron pyrites above and below, and a half-inch band of clean, brown blende on lower surface	$2\frac{1}{2}$
4. Black, earthy limestone in 2-inch bands, separated by $\frac{1}{4}$-inch streaks of iron sulphide with a very little blende and calcite	10
3. Limestone, similar to above, with flat open cavities lined with iron sulphide and blende	6
2. Dark-brown, bituminous limestone of oil-rock type, with disseminated blende, and one thin discontinuous chert band	14
1. Dark limestone, with a few irregular flats of iron sulphide	24

Below the workings the regular oil rock, clay bed, and glass rock are shown in the sump.

The mine represents the tendency of solutions traveling down along the verticals to spread out along the top of the impervious oil rock and clay bed. The ore body is notable for its relatively large horizontal dimensions—100 by 700 feet, as now developed—in proportion to its vertical extent.

The Empress mine has a mill equipped with crushing and sizing machinery and with Blake electrostatic separators. In 1904 a series of test runs was made and considerable high-grade ore was shipped.

Benton Star mine.—This shaft is located west of Shullsburg Branch, in the northern part of sec. 14. It was not running when visited, but the stock pile showed blende rather free from galena in small flats up to 3 inches thick. One such flat showed the following cross section:

Section of flat at Star mine.

	Inches.
7. Dolomite, gray with increasing impregnation of iron sulphide toward the flat	1
6 Iron sulphide, presumably marcasite	$\frac{1}{16}$
5. Blende, brown, free from galena and iron sulphide	$\frac{1}{2}$
4. Calcite	$\frac{1}{2}$
3. Blende, as above	$\frac{1}{2}$
2. Iron sulphide, as above, but with occasional color of copper	$\frac{1}{16}$–$\frac{1}{8}$
1. Dolomite, impregnated with iron sulphide as above	$\frac{1}{2}$

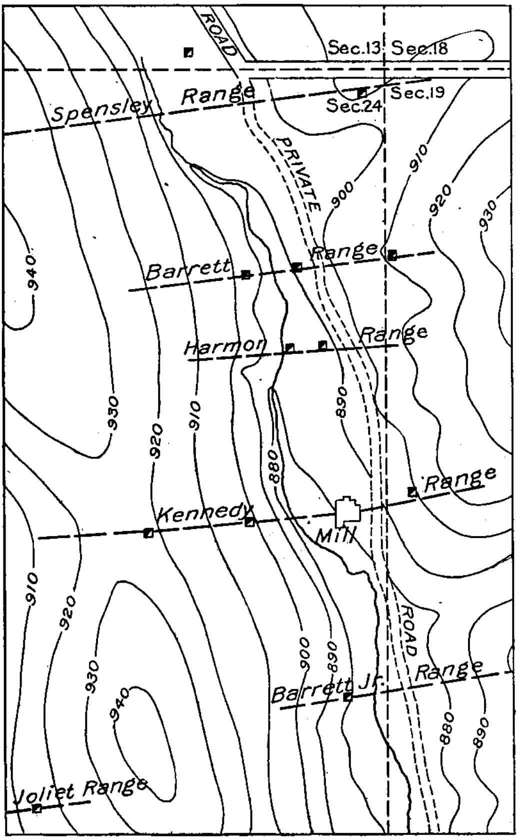

FIG. 22.—Crevices and old workings in the vicinity of the Hazel Green mine, Hazel Green, Wis.

The workings are evidently in the lower beds of the Galena formation. The ore is cleaned by hand jigs.

Hazel Green mine.—The Hazel Green mine is located in an area crossed by numerous crevices having a general east-west direction. The situation of the workings with reference to these ranges and topography is shown in fig. 22, redrawn from a map of the area made by Grant.[a] The mine is opened by shafts located on the old Kennedy range. The ground plan of the lower workings, with cross sections both east to west and north to south, is shown in fig. 23, from surveys made by Ellis. The principal workings are in the flint beds of the Galena at a depth of 63 feet. At this depth the vertical crevice gives way to a long, narrow opening with outward-pitching crevices on either side. About 20 feet above an ordinary opening along the crevice was formerly worked. It was 7 to 12 feet wide and was developed for an east-west length of approximately 300 feet. At the east end the ore extended upward in a chimney for 40 feet. These workings are not indicated in the figures.

In the main workings there is a well-marked vertical crevice in the roof, with pitching crevices at the side. Near the east shaft a couple of quartering crevices are present, and

[a] Bull. Wisconsin Geol. and Nat. Hist. Survey No. 14, 1906, p. 66.

along one of them an open cave lined with blende extends approximately 100 feet. The main workings are 12 to 40 feet wide and 8 to 50 feet high. In the sump at the west another opening may be seen about 6 feet below the present track.

All the workings described are below water level and are drained only by continuous pumping. The amount of water handled has been estimated at 800 gallons per minute.

The ore in the upper or "flint opening" was principally blende. Very little carbonate of zinc was present, and the concentrates were low in iron. The wall rock shows some oxidation, but the ore has been little affected. The ore found in the main workings is mainly "honeycomb" ore or "sprangle." It is illustrated in fig. 16 (p. 62), which represents typical honeycomb ore. The gray dolomite shows small, irregular cavities, which are almost always lined with marcasite. This seems to penetrate the dolomite slightly, becoming less and less abundant as distance from the cavity increases. The sheet of marcasite covering the surface of the cavity is 0.5 to 1 mm. thick. On it both galena and blende occur. In the smaller fractures and cavities the galena when present is apt to occupy the entire space and to show a uniform crystallographic orientation. Larger spaces show the free crystallo-

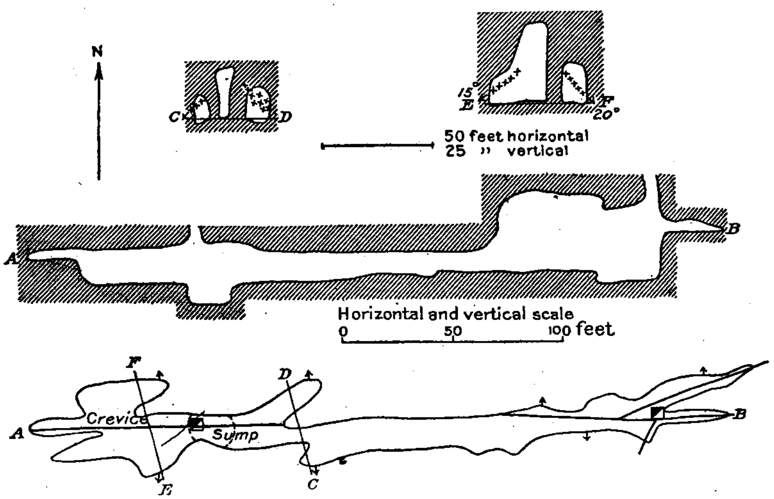

FIG. 23.—Ground plan and cross section of Hazel Green mine, Hazel Green, Wis.

graphic surfaces of the galena. Brown blende occurs in the same relations, but there is a notable tendency for each mineral to be segregated and to occupy different cavities or different portions of the same cavity rather than to be intergrown. This is not, however, an absolute rule. In some of the ore the fractures are so close spaced and the cavities form so large a portion of the mass that the ore seems to be a breccia of dolomite partially cemented by the sulphides. This ore is known as "sprangle" or "brangle."

The cave along the northeast quartering shows a nearly open space as much as 20 feet wide. When the water was first pumped out of this the walls and the blocks of fallen rock were crusted over with blende to a thickness of 3 inches. The blende also forms great warty masses attached to the wall by thin stems, as in the cave at the California mine in Illinois. Here, as usual, the thin layer of marcasite showed below, and a certain amount of galena was associated with the blende. Pyrite showing crystal form also occasionally coats the blende. The wall rock back of the ore is porous and in places shows distinct oxidation effects.

At the lowest level, the opening referred to as seen in the sump, honeycomb ore is shown, with both galena and blende present. The galena is notable from the fact that it occurs here in large, well-developed cubes, measuring as much as 2 inches on an edge.

The Hazel Green mine is well equipped with mill and roaster, and also uses an electric hoist at one of the shafts. It is an important and steady producer. The lower beds, reaching down to the oil rock, have not been explored. On neighboring ground to the south a number of the old lead diggings are being explored by sinking.

Within the district are a number of mines which were not working at the time the area was studied. Mr. Grant has kindly supplied the following notes on such of them as he visited:

Honest Bob mine.—This is situated in the SE. ¼ NE. ¼ sec. 25, T. 1 N., R. 1 W., just southeast of Hazel Green. It is owned by a Madison (Wis.) company, and in the summer of 1903 a large shaft was being sunk. The sinking went on during 1904, but the mine had not then become a producer.

Mermaid mine.—This mine, situated in the NW. ¼ SW. ¼ sec. 19, T. 1 N., R. 1 E., about a mile northeast of Hazel Green, is also owned by a Madison (Wis.) company. No mining was done here in 1903. In 1904 some little work was taken up, though soon discontinued. The mine is situated in the same valley as the Hazel Green mine and about one-half mile farther south. It is extremely wet, and from that fact takes its name, Mermaid.

Keystone.—This mine is variously known as the Beninger, Murphy, or Last Chance. It is situated in the center of the S. ½ sec. 19, T. 1 N., R. 1 E., about a mile east-northeast of Hazel Green. In 1903 some work was done here on an old east-west crevice, and in July, 1903, the shaft was down 93 feet, but was producing nothing.

Strawberry Blonde mine.—The ore here occurs in a flat, ranging in thickness from 1 to 5 feet, and is a typical honeycomb ore. The usual order of deposition in the cavities of this rock is marcasite, blende, calcite. A small amount of lead was noted. The ore body, which is now exposed in drifts, is 60 to 70 feet wide, and appears to run east-west. The connection of this ore body with other flats, or with crevices or pitches, is not evident. The mine is well situated and equipped, but has not been operated in recent years.

Coltman mine.—This mine is situated near the center of the S. ½ sec. 10, T. 1 N., R. 1 E., about 2 miles east of Benton. The concentrating mill was built here in 1903, but the mine has not produced much ore. Considerable dry bone and some sphalerite were mined here before the mill was erected.

Etna mine.—This is in the SE. ¼ SE. ¼ sec. 2, and NE. ¼ NE. ¼ sec. 11, T. 1 N., R. 1 E., about a mile north of Etna. The principal workings are about 40 feet from surface and a few feet below water level, along a "ten-o'clock" (N. 32° W.), and on flats and pitches in this range. There is another ten-o'clock about 48 feet northeast of the first, but this has been worked only along the vertical crevice. The ore is mostly in porous, soft, honeycomb rock, though there is a little in regular sheets.

A porous gray limestone bears galena, and below this is an intimate mixture of rock, galena, jack, and marcasite, commonly more or less in the honeycomb form. In places the galena is very intimately associated with the marcasite.

There are many small open spaces in the rock, and these usually show calcite crystals with rhombohedral habit. In one place where the marcasite is abundant there is said to be at times heat enough to cook eggs. Where marcasite is altering at this place are some white to colorless (or greenish) transparent radiating needle-like crystals, bitter tasting, which are probably iron sulphate.

Considerable disseminated ore is shown on the dump and is reported to occur in the form of a flat.

In the lowest part of the mine, about 40 feet from the surface, there are abundant flints. Here there is very little marcasite that is clearly later than the sphalerite, and very much that is clearly earlier. Occasionally, on weathering, the marcasite inside a layer of sphalerite shows a copper stain.

Sallie Waters.—This mine is near the northeast corner of sec. 23, T. 1 N., R. 1 E., near New Diggings. A concentrating mill was built here in 1903 to work on a series of flats and pitches from which in previous years a considerable amount of ore had been taken. The mine was worked to some extent in 1903, but did nothing in 1904. The mine is owned by the Consolidated Lead and Zinc Company, of Chicago.

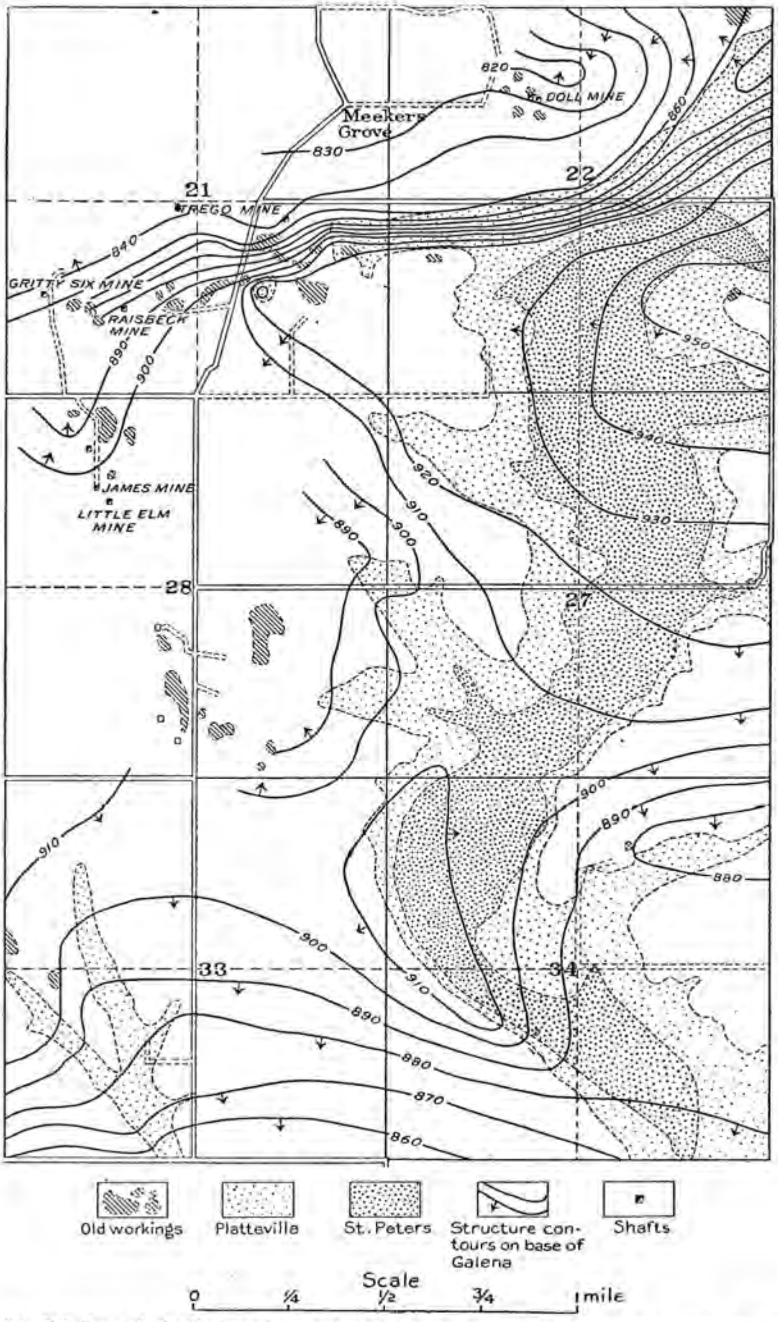

FIG. 24.—Relations of the Meekers Grove mines to geologic structure. (From Wisconsin Geol. and Nat. Hist. Survey.)

Jack of Clubs mine.—This is in the NE. ¼ sec. 17, T. 1 N., R. 1 E., about one-half mile southwest of Benton. It is also known as the Dawson mine. It was not worked in 1904. About 100 tons of blende were produced in 1903, although most of the efforts made in that year were devoted to sinking the shaft. The shaft is 130 feet deep, with the main level at 35 feet. A drill hole at the shaft is said to have shown 3 feet of oil rock at a depth of 141 feet, or at an altitude of 752 feet above sea level. From the bottom a drift runs southeast 80 feet. The work is along a steep pitch that runs N. 40° W. and pitches 40°–50° to the northeast.

The ore is in sheets (large open cavities along the pitch) and in rough honeycomb form. The rock for 2 to 6 feet either side of the pitch is exceedingly porous and carries blende and much marcasite. The latter mineral is very abundant here, but there is also considerable blende.

Coating many of the cavities are small calcite crystals (up to 1 inch across), and these rest on the jack or on the marcasite where the jack is absent.

In the upper part of the mine—about 25 feet above the bottom—is some coating of marcasite on the jack. This is the only place where this was observed. This marcasite (that is, the later marcasite) is older than the calcite.

MEEKERS GROVE DISTRICT.

General.—The Meekers Grove mines include the Doll, Trego, Raisbeck, Gritty Six, James, and Little Elm. When the district was visited only the first-named mine was working. Mr. Grant has, however, published certain notes on the Gritty Six, Raisbeck, and Trego, and Mr. F. H. Trego has courteously supplied maps and a section based upon drill records.

The general geology is shown in fig. 24, based upon the Meekers Grove sheet of the Wisconsin Survey.[a] The St. Peter sandstone and the Platteville formation outcrop in the valleys, while the Galena dolomite underlies tbe upland. The rocks rise from the south in a long, gentle swell, and then bend down sharply to the north. In the extreme northern portion of the area they begin to rise again. This is the best defined and most pronounced anticline so far observed in the entire region. The mines are located north of its crest, on the steep slope or in the synclinal basin beyond.

Trego, Raisbeck, and Gritty Six mines.—The section at the Gritty Six mine is given by Mr. Grant as follows:

Section at Gritty Six mine.

	Feet.
4. Blue limestone (Galena).	
3. Layers of yellow and blue limestone, with narrow bands of oil rock and some yellow sandy shale	4
2. Main oil rock	2
1. Blue shale and blue limestone, the shale being rather hard	2

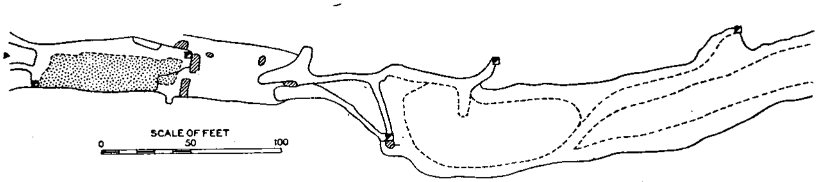

FIG. 25.—Map of a portion of the workings of the Trego mine, Meekers Grove, Wis.

Fig. 25 shows a portion of the workings in the Trego mine. These are at an average depth of 75 feet below the surface and show a long, narrow run of ore paralleling the anticline. Fig. 26 is a cross section from north to south, based upon drill records and showing an increase in the thickness of the oil rock to the north, which corresponds to a thickening toward the deeper part of the basin.

[a] Grant, U. S., Hancock, E. T., Ellis, E. E., Perdue, M. J., and Crider, A. F., Meekers Grove sheet: Bull. Wisconsin Geol. and Nat. Hist. Survey No. 14, 1906, pl. 16.

Mr. Grant's notes on these mines are as follows:

These three mines are probably on the same line of crevice, which runs approximately east and west, and the workings are along flats and pitches. At the Trego mine the common order of deposition is (1) marcasite, (2) blende. At the Raisbeck there is a noticeable amount of barite, and in cases this is clearly seen to be later than the galena.

At the Gritty Six mine the usual order of deposition is marcasite, blende, and then calcite. In fact, at some points in this mine there are very fine masses and crystals of calcite. Another order is marcasite, blende, cavity, and then much marcasite on the lower side of the cavity, especially in radiating, concentric arrangement. Occasionally the order is marcasite, blende, cubes of galena. Calcite occurs in places on the galena, and near the oil rock is some barite, which in places is seen to be later than the calcite. The usual order then is (1) marcasite, (2) blende, (3) galena, (4) calcite, (5) barite. In some cases a later coating of marcasite is seen on the galena, but whether this coating is ever earlier than the calcite and barite is not evident. The mine is about 90 feet deep and goes down to the oil rock. In the oil rock are a few scattered cubes of galena. Small flats are also seen in the upper part of this oil rock. A short distance southwest of the main shaft the rock is much broken, and it seems as if the flats were pitching down through the oil rock, but this point was not determined definitely. The rocks at this mine dip irregularly, but in general there is a dip from 5° to 10° toward the north-northeast.

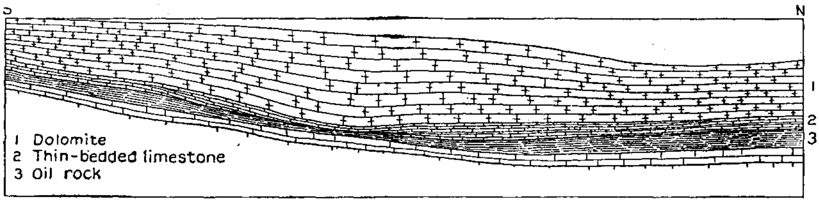

FIG. 26.—Cross section from north to south, based on drilling near Trego mine, Meekers Grove Wis.

Doll mine.—The Doll mine is located in a pronounced syncline to the north of the main anticline. It is unusual in that there were no old workings to guide exploration, and the ore body was found entirely by drilling. The workings are in the Galena 20 to 40 feet above the oil rock and are along and near a big south pitch (fig. 27). This has a general course N. 30° W. and pitches 45° from the horizontal In the mine ore has been developed along a distance of approximately 300 feet, and drill holes indicate its continuation to a total of at least 900 feet. The main or upper flat is exposed about 25 feet wide through most of the workings, but is reported to show workable ore for a total width of 70 feet in places. In its roof are some small vertical crevices, but no particles, and in a crosscut to the north there are several south pitches. Neither in the underground workings nor in the drill holes was a north pitch found, though to the northeast some drillings show ore which may represent it. The main pitch is not a straight line, but a line that curves to the north, both to the west and to the east of the shaft. As developed in 1905 it represented a portion of a long, gently curved fracture plane. In blasting it is found that there are minor pitches not containing ore but sufficiently developed to control the breaking of the rock. These strike at an angle with the main pitch, but dip outward from the shaft as it does. A short distance east a similar pitch has been followed down to the oil rock in a prospecting shaft.

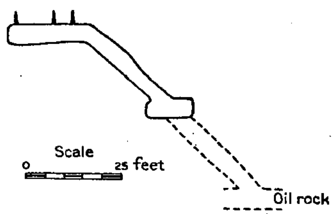

FIG 27.—Cross section of workings in Doll mine, Meekers Grove, Wis.

The ore consists mainly of blende, but with the usual amount of iron sulphide and irregular amounts of galena. The top flat shows more galena than below, and there is also some evidence of oxidation there. It is evidently slightly below the normal water level. When galena is found in the pitch it is intimately intergrown with the blende. There has been some post-mineral fracturing and cementation, as is shown by the presence of brecciated blende in a matrix of marcasite. The upper flat is usually workable for a thickness of 5 to 6 feet. At its top is a sheet of blende 6 to 8 inches thick, as sketched in fig. 28. Below, the sandy dolomite is cut by irregular fractures, cemented by blende and iron sulphide. Along this flat there are small local dips due to irregularities in original deposition, as shown by the thickening and thinning of individual beds of dolomite.

The pitch is usually workable with a breast 4 to 5 feet wide, but the main sheet is a streak of nearly clean blende, usually about a foot thick, and clinging to the hanging wall. At the place where the upper flat and the pitch join, as much as 2 feet of clear blende occurs. How extensively the foot wall is mineralized can not yet be stated, as it has only been crosscut at one point. Along the upper flat, as already indicated, the present workings extend back for 25 feet and the ore is known to go somewhat farther.

The mine is opened by the shafts and is well equipped with steam hoists, pumps, concentrating mill, roaster, etc. An excellent grade of ore, running 57 to 60 per cent zinc, is produced.

SHULLSBURG DISTRICT.

General.—As already stated, the Shullsburg mines are among the oldest in the region, active mining having been begun here under military protection in 1819. The district was noteworthy in later years for the fact that it was the scene of the first commercial success in dressing the mixed sulphide. It was here that, ten years in advance of similar work elsewhere in the region, W. P. Blake[a] successfully roasted and cleaned the ores.

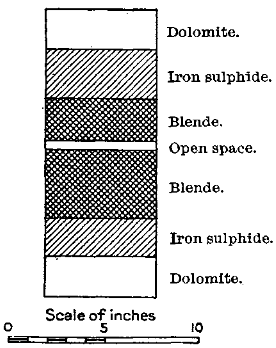

FIG. 28.—Characteristic section of flat in Doll mine, Meekers Grove, Wis.

The general geology of the area is shown on the Shullsburg sheet of the Wisconsin Survey.[b] The most prominent structural feature is a monoclinal dip to the southwest, interrupted by a flat, carrying a small sag. (See fig. 4, p. 36.)

The Little Giant and Helena mines are the two best known properties in the district, and were the scene of Blake's work. The Helena was not working when the region was visited. Mr. Grant's notes on the Little Giant mine are given below.

Little Giant mine.—This is situated at the extensive open-pit excavation made some years ago by the Wisconsin Lead and Zinc Company. From the north side of this excavation the present Little Giant mine has a tunnel running into the hill for about 250 feet. Here ore occurs in flats and pitches, the pitches dipping toward the north. There is marcasite and a little barite in this tunnel.

Near the south side of the old open workings the Little Giant mine has sunk a shaft through the oil rock. This is about 30 feet in depth and shows the following section:

Section at Little Giant mine.

	Ft.	in.
6. Yellow decayed limestone	1	
5. Soft, sandy material, oil rock and soft yellow sandy clay confused with the oil rock mainly in the lower half	3	6
4. Blue shale	2	
3. Blue shale with thin layers of oil rock	1	
2. Very hard, compact, fine-grained limestone, resembling, but coarser than, the typical glass rock	6	
1. Same as the last, but holding small flats and fractures which are filled with ore	7	

The shaft is said to have been sunk 22 feet farther through the same kind of rock, and in this rock is said to have existed similar flats and crevices filled with ore. At the present time these

[a] Trans. Am. Inst. Min. Eng., vol. 22, 1893, pp. 569–574.
[b] Grant, U. S., Hancock, E. T., Ellis, E. E., Perdue, M. J., and Crider, A. F., Shullsburg sheet: Bull. Wisconsin Geol. and Nat. Hist. Survey No. 14, 1906, pl. 14.

lower workings are hidden from view on account of water, as they are below the level of the creek at this point. The general order of deposition of the ore at this point is marcasite and then blende. The rock at this place which lies below the oil rock is a hard, brittle, fine-grained limestone, and it has been fractured through and through, the fractures being filled by deposition of metallic sulphides. It is reported that a short distance from this place the pitches had been traced actually down through the oil rock and the clay which lies below it and into this brittle, hard limestone, which corresponds in general to the glass rock farther west.

Hardy and Lucky Hit mines.—Half to three-quarters of a mile north of the Little Giant are the Hardy and Lucky Hit mines, which have been recently developed. Both are well-equipped properties. The Hardy mine is about 80 feet deep, and is working in beds about the base of the flints.

The Lucky Hit mine is working on pitches and flats above the oil rock but near the base of the Galena. The range runs N. 70° W., and the ore carries galena, blende, and marcasite. The latter is so abundant as to necessitate roasting and magnetic concentration.

PLATTEVILLE DISTRICT.

General.—Platteville is one of the best known towns in the region, and is the center of a great deal of mining activity. Some of the first and most successful mines in the region are located within the town limits, while a few miles west of the town and beyond Little Platte River there are two subordinate centers of mining in sections 12 and 18. The general geology and topography of the district is shown in Pl. XI, reduced from the special map made by the Wisconsin Survey.[a] The section exposed in the city quarry, which is typical for the Platteville formation, has already been given. The most significant structural features of the district are an east-west basin under Platteville and a subordinate basin to the southwest. The mines are within these basins.

As is true of the region in general, early mining here was for lead ores and was confined almost entirely to the crevices and openings. With the revival of interest in recent years the pitches and flats below have come into great prominence. Honeycomb ore also has been mined, and along Little Platte River there are some of the most extensive and typical deposits of disseminated ore found in the entire region. The various mines working at the time the area was surveyed are located upon the map, but only a few of the typical will be described.

Enterprise mine.—The Enterprise was the first of the new mines to become largely profitable, and its success has greatly stimulated the development of the district. At the beginning of 1905, after two and one-half years' operations, the mine had a record of $40,000 paid in dividends on a capitalization of $20,000. In addition, a plant costing $32,000 had been paid for and approximately $18,000 had been paid in royalties. The proceeds of sales of ore had amounted to about $180,000, derived from the sale of something over 7,000 tons of blende and 600 tons of galena. In 1905 dividends were paid at the rate of $5,000 a month.

The main shaft is at 960 feet above sea level, and the oil rock occurs at about 830 feet. The principal mining is done in the 40 feet of rock above the oil rock, though higher ore horizons are known. The shaft is sunk on a vertical east-west crevice, originally worked for lead ore. At a depth of 40 feet one of the ordinary openings was found, carrying galena and zinc carbonate. At about 90 feet is a flat of honeycomb ore and immediately below are the big pitches and flats from which most of the ore has come.

The general course of the deposit is slightly north of east, and accordingly at an angle with the course of the structural basin in which it lies. The main work is on a south pitch. In the upper workings east pitches and west pitches have been found, but the north pitches have been developed only in the extreme western portion of the mine. Here, as is shown in

[a] Grant, U. S., Burchard, E. F., Hancock, E. T., Ellis, E. E., and Perdue, M. J., Platteville sheet: Bull. Wisconsin Geol. and Nat. Hist. Survey No. 14, 1906, pl. 10.

fig. 29, from a sketch made in the mine, the south pitch circles around and becomes the north pitch, completely closing in the workings at this level. Farther east only the south pitch has been developed. A cross section of this, drawn to scale, is shown in the figure, together with two cross sections of the mine workings corresponding to the lines C–D and E–F on the ground plan. The cross section E–F is narrower and at a higher level than C–D, so that the big flat down to which the pitches come rises to the west. Indeed, it rises slightly toward the periphery in all directions, and in form resembles the end of a great shallow spoon. Both the roof and the floor sag about 1 foot in 50 toward the center. The oil-rock flat is extensive, especially in the eastern end of the property.

The oil rock proper is a brown, petroliferous shale about 1 foot thick. Below it for at least 4 feet the limestone is fine grained, chocolate-brown in color, and divided by thin, shaly partings. Both lead and zinc ore occurs in the oil rock in disseminated form, and the galena in particular is characteristically sharp angled and idiomorphic. This seems best explained by supposing that such galena represents metasomatic replacement. There are also thin bands or nodules of limestone, apparently magnesian, and these frequently show a considerable amount of iron sulphide.

The ore occurs most commonly in flats and pitching joints. The blende is in sheets from a quarter of an inch to a foot thick. It is usually free from admixture of other sulphides,

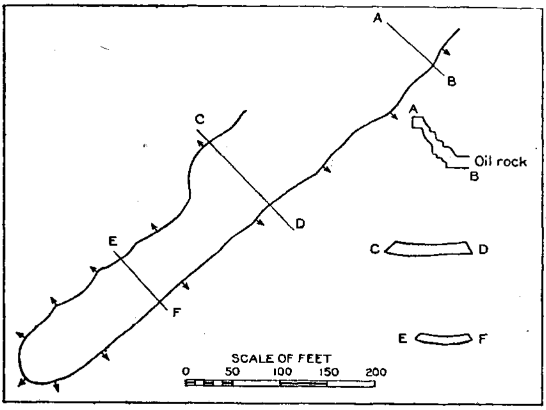

FIG. 29.—Sketch of a portion of the Enterprise workings at Platteville, Wis., showing ground plan, cross sections, and pitches.

but in places small masses of galena and marcasite are present. Usually the marcasite forms a very thin sheet lining the cavities. On top of it is the brown blende, which either completely fills the space or forms a thick coating over the marcasite. Calcite is occasionally found on top the blende. The whole mode of occurrence is characteristic of crystallization in open spaces, and there is very little, if any, metasomatic replacement. It frequently happens that within a fraction of an inch of the thick sheets of blende the wall rock shows numerous open spaces, due to the leaching out of fossils or to shrinkage during dolomitization, and these are quite free from either sulphides or calcite. In the sheets of blende there are often sharp-angled little fragments of dolomite, broken from the wall rock, reenforcing the conclusion that the crystallization was in open spaces.

In the lowest portion of the mine Mr. Grant found some barite within which were crystals of both blende and galena. This mineral is not, however, common either here or elsewhere in the region.

The mine is well equipped with steam hoist, air drills, concentrating mill, and roaster. The latter has only recently been added, since at first the concentrates were of sufficiently high grade to be salable without roasting. It is now economical to handle the lower-grade material, even with the more expensive treatment. Before the change was made in methods

Mr. Benjamin Hodge conducted a three-day test of the plant, which showed the mill dirt to run 17 per cent zinc and the saving to be 86 per cent.[a] The manager of the mine, Mr. J. W. Murphy, has conducted an interesting series of experiments, which suggest the possibility of using some of the oil rock for fuel in roasting the ore. The tests are as yet incomplete.

Empire mine.—The Empire is a short distance northeast of the Enterprise and presumably on the same range. It is a newer mine, but began milling with a larger plant and has paid dividends faster. The capitalization of the company is $30,000 and the total expense before ore sales began was about $35,000. Up to June 1, 1905, the ore sales had amounted to approximately $156,000, out of which $70,000 had been paid in dividends after meeting expenses of mining, up-keep of plant, and royalties, and accumulating a surplus of $6,000.

The ground plan of the mine and a cross section are shown in fig. 30 from surveys made for the company by Mr. Benjamin Hodge. The work is mainly on a great south pitch, one of the best developed in the district, with flats at various levels from the base of the flints and the lower Receptaculites zone to the oil rock. Specimens of *Receptaculites* are abundant along the upper flat and help to fix its stratigraphic position.

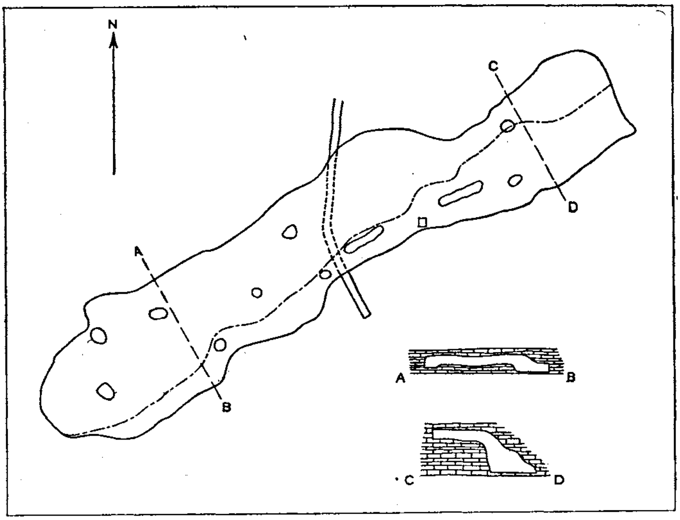

FIG. 30.—Ground plan and cross sections of the Empire mine at Platteville, Wis. (From surveys by Benjamin Hodge.)

The main pitch varies a little in its course, as is shown on the map. There are several parallel pitches, and a number of vertical crevices may be seen in the roof of the upper flat. The north pitch has not so far been located, though in the long cross drift on the lower level there are, well to the north, a few tight crevices which have a northerly pitch. It is known that in this direction there is at least one large vertical crevice, but the exact relations of the ore body to it are unknown, since no drilling has been done.

The oil rock is well exposed in the lower workings and shows about the same thickness and character as in the Enterprise mine. The pitch itself carries usually a sheet of ore 6 inches to 12 inches thick. At the bend where a flat joins the pitch the ore thickens occasionally to 18 inches of nearly clean blende. The mineralization extends inward from the pitch 20 to 25 feet in the form of small flats.

In the eastern part of the mine and at the horizon of the big upper flat there is an area within which the roof shows striations indicating a slight horizontal movement. These

[a]Hodge, B., Notes on a mill test: Min. Mag. vol. 13, June, 1906, pp. 480–483.

striations are molded upon the sheet of ore lying next to them, but with a less degree of perfection and with rough surfaces. Since there is, as usual, a very thin sheet of marcasite between the blende and the rock, and since this is not smoothed and polished, it is believed that the movement took place before the ore was formed and that the sulphides merely present a cast of the striated surface. Drag phenomena indicate that the lower beds move to the north with reference to the upper, and while the area affected is measured in feet the total movement was evidently only an inch or less. The wall near by shows no evidence of horizontal displacement.

While a small amount of blende occurs in forms suggestive of metasomatic replacement, the common occurrence indicates crystallization in open space. Very little iron sulphide is present in the blende, though the usual thin outer crust of marcasite, a millimeter or so thick, is nearly everywhere present. Galena is irregularly distributed, being in places abundant and elsewhere entirely absent at the same horizon. Calcite fills narrow seams or is freely crystallized in open spaces.

The main upper flat is ordinarily worked with a breast 6 feet high. At its top is a solid sheet of blende 6 to 12 inches thick, with the usual marcasite casing. This sheet is thickest near the outer pitch and thins away from it. Below it are thinner sheets joined by reticulating crevices so abundant that the average mill dirt from this horizon is said to run 17 to 18 per cent in zinc.

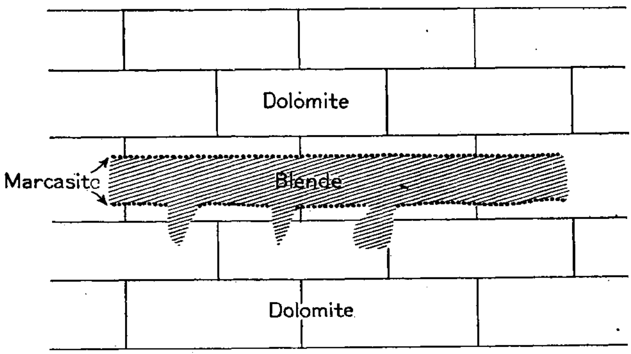

FIG. 31.—Sketch of a small sheet of blende in the Empire mine, showing extensions into the dolomite below.

The surfaces of the rock above and below the sheet of ore show slight irregularities. These are, however, subdued and similar to those seen in an ordinary limestone quarry along bedding planes. They do not show the pitted cup-shaped cavities and sharp edges which are characteristic of solution surfaces on limestone. When the sheets of blende are thin enough to allow the comparison to be made, the irregularities above and below fit together or mesh. If the blende could be taken out and the lower rock lifted, the two would fit snugly together. These facts, together with the evidence of crustification already given, are interpreted as meaning that the ore formed in an open cavity and that this cavity was not the direct result of solution of the dolomite by underground water moving along bedding planes, but was caused by the settling down of the lower layers, so as to leave a free space. This interpretation is reenforced by the fact that the mode of occurrence of the ore is the same in these flat sheets as in the pitches and minor open crevices, which are certainly the direct result of fracturing. There is, further, the suggestive fact that in certain places where the blende reaches down into the lower layer of dolomite in irregular processes, as shown in fig. 31, the customary layer of marcasite is absent, except between the processes. The blende apparently in these prolongations replaced the dolomite metasomatically, and the absence of the usual crustification is considered extremely significant. Where, on the bend from flat to pitch, the ore body is so greatly thickened, it is possible that somewhat the same explanation applies, though in places where there is the usual crustification it seems more probable that solution had somewhat enlarged the space before deposition occurred. It is obvious that, the angle of dolomite at such place being exposed to attack on two sides, solution would be unusually effective.

The mine is excellently equipped with pumps, power hoists, drills, electric lights, and a large well-arranged concentrating mill.

Other Platteville mines.—The Trego and the Great Northern are two well-equipped mines immediately north of Platteville, working a well-developed set of pitches and flats. Other mines in or near town are the Hiberina, Lucky Four, Highland Park, and Eclipse.

Little Platte mines.—About 3 miles west of Platteville, on Little Platte River, there is a group of mines working on disseminated ore. They include the Graham and Stevens, the Capitola, and the Dugdale. A mile farther west, on Whig Branch, is the Tippecanoe mine, where the mode of occurrence is similar. The ores are all found in the oil rock at the base of the Galena dolomite, and all of the mines are within a broad shallow structural basin, which seemingly has a slight pitch to the east. The three mines first named are a little east of the center of this basin.

Mr. Grant measured the following sections at the Graham and Stevens, Capitola, and Tippecanoe mines:

Section at the Graham and Stevens mine.

	Ft.	in.
11. Yellow-gray limestone, typical Galena dolomite	10	0
10. Blue shale, not seen, but reported by the miners	1	6
9. Yellow-gray limestone, similar to No. 11, above	8	0
8. Thin beds of blue limestone, separated by narrow bands of oil rock. Frequently this blue limestone is turning brown along the cracks and edges of the bands. This is the chief ore horizon, the blende and galena being disseminated through these blue limestone bands	4	0
7. Oil rock mixed with sandy shale and some thin bands of blue limestone, which carries ore in the same manner as No. 8	0	8
6. Main oil rock, containing ore also	1	6
5. Blue shale	1	6
4. Oil rock	0	3
3. A soft yellow to white clay, called "pipe clay"	1	0
2. Black carbonaceous shale or slate	0	2
1. Buff limestone	1	0

Section at the Tippecanoe mine.

	Ft.	in.
5. Thin beds of blue limestone and narrow beds of oil rock. This is the ore horizon	5	0
4. Main oil rock	1	0
3. Blue shale. In places some of this is closely like the oil rock, and at the bottom there is a fairly continuous layer of blue to gray-yellow soft clay	4	0
2. Black carbonaceous shale or slate		2
1. Hard blue limestone	3	0

Section at the Capitola mine.

	Feet.
4. Ordinary buff Galena dolomite	3
3. Thin beds of limestone, some of which look much like typical glass rock, separated by thin bands of oil rock	5
2. Main oil rock	1
1. Blue shale	1

It will be observed that there is a black shale present below the main oil-rock and ore-bearing horizon. Yet it is believed that the clay bed found beneath the ore represents the best datum line for dividing the Galena from the Platteville. At the Tippecanoe mine the sequence is normal down to and including the glass rock, but along the neighboring stream characteristic dolomite of the Galena continues downward to the thin beds of the Platteville usually found below the glass rock. Whether this is properly to be interpreted as an unconformity or is evidence rather of dolomitization affecting lower beds than usual, can not be decided at present.

The ore found in these mines is in the main blende. Very little galena is present, and iron sulphide is much less abundant here than elsewhere. All three minerals, however, occur. The blende occurs in idiomorphic crystals and crystalline masses from a sixteenth to a half inch in diameter, both in the oil rock proper and in the dolomite lenses and nodules, which are interleaved with the shaly material. In the brittle limestone beds the ore fills distinct fracture planes and evidently represents crystallization in open spaces. The ore in the oil rock seems to represent growth in place by metasomatic replacement and shows a distinct tendency to seek out the lenses and stringers of dolomite in the shale.

The ore occurs in flat sheets or runs, 2 to 4 feet high. These follow the course of narrow crevices in the roof, the mineralization extending along the top of the clay bed 6 to 20 feet on either side of the crevices. The latter are generally east-west in course, and some have been worked above for lead. The clay floor rolls slightly, as under a coal bed, but its irregularities do not seem to condition the mineralization. The whole of the evidence favors the view that the ores originated by simple downward concentration acting against an impervious bed of clay.

Mr. Grant's description of the Graham and Stevens mine is given below:

> This mine is a typical one of the class of disseminated deposits. The section has already been given. While the work has not developed far enough to show the form and the size of the ore deposit, it appears that the main ore is running in a general east-west direction, or, more strictly, probably a little south of east. The ore is mainly the disseminated sphalerite, but there is some galena, and this is especially the case near the crossing of two crevices in the mine, at which location galena is very abundant and seems to replace the sphalerite at least in part. The thin band of blue limestone found above the oil rock is the main ore horizon. Along the cracks and bedding planes of this limestone there has frequently been considerable oxidation. By this oxidation some of the marcasite may have been altered, so that its presence is not easily recognized. At the same time there is considerable of this rock which seems to be fresh and unoxidized, and in this marcasite is very rare, although there are occasionally small amounts of it. The practical absence of marcasite from these disseminated deposits has already been commented upon.

The mines are all opened by adits. The Graham and Stevens has a concentrating mill; the others clean their ore by hand or in the Graham and Stevens mill on a custom basis. The ores are soft and very easily cleaned. In general, approximately 8 to 16 tons of concentrates are produced from 100 tons of mill dirt. The extent of the flats is entirely unknown.

MIFFLIN DISTRICT.

General.—The geology and topography of the Mifflin area are shown in Pl. XII, reduced from the special map made by the State survey.[a] Its striking feature is the presence of two long, narrow basins pitching slightly to the east. The Mifflin mines proper, the Penitentiary and Gruno, are located in the lowest part of one of these basins. A second group, sometimes spoken of as the Livingston mines, is found in the other basin on its long western gentle slope. The area illustrates, perhaps better than any other in the region, the location of deposits in gently pitching structural troughs, and it is significant that the mines are among the most productive in southwestern Wisconsin.

Penitentiary range.—The Penitentiary range is stated by Strong[b] to have been opened in 1842. Up to 1877 it had yielded about 1,500 tons of galena and 12,000 tons of blende. The production since that date is unknown but large. The range is spoken of as 300 feet wide and the thickness of the deposit as varying from 6 inches to 2 feet. Chamberlin[c] figured a cross section of the range as typical of the occurrence of flats and pitches except in the relative unimportance of the pitches. He also figured the occurrence of the disseminated blende, or "speckled jack," in the oil-rock beds. The mine was opened by a level and the deposit was followed several hundred feet in a generally northwest direction, which would be diagonally down the structural slope.

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[a] Grant, U. S., Perdue, M. J., Fulcher, G. S., Cox, G. H., Bannister, J. R., and Cady, G. H., Mifflin sheet: Bull. Wisconsin Geol. and Nat. Hist. Survey No. 14, 1906, pl. 3.
[b] Geology of Wisconsin, vol. 2, 1877, p. 721.
[c] Ibid., vol. 4, 1882, pp. 473–475.

Gruno mine.—The Gruno, located a short distance north and west of the old Penitentiary range, was the most important mine near Mifflin that was accessible when the area was studied. It is located on a topographic slope, the main shaft being at 1,011 feet above sea level. The deposit is in the deepest part of the structural basin and has a general course N. 18° W., extending diagonally across the basin. Both east-west and north-south crevices may be observed in the mine, but the zone of mineralization follows a diagonal direction. The ground plan of the workings is shown in fig. 32, from a sketch map prepared by Mr. Ellis. Between 200 and 300 feet east of the present workings is an old range similar in many particulars to the deposit now working.

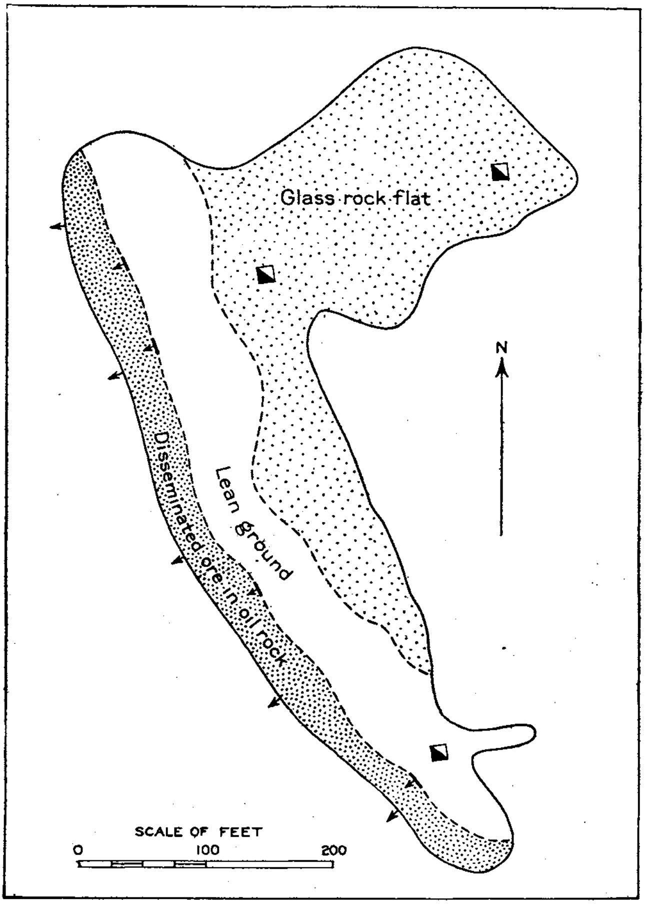


FIG. 32.—Sketch map of the Gruno workings near Mifflin, Wis.

In the Gruno mine three separate flats connected by pitching and vertical crevices are worked. The highest is a small sheet above the oil rock, generally worked in connection with the glass-rock flat. The area over which this upper flat has proved productive is not indicated on the map, but in a general way coincides with that of the glass-rock flat. The middle opening is in the oil rock, and it does not seem to be productive in the area of the other flats. It is worked over a long, narrow strip paralleling the other flat and lying west of the glass-rock workings and at a slightly higher level. Between the two is a long, narrow stretch of relatively lean ground.

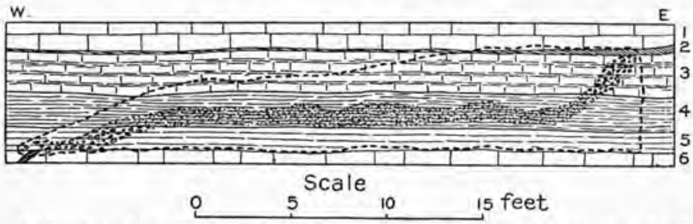
The disseminated ore in the oil rock is connected with the top flat by a pitch to the west and with the glass-rock horizon by a second pitch in the same direction. The latter does not seem to lead to good ore at the glass-rock horizon, so that the main glass-rock flat is east of the pitches, and if the complete set is present there should be a bounding set of pitches to the east. It may be noted, however, that here, as in the Penitentiary range, the pitches seem to be relatively unimportant and the whole vertical range of the deposits slight.

A general section of the beds seen in the mine would be as follows:

General section in Gruno mine.

	Ft.	in.
9. Dolomite, normal, sandy textured.		
8. Blende, upper flat		2-5
7. Limestone, fine-grained, in thin beds separated by bituminous partings	1-2	
6. Oil rock; bituminous, calcareous shale	1-2	
5. Blue clay		8
4. Glass rock; hard, chocolate-colored limestone	5	
3. Shale, dark-brown, hard		4
2. Clay, brown to red		3
1. Dolomite		

The top flat is a sheet of blende varying from 2 to 5 inches in thickness. Its position is shown in fig. 33, which also shows the disseminated ore in the oil rock. The top flat is the



1. Limestone above oil rock. Galena dolomite.
2. Two-inch sheet of blende.
3. Upper phase of oil rock. Thin beds of hard, fine-grained limestone with partings of carbonaceous shale.
4. Typical carbonaceous oil rock.
5. Blue clay.
6. Glass rock.

FIG. 33.—Typical section across breast in oil-rock opening, Gruno mine.

least important in the mine, though it has been worked the most, owing to its presence above water level.

The oil rock has two phases in this mine, the lower one consisting of from 1 to 2 feet of dark-brown carbonaceous shale and the upper one of the same thickness of 1 to 2 inch bands of hard limestone of glass-rock texture, alternating with thin layers of typical carbonaceous oil rock. In the oil rock is a flat 25 feet in width, having a pitch coming down from a sheet on the east side and passing into a second pitch dipping into the clay bed and limestone below on the west side. Where the ore pitches through the upper phase of the oil rock it occurs as thinly disseminated blende in large crystals, but as it passes into the carbonaceous shale it forms a flat, 1 to 1½ feet in thickness, of very thickly disseminated ore in small crystals from 1 to 4 mm. in diameter. On the west side, as the ore again pitches and passes into the clay bed below, it forms loose rounded aggregates of crystals varying in diameter from one-fourth inch to 1 inch, called locally "strawberry jack." The ore then forms a pitching sheet in the glass rock, but has not been found to lead to any important ore bodies below. All of the disseminated ore is entirely free from marcasite and is milling ore of exceptionally high grade.

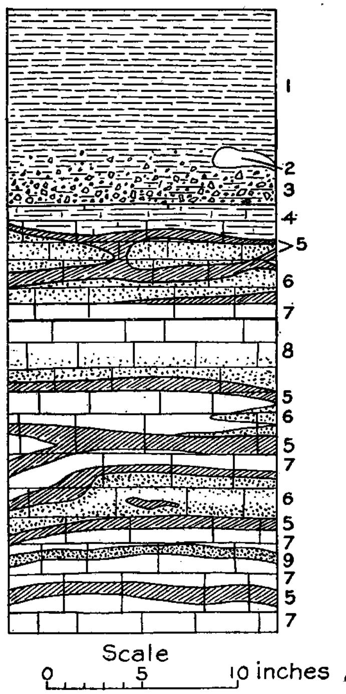
The glass rock consists of from 3 to 5 feet of bands of crystalline limestone and dolomite and is separated from the oil rock above by an unusually heavy and uniform bed of clay 8 to 10 inches thick, while the bottom of the glass rock is marked by a bed of hard dark-brown carbonaceous shale. Below this shale lie 2 to 4 inches of brown clay, oxidized in places to a bright-red color. The ore occupies a horizon 2 to 4 feet thick in the middle portion of the glass rock and occurs mainly in sheets one-fourth inch to 2 inches in thickness along the bedding planes, although many irregular seams of blende traverse the rock layers between the horizontal sheets (fig. 34). In some places, however, the rock manifestly has been shattered and the blende occurs as a cement in a breccia of sharply angular marcasite; but there is frequently in the rock next to the blende a zone impregnated with the iron sulphide to a thickness of one-half inch.

A notable feature of the ores of this mine is the very small amount of galena and iron sulphides present. The blende is so clean that simple concentration produces a merchantable ore and no roaster is necessary.

The glass-rock and oil-rock flats are now below water level and are kept free only by pumping.

The main water channels in the lower horizons evidently have been along the shale beds below and above the glass rock. There is a very general oxidized area immediately below the lower shale bed, and in some places there is a red oxidized zone, as much as 6 inches in thickness, directly below the upper shale bed, although an oxidized zone is more general just above this bed.

The plant consists of a 40-ton concentrating mill, which is equipped with the customary jigs and also with a concentrating table capable of separating 500 to 600 pounds of finely ground blende and galena or sludge daily. In 1904 this mill was turning out an average of 25 tons of concentrates a week with a zinc content of about 55 per cent.



1. Soft, light-gray shale.
2. Oxidized chert.
3. Disseminated ore in base of shale.
4. Dark-brown carbonaceous band; shaly.
5. Blende mingled with marcasite.
6. Gray, fine-grained limestone impregnated with FeS_2.
7. Hard, chocolate-colored, fine-grained limestone.
8. Brown, coarsely crystalline dolomite.
9. Band heavily impregnated with marcasite.

Dotted portions represent marcasite impregnating rock.

FIG. 34.—Section of breast in glass-rock opening, Gruno mine.

Ellsworth mine.—The Ellsworth mine, or Coker mine, as it is sometimes called, forms one of the western group of Mifflin mines. It is located pretty well down on both structural and topographic slopes. The top of the shaft is at 1,059 feet above sea level, while the oil rock lies between 970 and 980. Mr. Grant measured the following section in the mine:

Section at the Ellsworth mine.

	Ft.	in.
5. Hard, gray Galena dolomite.		
4. Thin layers of fossiliferous limestone with narrow partings of oil rock. This limestone is in places very similar to the typical glass rock	7	
3. Oil rock, locally called "liner"	1	6
2. Blue clay		2
1. Hard blue limestone.		

The glass rock is reported to be only 18 inches thick and to rise up to the level of the oil rock on either side of the flat now worked. Drill holes through it show the presence of water below, under artesian pressure believed to be local. In fig. 35 the ground plan and a cross section of the mine by Mr. Ellis is shown. His notes upon the mine are given below:

The ore mined is zinc blende with a small quantity of galena, and occurs in a flat from 1 foot to 5 feet above the oil rock. A thickness of from 4 to 5 feet of rock and ore has been removed. The range runs in a general southeast direction with an average width of 100 feet.

The ore occurs in dolomite, the main factor in its deposition having been the oil rock, which has acted as an impervious layer below and has directed the underground circulation along its upper surface. There is an unusually heavy flow of water in the mine, and practically all along the top of the oil rock or from fissures extending partially through this shale. The clay bed below the oil rock is very thin, rarely more than 3 inches in thickness.

The working breast is between two parallel pitches running N. 20° W., 85 feet apart and dipping in opposite directions. The pitches carry ore below the oil rock, but in the area between, the ore occurs in the limestone above the oil rock in horizontal sheets and irregular seams with vertical connecting crevices as shown in the cross section. West of the main hoisting shaft is a series of parallel quartering pitches running N. 30° E. and pitching to the northwest. These quartering pitches carry blende with small quantities of galena and pass through the oil rock in irregular seams as shown in fig. 36.

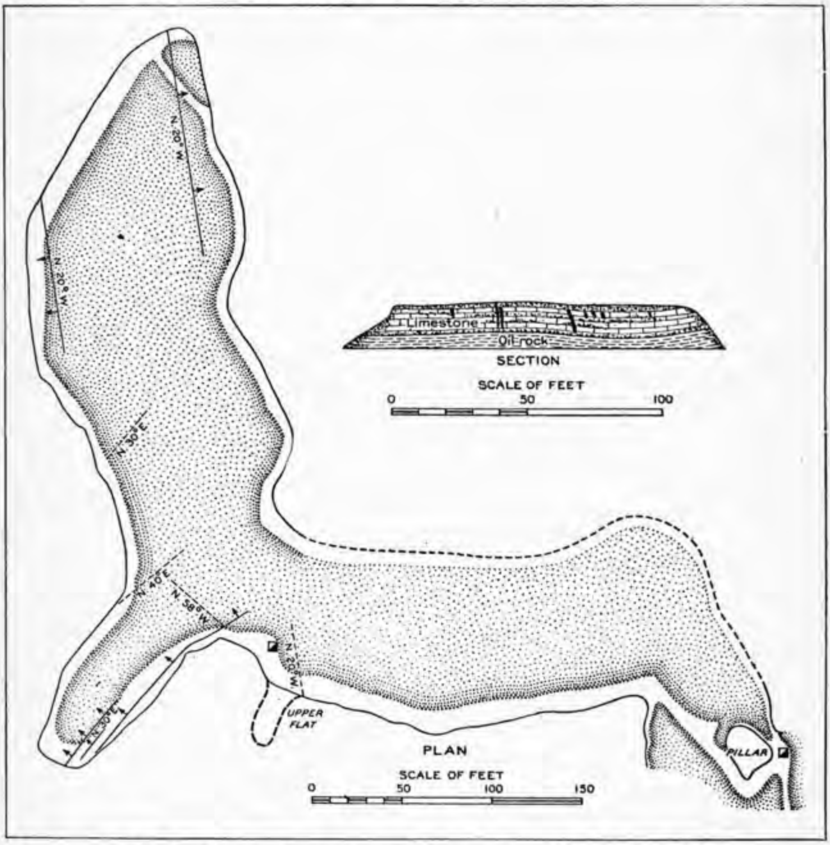


FIG. 35.—Map and cross section of Coker or Ellsworth mine, Mifflin, Wis.

The ore horizon varies from 2 to 4 feet in thickness, but except in the pitches the ore rarely is found in any quantity closer than 1 foot to the oil rock. However, a small sheet one-fourth to 1 inch in thickness very generally occurs directly above the oil rock.

The blende in the upper horizon is comparatively free from marcasite, which frequently occurs in a thin film 1 to 2 mm. in thickness between the wall rock and the blende. As the ore approaches to within 2 feet of the oil rock there is a marked increase of the marcasite, which occurs intimately mingled with the blende, both having crystallized at the same time. In this horizon there is as much marcasite as blende.

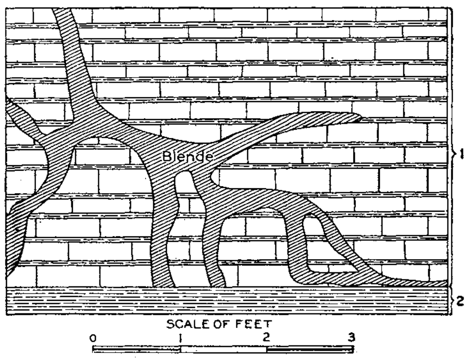
The mine has two hoisting shafts and one pump shaft. The pump used is a Cornish lift, which hoists approximately 800 gallons of water a minute through a 16-inch pipe. One compressed-air drill is used, the larger proportion of the work being done by hand drills. The mine is equipped with a 40-ton concentrating mill, which cleans an average of 40 tons of concentrates a week. Two grades of ore are prepared—one running about 50 per cent in zinc, shipped to Waukegan, and the other lower, going to Mineral Point. A roaster has recently been installed.

Sunrise and Sunset mines.—These mines, near the Ellsworth, work flats and pitches in the Galena above the oil rock. Both are well equipped with mills and roasters, but were not especially studied in the course of this survey. Other mines in the vicinity are the Ludd and the Crescent, the latter about 3 miles south, near Rewey.

LINDEN DISTRICT.

General.—The geologic and topographic features of the Linden district are shown on Pl. XIII, reduced from the Mineral Point special map of the Wisconsin Geological Survey.[a]

The Galena formation covers most of the surface, but the Platteville and St. Peter are found along the headwaters of Mineral Point Branch and cross the area. The most important structural feature is a long, narrow basin crossing the area from east to west. It has an ascertained depth of 60 feet and at the 1,020 contour (structural), which includes most of the mines, is about one-half to three-quarters of a mile wide and nearly 3 miles long, with an unknown western extension beyond the area mapped. Within this basin are the Mason, Glanville, and Milwaukee mines. In a subordinate basin on the north the Robarts mine is located, while old surface workings are spread over the long, gently sloping northern side of the basin parallel to the stream which crosses it.



1. Thin-bedded limestone with partings of carbonaceous shale or oil rock. This represents the oil-rock horizon.
2. Blue shale.

FIG. 36.—A sheet of blende and marcasite in the Coker or Ellsworth mine, pitching through the oil rock in irregular seams.

Mason mine.—The most important mine in this district is the Mason, or Heathcock. Work began here in 1833 and according to Strong[b] about 20,000 tons of lead ore were produced previous to 1853. From that date to 1866 about 3,000 additional tons were won, while from 1866 to 1874 the mine stood idle. Since 1874 it has been more or less continuously operated for zinc ore, and it is now an important producer. As is usual with such mines the early production was of galena from vertical crevices. Later galena and smithsonite were found at lower levels, in the ordinary flats and pitches, while now a big flat with only minor pitches is being worked for blende.

Chamberlin[c] in discussing this range in 1882 pointed out that in the early stages of mining here the ratio of lead to zinc produced was about 7 to 1. As the lower horizons were worked the ratio changed to 1 to 24, and at that time the total production of the property had been about 42,000,000 pounds of zinc ore. Since that time the zinc production has been large and fairly steady. In 1904, 200 to 300 tons of blende per month were being produced. These figures, as pointed out by Chamberlin, give definiteness to the statement that in abundance lead predominates in the upper beds and zinc in the lower.

The main flat, now being worked has a J-shaped ground plan, as shown in fig. 37, from a map of the mine workings now accessible made by Mr. Ellis. The longer arm extends for nearly half a mile with a generally northwest course. At the eastern end the flat bends sharply

[a] Grant, U. S., Perdue, M. J., Ellis, E. E., Fulcher, G. S., Cox, G. H., Bannister, J. R., Mineral Point sheet: Bull. Wisconsin Geol. and Nat. Hist. Survey No. 14, 1906, pl. 6.
[b] Geology of Wisconsin, vol. 2, 1877, p. 726.
[c] Ibid., 1873-1879, vol. 4, 1882, p. 473.

round, forming a hook with a course finally almost southwest. The flat is generally 50 to 60 feet wide, but narrows to 20 feet and widens to 100. Numerous vertical and pitching crevices

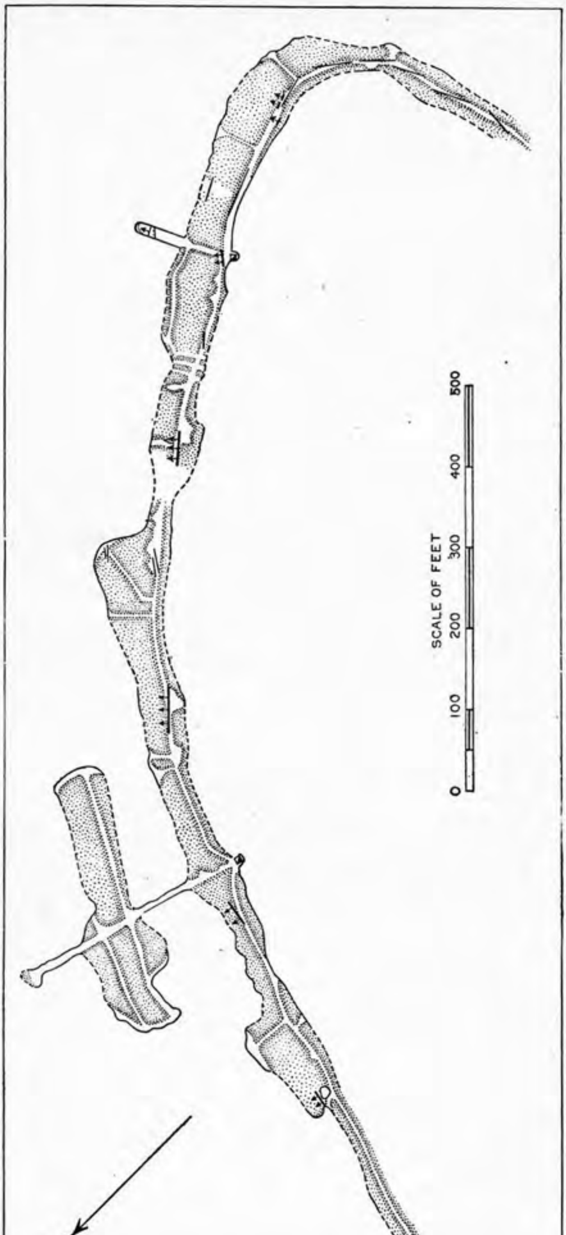


FIG. 37.—Map of the Mason mine, Linden, Wis.

are shown in the roofs. Most of them are indicated in the figure. The direction in which the crevices pitch, where it could be determined, is shown by the small arrows. While the condition of the old workings do not permit the determination of the relations of these crevices to the pitches worked above, it may be noted that in the observed cases the pitch is uniformly outward—that is, toward the north and east. According to Strong and Chamberlin the upper workings, beginning in the flint beds, consisted of three parallel crevices showing the ordinary openings containing fallen rock and dolomite sand. When traced downward these were found to join a common wide flat sheet. On the north this is said to have—

dipped quite uniformly to the lower flat in the glass rock opening. But on the south side, the more common habit of alternate pitches and flats was found to prevail, complicated by subordinate sheets which unite with it and join the common flat below. This lower flat lies in the glass-rock opening and has been proved to stretch across to the foot of the north-pitching sheet, a distance of 180 feet. This flat as is common is depressed along the center.[a]

According to this interpretation, the main workings represent the big flat commonly found between the pitches, and accordingly a long, curved, slightly depressed basin with its limits marked by pitching joints. It may not be amiss to point out here that while this small basin or channel is wholly within the larger structural basin already discussed, and in the hook at the eastern end is roughly parallel to the end of the basin, the long arm runs diagonally down the structural slope. The pitching joints, as already noted, conform in direction to the ore body rather than to the larger structural basin.

North of the main run is a second one, which is parallel through the portion so far developed. It is unique in that so far as known there are no old workings over it. It was discovered by a crosscut driven north from the main workings, and has so far been developed for a length of approximately 300 feet and a width of 75 to 100 feet. Its structural relations are wholly unknown. The present workings are at the glass-rock horizon, and according to Strong the main flat is a little more than 20 feet above the St. Peter, which was reached in one shaft on the property. As seen in the mine the glass rock averages about 7 feet in thickness and has a thin bed of soft clay above, with a band of harder shale separating it from the gray limestone below. The mineralized portion of the rock varies generally from 1 to 4 feet, but at many places is as much as 5 feet in thickness. The ore consists mainly of blende, there being very little galena at this level. Marcasite is present, impregnating the surrounding limestone and lining cavities in the rock, but not generally intimately intergrown with the blende. Calcite is the only gangue mineral. The sulphide and the calcite line and fill small cavities and fracture planes in the glass rock. In fig. 38, made from a section by Mr. Ellis, two pitching crevices are shown coming down from the roof and connecting with small flats of ore. More or less ore is found running down into the gray limestone forming the present floor of the mine, and near the east hoisting shaft a 3-inch sheet of blende, pitching downward, was observed.

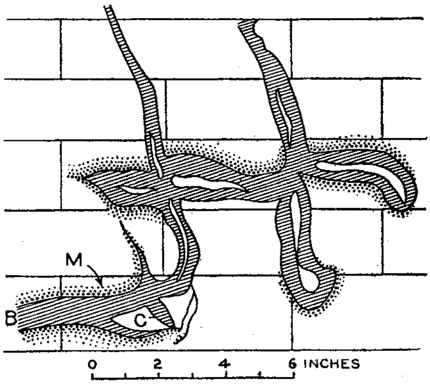


FIG. 38.—Relations of marcasite (M), blende (B), and calcite (C) in the Mason mine, Linden, Wis.

While mill returns are not available, careful estimates of the various faces of ore indicate a yield of 3 to 15 per cent, with an average of perhaps 8 per cent of concentrates. Up to the present it has not been found necessary to roast the ore to clean it.

Robarts mine.—About three-quarters of a mile north of the Mason mine is the Robarts. This, as already noted, is in a subordinate structural depression within the larger one already discussed. The shaft is on a topographic slope at about 1,100 feet above sea level. It is 40 feet deep. The mine shows the flats indicated by Mr. Ellis's map (fig. 39), and a cross sec-

[a] Chamberlin, T. C., Geology of Wisconsin, vol. 4, 1882, p. 471.

tion shows two outward-pitching crevices. An examination of the map shows that other pitches are present and that a wide variety of courses is represented. The upper flat and the main pitch running down from it is above water level and in the dolomite beds of the Galena about at the lower Receptaculites zone, the fossil being abundant along the pitch. The ore mainly found here consists of galena in great cubes showing edges 2 inches or more long and apparently freely grown from solution in open space. A sheet of nearly clean galena 8 inches to 1 foot thick was exposed when the mine was visited.

The lower flat is said to yield blende, and specimens of ore from it showed blende, marcasite, and galena intergrown, though the galena was very subordinate. The mine seems to represent secondary precipitation of galena at water level and above the main deposit of mixed sulphides.

Glanville mine.—Near the eastern end of the structural basin are two mines, the Glanville and the Milwaukee. The Glanville shaft is on a topographic slope at 1,120 feet above sea

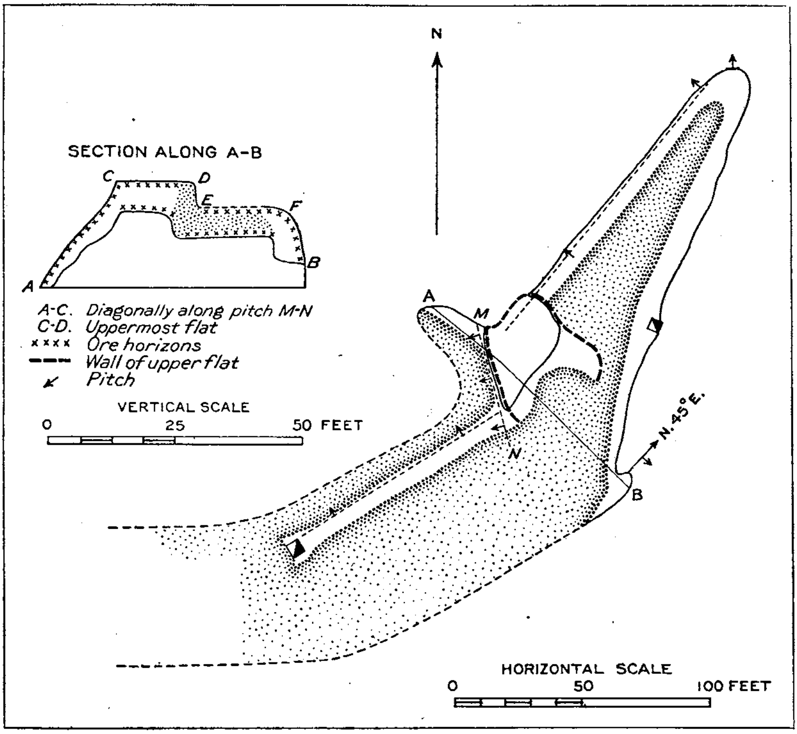


FIG. 39.—Ground plan and cross section of Robarts mine, Linden, Wis.

level. The oil rock lies at about 1,010 feet, and the work is at that horizon and in the glass rock, 8 feet below. The ground plan of the mine and two cross sections are shown in fig. 40, prepared from surveys by Mr. Ellis.

A peculiar feature, unusually prominent here, consists of certain rolls and dips in the rock below the glass rock. From the bottom of the shaft the floor dips to east, being depressed 5 feet in 50. On the other side it rises, and similar dips were observed elsewhere in the mine. Equivalent irregularities are shown by the higher lying beds, so that whether the depressions represent deformation or not the forces producing them affected the beds as a whole. The ore is found indiscriminately over the depressions and the rolls.

The ore in the glass rock consists mainly of blende, with subordinate amounts of galena. The two are intimately intergrown, but such iron pyrite as is present seems to occur mainly in distinct bands. The ore bed consists of a dark shaly material 18 inches to 2 feet thick, in which the ore occurs chiefly in a single sheet 3 to 8 inches in thickness.

The oil-rock horizon shows a similar flat, which has been more extensively worked. To the north and seemingly toward the edge of the ore body the blende disappears and only calcite and iron pyrite are found, although the rock retains its character and the small druses and fractures are present, as in the productive portion of the mine. The oil rock varies in thickness from 1 to 2½ feet, but more or less ore is found through 5 to 10 feet of rock.

The mine has no mill, the ore being prepared for shipment by cobbing. A few shipments of marcasite have been cleaned up and sold for acid making.

MINERAL POINT DISTRICT.

General features.—Mineral Point is one of the oldest and best known places in the region. In the past its mines have been heavy producers of both lead and zinc, the latter occurring mainly in the form of zinc carbonate. Since the St. Peter sandstone outcrops in most of the

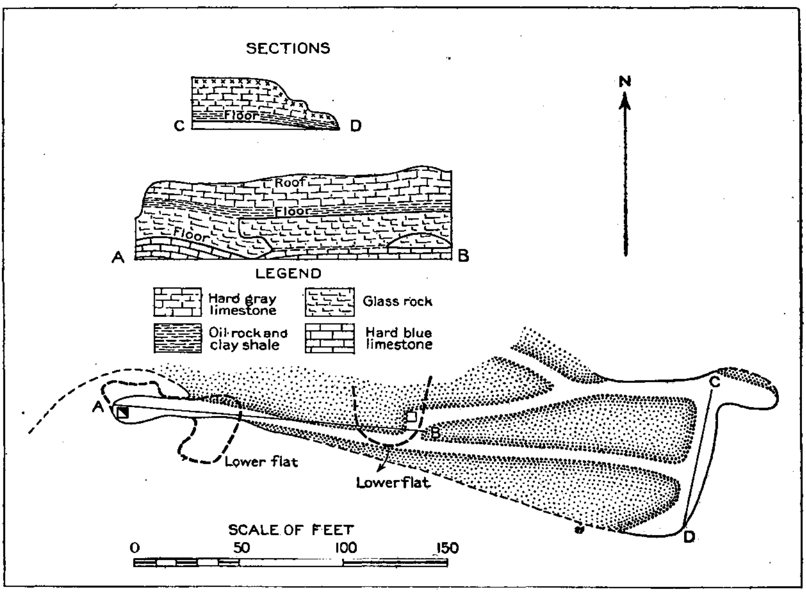


FIG. 40.—Ground plan and cross sections of Glanville mine, Linden, Wis.

streams, the zinc-bearing beds are mainly above water level. This favored their early development and at the same time minimized the chances of finding additional ores of the sort now in demand. Such mines as may be located will doubtless be found by drilling back some distance from the main streams. Two mines recently opened, the Tripoli and Western, are located near the headwaters of small tributaries to Spensleys Branch. The general geology of the district is shown on the Mineral Point special map of the Wisconsin Survey,[a] and information regarding the old ranges may be found in the older Wisconsin reports, particularly that of Strong.[b]

Tripoli mine.—This mine is located in the SW. ¼ NE. ¼, sec. 26, T. 5 N., R. 2 E., at the locality known as the "Old Harris diggings." The mine is being reopened by Milwaukee capitalists. The shaft, which is about 90 feet deep, is located at 1,130 feet above sea level, the oil-rock horizon being at about 1,050 feet above sea. In the mine there are three

[a] Grant, U. S., Perdue, M. J., Ellis, E. E., Fulcher, G. S., Cox, G. H., Bannister, J. R., and Cady, G. H., Mineral Point sheet: Bull. Wisconsin Geol. and Nat. Hist. Survey No. 14, 1906, pl. 6.
[b] Geology of Wisconsin, 1873-77, vol. 2, 1877, pp. 733-738.

separate openings or levels. The first, called the "brown-rock opening," is about 8 feet above the oil rock. It is developed only in the eastern part of the mine and is 3 to 4 feet high. Some ore was found at this level in a greenish-colored sandy dolomite. The true "green-rock opening" is supposed to be 4 to 6 feet still higher, though it was not seen in this mine.

The main work is along flats, with small pitches at the oil-rock horizons. This bed is about 3 feet thick and the face shows a brown, brittle limestone, separated into bands by dark shaly partings. Blende, galena, and iron sulphides occur in sheets one-half to 3 inches thick along the bedding planes. Occasionally there are flat druses lined with ore, which also occurs in pitching and vertical crevices. A small amount of calcite is present. At one point there is a small monoclinal fold with an amplitude of about 10 feet, and with oxidized rock below the fold and along the crevices which cut it. The workings are, in general, about at the natural water level.

Ten feet below the main workings the glass-rock level has been opened. The breast shows a thin-bedded brittle limestone not exactly like the typical glass rock at Platteville, yet resembling it. There are thin shaly partings and the rock has been slightly brecciated. The ore occurs in the fractures and along the bedding planes through a thickness of 18 inches to 2 feet. At its base is a thin shale or clay band, which the miners undercut, as in coal mining, shooting the rock down to it. The ore makes a rather regular sheet on this band.

The mine is well equipped with a steam hoisting and milling plant, housed in corrugated-iron buildings. When first reopened, a considerable amount of the stored waste or rock from the old workings was run through the mill. From a quantity of this material, estimated at 75 tons, milled in ten hours, 15 tons of concentrates were made. The concentrates were very high in iron sulphide, and the content of zinc ore proper is not known. A roasting plant has since been installed.

DODGEVILLE DISTRICT.

General features.—The general structural and geological features of the Dodgeville district are shown in fig. 41, based upon the map of the area published by the Wisconsin Geological Survey.[a] The district was especially studied by Mr. Ellis and has been described by him. From[b] this paper and from his field notes, supplemented by a few personal observations the following account has been compiled.

Location.—The Dodgeville district lies in the extreme northeast portion of the Wisconsin lead and zinc region. The area in which mining has been carried on is relatively small, including not more than 10 square miles, and nine-tenths of the mining has been done within the limits of four sections of land.

The history of this portion of the district has been the same as that elsewhere in southwestern Wisconsin. Mining was first carried on for galena alone; then for galena and smithsonite, as a market was found for the zinc carbonate, and of late years attention has been largely turned to the deposits of zinc blende.

Dodgeville is situated on the divide between the drainage of Pecatonica and Wisconsin rivers, while the center of the mining district is among the small headwater streams of Dodges River, which flows into the Pecatonica. The country is perfectly drained, and, as the streams flow to the southeast and are nearly parallel, a series of long, narrow ridges has been formed. In the least eroded portion of the area the hills rise to a little above 1,200 feet above sea level, which marks approximately the height of an old peneplain. The small streams have an average fall of 60 feet to the mile near their sources and have flat bottoms, and the valleys have gently rounded side slopes.

Stratigraphy.—The formations occurring here are Galena dolomite, Platteville limestone, and St. Peter sandstone, while a short distance north of town, Prairie du Chien or "Lower Magnesian" limestone outcrops. The full thickness of the Galena does not occur within the

[a]Grant, U. S., Perdue, M. J., Fulcher, G. S., and Cady, G. H., Dodgeville sheet: Bull. Wisconsin Geol. and Nat. Hist. Survey No. 14, 1906, pl. 4.
[b]Ellis, E. E., Zinc and lead mines near Dodgeville, Wis.: Bull. U. S. Geol. Survey No. 260, 1905, pp 311-315.

area, although at places 200 feet of the dolomite remain. In the territory where the larger proportion of the mining is carried on erosion has left not more than 100 feet of the Galena, ncluding the lower 50 feet of nonflinty dolomite, above which lie the intercalated beds of

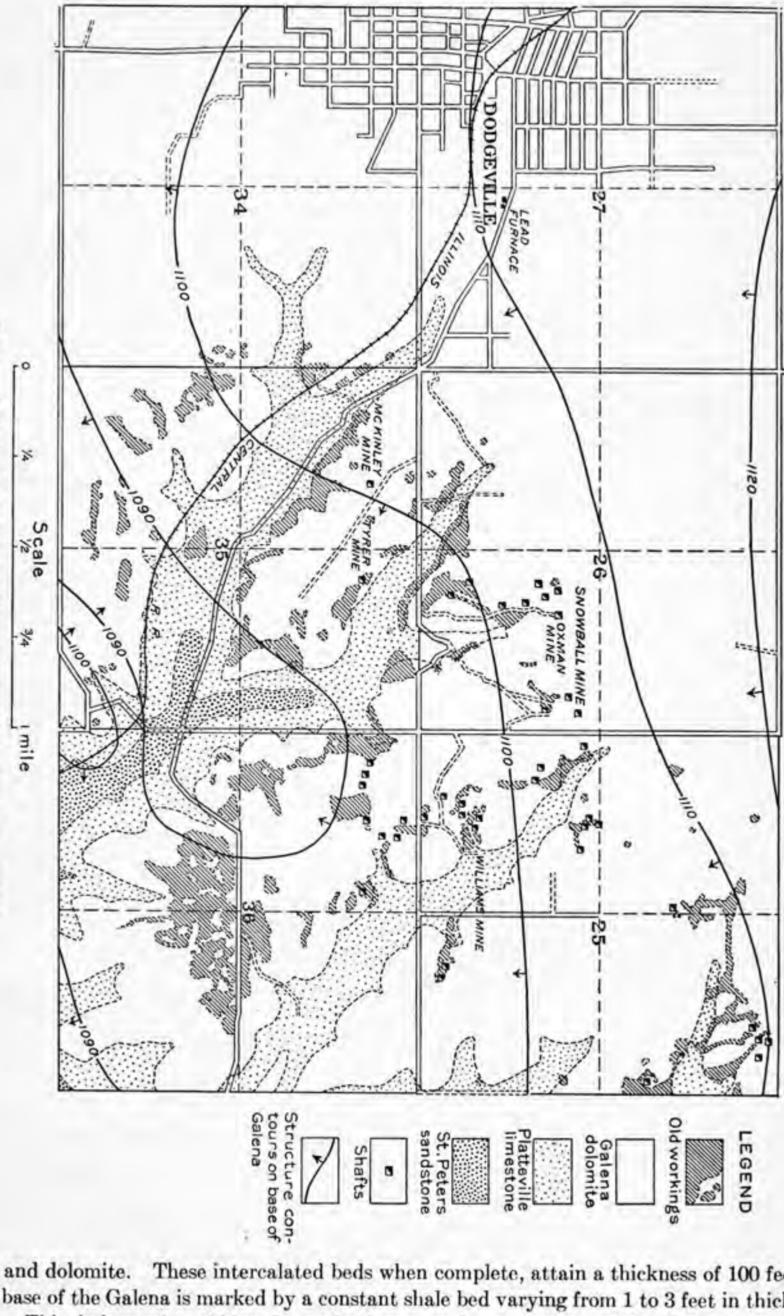


FIG. 41.—Relations of mines to structure in the Dodgeville, Wis., district.

flint and dolomite. These intercalated beds when complete, attain a thickness of 100 feet The base of the Galena is marked by a constant shale bed varying from 1 to 3 feet in thickness. This shale consists of blue clay and of brown carbonaceous material or "oil rock."

The Platteville limestone has here a rather uniform thickness of 65 feet, and is much less magnesian than the Galena. The upper beds, called the "glass rock," constitute the important ore horizon. The glass rock is very fine-grained, hard limestone, varying from 4 to 12 feet in thickness. It is brittle, nonmagnesian, and frequently breaks with a conchoidal fracture. Near the base of the Platteville is the magnesian limestone known as the "quarry rock."

Generalized section of the Platteville limestone near Dodgeville.

	Ft.	in.
7. Glass rock	10	
6. Dark-brown to black, hard, carbonaceous shale		3
5. Hard gray limestone	10	
4. Fossiliferous limestone, fine grained and separating into thin, irregular beds	18	
3. Clay bed		2
2. Dolomite limestone in heavy beds (quarry rock)	25	
1. Sandy shale		8

The most important structural feature in the district is a broad, shallow basin within which all the mines are located. The area mapped is so small that the full extent of the basin is not known, but its extreme shallowness is apparent from the fact that in 1½ miles the maximum difference in elevation is less than 20 feet. Apparently there is an interrupted slope to the south with a shallow depression on the resulting flat. It is believed that this structure reflects depositional conditions and is not deformational.

Ore deposits.—The ore bodies occur in three general modes—in vertical crevices, in pitching crevices, and in flats, occupying a large horizontal space. The pitching crevices are few and unimportant. The quantities of sphalerite and galena produced are at present nearly equal, while a small amount of smithsonite is also mined. Calcite is frequently associated with these ores, and marcasite almost invariably accompanies the blende in varying amounts.

Very little mining in this area has been done in the Galena, the important ore bodies occurring in the glass rock of the Platteville. The ores obtained from the Galena have been galena and smithsonite, which occur mainly in vertical crevices, though with a small development in flats and pitches.

The ore bodies now worked are in the so-called "glass-rock opening" of the Platteville limestone, and consist of irregular flats with occasional small crevices leading from above. The horizon occupied by the flats of the glass-rock opening has a vertical height ranging from 1 to 7 feet, and the ore bodies have an average width of 60 feet, with frequently a very considerable longitudinal extent. The course of these flat ore bodies is not regular, as developed in the Dodgeville area, and even the individual ore bodies do not keep a single direction any great distance. This variation in direction probably follows the position of the feeding crevices above.

Where the ore bodies lie below the level of ground water, the predominant ore is zinc blende. Where they lie above or near water level, the important ore is galena, with associated smithsonite. In the ore bodies which have been above ground water, and which have been consequently subjected to the oxidizing influences of surface waters, the limestone is generally soft and disintegrated and the ore occurs in a flat at the base of the glass rock directly above a bed of hard impervious black shale 2 to 5 inches in thickness. These flats of galena and smithsonite are very irregular, varying from a solid sheet 4 inches in thickness to small lenticular masses only a few inches in longest diameter and separated by barren rock. In the ore bodies which have escaped the oxidizing surface waters, either because of an impervious bed of oil rock above or because they were sufficiently far below ground-water level, the predominant ore is zinc blende with a small proportion of intimately associated galena and with considerable iron sulphide, generally in the form of marcasite. While in this latter type of ore bodies the ore occurs in a flat at the base of the glass rock and above the thin shale bed, the main body of ore is in irregular seams traversing the rocks in diverse directions, but with the majority parallel to the bedding planes of the limestone. The irregular seams represent fractures in the glass rock which have been enlarged by solution and filled with ore, and give a marked brecciated appearance to the limestone. The horizon occupied by these bedding and cross seams has a vertical height of from 1 to 5 feet, and the proportion of ore varies greatly from place to place in the same mine.

The large horizontal extent of the flats and the small amount of pumping necessary makes the working of these mines relatively cheap and permits the development of leaner bodies of ore than would generally be profitably worked under the mining methods followed. The galena and smithsonite above the level of ground water occur in soft rock as a rule and are readily separated by hand sorting. They are relatively free from iron and are consequently of good grade. The ores below water level are intimately associated with marcasite and are separated from it with difficulty, the grade of the blende concentrates being in consequence considerably lowered, although holding well up with that of the average ore of the Wisconsin district.

Although the ores of the glass-rock opening constitute the most important bodies yet developed in the vicinity of Dodgeville the fact should be remembered that in the greater part of the Wisconsin lead and zinc district the more valuable lead and zinc deposits have occurred above this horizon, and there is no reason to suppose that such deposits may not exist in the less eroded portions of the Dodgeville area. Considerable work has been done in the past on lead-bearing crevices at these higher elevations, and one company has recently started development work on one of these old lead ranges.

Mention should also be made of the fact that some prospecting has shown the presence of galena in the upper portion of the Prairie du Chien or "Lower Magnesian" limestone near Dodgeville, although no development work has been done and no definite idea can be formed of the possible extent of such bodies.

Devlopment work.—There are at present seven producing mines in the area: The Williams Bros., producing blende and galena; the Hartford Lead and Zinc Mining Company, starting development work on an old lead range; the Snowball and Oxman mines, both yielding galena and blende; the Davy Pengelly mine, with galena and smithsonite; and the Tyrer and McKinley mines, the former producing galena and the latter blende. In the area are a number of abandoned mines which in the past have been producers of galena and smithsonite, while there are a number of small mines that are worked only during the winter.

Williams mine.—The Williams mine is located in the SW. ¼ sec. 25, T. 6 N., R. 3 E., and is the most important producer in the district. A map of the workings accessible at the time the mine was visited is shown in fig. 42.

Access to the mine is had through an incline. The main workings are in the glass rock, though ore was formerly taken from the basal beds of the Galena and lead was found in vertical crevices still higher. The oil rock is here about 3 feet thick and small cubes of galena are sprinkled through the rock where it is cut through in the incline. The main workings are about 10 feet below, though narrow crevices, some of these pitching, join the two horizons. In certain drill holes near by it is reported that a small amount of galena was found in the "big pipe clay"—the clay bed at the base of the Platteville and just above the St. Peter sandstone.

The glass rock in this mine is a brittle, brown rock apparently somewhat magnesian. At the base of the workings is a 3-inch bed of gray clay with a flat sheet of blende 2 to 8 inches thick lying just above. Similar sheets occur along the bedding planes and in cross fractures through a thickness of 3 feet of rock. The blende shows some galena crystallized with it but almost no iron sulphide. There is a little zinc carbonate present and apparently oxidation has gone far enough to destroy the iron sulphide and is beginning on the zinc.

The flat has an irregular course and where measured is about 150 feet across. Its full length has not yet been determined.

The mine is equipped with a steam concentrating mill and a rope haul for bringing cars out of the mine.

McKinley mine.—The McKinley mine is in the NW. ¼ sec. 35, T. 6 N., R. 3 E., and yields blende with small quantities of galena.

The work is done from a shaft 80 feet deep, which penetrates to the base of the glass rock. The ore body is worked in a direction 25° south of west and consists of a 2-inch to 4-inch sheet of blende directly below the glass rock. Considerable marcasite is intimately mixed with the blende.

A horsepower hoist is used, and as the mine is above the level of ground water no pumping is necessary.

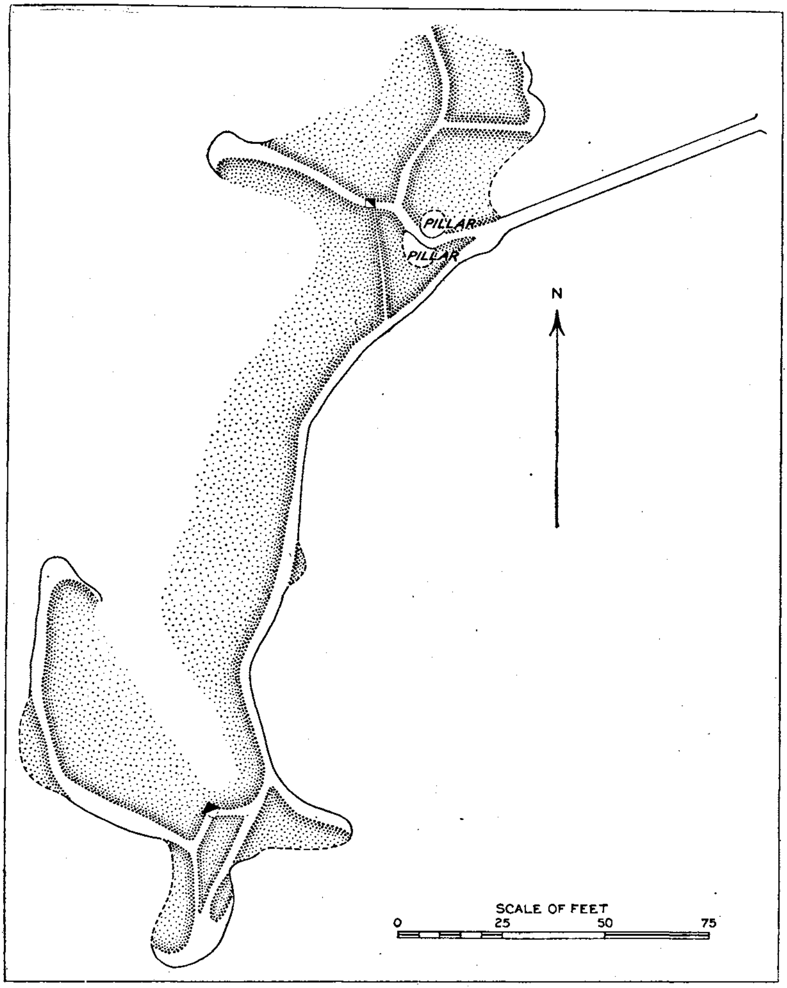


FIG. 42.—Sketch map of the Williams mine, Dodgeville, Wis.

Davy Pengelly mine.—This is a lead and dry-bone mine, in the NE. ¼ sec. 34, T. 6 N., R. 3 E. The ore occurs in a flat sheet 2 to 5 inches thick and lies directly below the glass rock, resting on 7 inches of shale. A considerable body of ore has also been developed in a pitching sheet leading from above. The ore is above water level and occurs in very thoroughly oxidized and softened rock. The zinc ore is entirely in the form of the carbonate, no blende being left, while the marcasite evidently has been leached out with the blende, leaving only a red stain.

Snowball mine.—This mine is situated in the SE. ¼ sec. 26, T. 6 N., R. 3 E., 1½ miles east of Dodgeville. It is located near the top of a hill at an elevation of 1,190 feet above sea level. The main shaft is 93 feet deep and penetrates to the base of the glass rock, which is 12 feet in thickness. The glass rock is very hard and very fine grained, and breaks with a conchoidal fracture. It is unaltered, the shale directly above having evidently acted as an impervious layer, as the oxidizing waters have reduced the overlying limestone to a red, chalky mass. Near the shaft, in this softened horizon, a quartering crevice has widened out into an open cave, in which a small quantity of galena was found.

The main ore body is a flat sheet of galena and blende, 3 to 6 inches thick, which lies at and below the base of the glass rock. Where the ore rests directly on the shale below the glass rock it occurs in a compact and uniform sheet, but as it passes in places up into the glass rock it breaks into irregular seams. The rock surface, when cleared of the shale on which the ore rests, is seen to be uneven and to have irregular rolls, which appear to have had no effect on the ore body.

There is considerable galena and a relatively small proportion of marcasite with the blende. The marcasite occurs both earlier and later than the other sulphides, and as an inner lining of cavities. While the blende and galena are intimately commingled, the marcasite is distinctly separated, forming a rather marked crustification.

The mine is pumped by a small gasoline engine, which is also used for hoisting. The ore is cleaned in hand jigs, to which water is furnished by the pump.

Tyrer mine.—The Tyrer mine is in sec. 35, T. 6 N., R. 3 E. The only ore at this mine is galena, which lies above water level. The galena is found in a flat at the base of the glass rock, and occurs in irregular lenticular masses, no solid sheet being found. It has been worked in a direction 25° west of north.

HIGHLAND DISTRICT.

General.—The Highland mines are the northernmost in the region that produce regularly. The district occupies a part of a high ridge between Blue and Otter rivers and stretching out toward Wisconsin River. The mines are on the old peneplain at an altitude of about 1,200 feet. The surface rock is the Galena, but the Platteville, St. Peter, and Prairie du Chien outcrop in the adjacent ravines. The ores occur mainly in flats in the lower beds of the Galena. The section shown at the Kennedy mine, as measured by Mr. Grant, is representative. It is given below.

Section at the Kennedy mine, Highland, Wis.

	Ft.	in.
7. Hard Galena limestone	15	
6. Bands of hard gray limestone, with thin seams of rock that resemble oil rock, but are harder. This is called the "lower opening"	6	
5. Oil rock, which is here harder and more compact than usual	1	
4. Gray to yellow soft clay		6
3. Very hard, fine-grained gray limestone. This is called the glass-rock opening, but the rock is not like the typical glass rock	4	
2. Oil rock	4	
1. Hard limestone		2

The principal structural feature of the district is a shallow, irregular basin running slightly north of east. This basin is divided by a low, narrow swell rising about 10 feet above its bottom and having its major axis parallel to that of the basin itself. The mines are on the north side of this structural swell and mainly at the foot of a structural slope at least 1½ miles long and rising about 40 feet to the north. These and other details of the area are shown on the special map of the district published by the State.[a] The main structural features are indicated in Pl. XIV reduced from this map. The mines were

[a] Grant, U. S., Perdue, M. J., Fulcher, G. S., Cox, G. H., Bannister, J. R., and Cady, G. H., Highland sheet: Bull. Wisconsin Geol. and Nat. Hist. Survey No. 14, 1906, pl. 2.

studied in 1904 by Mr. Ellis, and from his notes the following descriptions have been prepared.

Kennedy mine.—The Kennedy mine is the SE. ¼ sec. 28, T. 7 N., R. 1 E., one-half mile northeast of Highland. It is on the side slope of a shallow gulley at an elevation of 1,210 feet above sea level.

The ore is blende, galena, and smithsonite, with the zinc ores predominant, and occurs at nearly the level of ground water. The general direction of the ore body is northwest-southeast, but a bar of unproductive limestone crosses the mine in a northeasterly direction and separates the ore body into two distinct parts, in which the ore occurs in different beds and in different forms.

In the portion of the mine worked from the northwestern shaft the important ore body is a 16 to 18 inch sheet of disseminated blende and galena in a blue shale representing the oil rock. Above and below this shale the limestone has been very thoroughly softened and colored red through the agency of oxidizing waters. The disseminated ore within the shale has been protected from these oxidizing waters and has undergone no alteration except near the edges of the shale, where some blende crystals have been leached out, leaving cavities. In the softened glass rock below the shale considerable galena and smithsonite are obtained in irregular seams, while at the base of the glass rock, above a 2-inch bed of hard, black shale, is a fairly constant sheet of galena, 1 to 3 inches in thickness.

In the vicinity of the second shaft, on the south side of the bar, the main ore body is in the glass-rock horizon, although disseminated ore in the oil rock is also worked. While oxidation has been complete above the oil rock, the glass rock below has been protected in general from the surface waters. Small cavities lined with crystals of dolomite and with zinc carbonate are present in the glass rock and in places the blende has partially altered to carbonate, but the main ore body consists of unaltered blende and galena in sheets parallel to the bedding plane of the glass rock and in irregular seams crossing the beds.

The ore contains a relatively small quantity of marcasite which impregnates the glass rock next to the ore seams and also occurs within the seams as the last mineral deposited. In the disseminated ore the blende and galena are intermingled. In the glass rock also these two minerals are intimately intermingled, although another relation is common where crustification is marked, namely: 1, Wall rock frequently impregnated with iron sulphide; 2, blende; 3, galena in octahedral form; 4, occasionally a thin layer of blende.

The two shafts are, respectively, 90 and 88 feet deep and penetrate about 3 feet of the glass rock, which has an elevation of 1,130 feet above sea level. The strata are nearly horizontal here, but they rise both to the north and to the south, so that the mine is near the middle of a broad, shallow syncline, with a width of 1 mile and a vertical difference between trough and crust of 30 feet. In the mine are a number of small vertical and pitching crevices, running from 30° to 60° west of north, with an average direction of 45° west of north. The old surface workings in the vicinity indicate that this is the direction of a long range.

The ore is hoisted by horse power and is cleaned at an old-fashioned plant of small capacity. The cleaned ore, however, is of good grade, running up to 58 per cent zinc in the blende concentrates. A new 100-ton mill will shortly be installed on the completion of the new railroad.

Kennedy dry-bone mine.—This mine is about 400 feet north of the Kennedy mine and is at about the same elevation.

The only ore obtained from this mine in quantity is smithsonite, although small quantities of galena are sometimes obtained. No blende whatever has been found here. The ore occurs in what the miners call "brown rock," 6 to 10 feet above the glass rock, and is all above water level. Oxidation has been so thorough that the limestone is completely softened and is universally of a reddish-brown color. The ore and rock are of the same color and frequently can be distinguished from each other only by the superior hardness and weight of the ore.

In this mine a great many dry-bone-bearing crevices cross one another at every angle; some of these are vertical, but most of them are pitching. The greater part of the ore occurs in the pitches, but good ore is obtained in flats having a lateral extent of only a few feet. The ground plan of the mine, as well as the general distribution of the pitching crevices, is shown in fig. 43. It will be noted that the crevices are notably inconstant in direction. In that portion of the mine indicated by B–C–D–E it may be further noted that the pitches outline an irregular oval area 50 to 100 feet wide and approximately 150 feet long. It seems not improbable, in the light of observations in other mines, that if the whole area were open to observation these crevices would be found to interlock or join, forming a complete circuit of outward-pitching joints. In the other parts of the mine the area open to observation is too small to permit generalization.

All the work is done from one 69-foot shaft, and the ore is raised by horse power, being ready for shipment when brought to the surface.

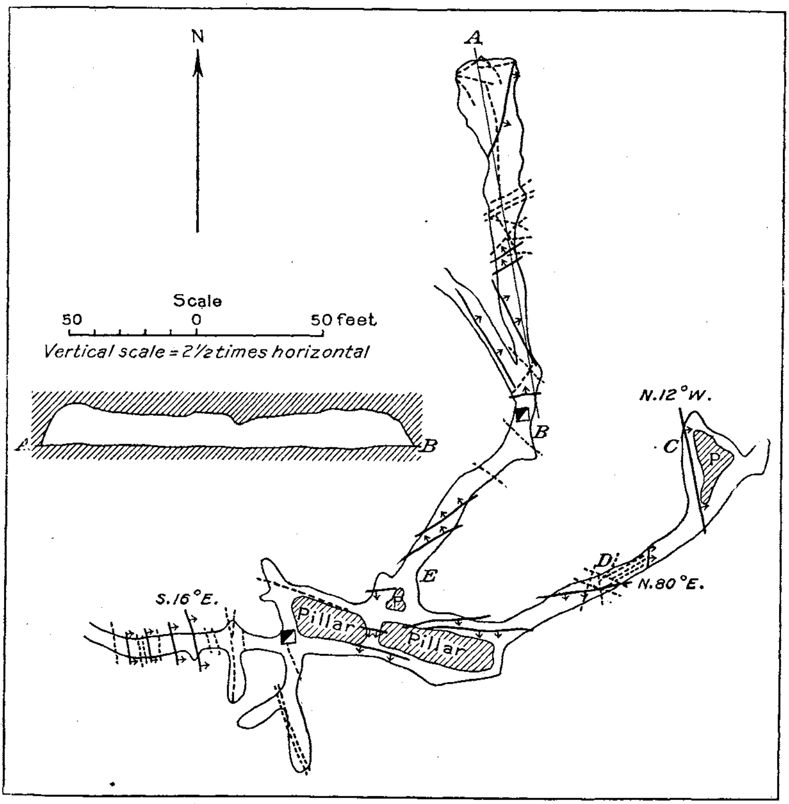


FIG. 43.—Ground plan and cross section of the Kennedy dry-bone mine, Highland, Wis.

Lewis mine.—The Lewis mine is in the same section as the Kennedy. The main shaft is at 1,185 feet above sea level, and the oil rock occurs at 1,130 feet.

The ore is a mixture of zinc carbonate and galena and lies above the level of ground water, no pump being necessary. The ore occurs at two horizons—a flat at the top of the glass rock and one immediately above a black shale bed at the base of the glass. These flats are from 2 to 4 inches thick, and the lower one carries unusually light-colored smithsonite, called by the miners "white bone." The glass rock is thoroughly oxidized and soft. The crevices which can be seen in the roof of the workings run N. 45° W. and carry little ore.

There are two shafts, the west and main one being 62 feet deep and penetrating 3 feet of glass rock. A horse-power hoist is used.

Eberle mine.—The Eberle mine is located 3 miles southeast of Highland in the NW. ¼ sec. 2, T. 6 N., R. 1 E. The mine is situated at the head of a gulley, where the ground is relatively high and is little below the level of the old peneplain.

The ore is blende, galena, and smithsonite, the zinc ores constituting 80 per cent and the galena 20 per cent of the production. It occurs in a series of flats and pitches occupying a vertical extent of 22 feet between the "green-rock opening" above and the glass rock below. Ore is present in the glass rock, although little has been taken out at this horizon because of inadequate pumping facilities.

The general direction of the ore body as opened is nearly east-west, though with a slight northwest trend. There are two main series of pitches, one N. 20° E. to N. 30° E., pitching to the southeast, and the other about N. 70° W., pitching to the northeast. The flats and pitches are of the typical order, and the flats carry more ore outside of the pitches than within. The ore body opened is all below water level and consequently the sulphide ores are unaltered except directly in the main water channels, so that practically all the zinc carbonate occurs in the pitches.

Besides the solid ore in the flats and pitches there are two marked horizons of disseminated ore. In the oil rock there is a very constant sheet of disseminated blende, from 4 to 18 inches thick, in blue shale and typical oil rock. Eighteen feet above the glass rock there is a 4 to 6 inch bed of blue clay, in which blende occurs in irregular, somewhat rounded lumps, from one-half inch to 3 inches in diameter.

The blende and galena occur both intermingled and in separate sheets containing only one of the minerals. The ore is unusually free from marcasite, although the iron sulphide is said to be much more abundant in the glass-rock horizon than above. The freedom from marcasite is evidenced by the high grade of the concentrates, which frequently run to 60 per cent and even 62 per cent metallic zinc.

The mine has two shafts, the upper or hoisting shaft being 63 feet deep and penetrating to within 9 feet of the glass rock. The second shaft, 300 feet away and 25 feet lower, is used for a pump shaft. At the time the mine was visited the ore was raised by horse power and cleaned in a small plant equipped with 4 shaking jigs run by a gasoline engine and with one hand jig. The ore was sized for the different jigs by a trommel screen. This small plant yielded 5 tons of cleaned ore a day, the annual production being close to 400 tons. Recently the mine has been equipped with a new 50-ton concentrating mill.

MONTFORT DISTRICT.

General.—Montfort occupies a situation somewhat similar both topographically and geologically to that of Highland. Comparatively little mining has, however, been so far done in the vicinity. The district is notable for the presence of a mine which is worked mainly for the sulphur content of the marcasite. The following data concerning the mines are derived from Mr. Ellis's notes.

Montfort Mining Company.—This company has sunk a 100-foot shaft near the south limits of the town. A low-grade ore has been found, containing blende and marcasite.

Jones and Snow mine.—This mine is located in sec. 26, T. 6 N., R. 1 W., 1½ miles southwest of the town. It has been worked intermittently for ten years and steadily since March, 1903. The ore is marcasite with a small quantity of zinc blende, the mine being worked mainly for the marcasite.

The ore body occurs 18 feet below the surface of the ground and is worked directly in the center of a valley. Glass rock shows at the lowest point. Above the glass rock occurs 6 inches of oil rock followed by 2 feet of hard blue shale. The ore occurs in a sheet, from 6 to 12 inches thick, lying directly above the blue shale. At one place the ore pitches to the west through the blue shale and oil rock. While the limestone above the ore body is reddened by oxidation, little change has been effected in the ore, which lies a few feet below the level of ground water.

Although the ore is mainly marcasite, considerable associated blende is locally present, the amount varying from zero to nearly 50 per cent. Where the blende occurs there is marked crustification. Marcasite occurs as the lowest layer, followed by from two to four alternate layers of blende and marcasite.

When the mine was visited 400 tons of marcasite in all had been produced and sold at from $5.50 to $6 per ton. The profitable mining of ore of this low grade is possible because of the nearness of the ore body to the surface and the ease with which the ground may be worked.

LANCASTER DISTRICT.

General.—Comparatively little mining is now going on near Lancaster, attention being directed more especially to the eastern part of the region. In earlier years there were important mines on Pigeon Creek, near Beetown, Cassville, Fennimore, and other points. In the summer of 1904, when these localities were visited by Mr. Ellis, mining was being carried on at only three places. His descriptions of the mines are given below.

Coon Hollow mine.—This mine is in the NE. ¼ sec. 25, T. 4 N., R. 4 W., 6 miles southwest of Lancaster, Wis. The mine was opened in April, 1904, and consists of a drift 60 feet long, which runs into a hillside practically at the level of ground water. This drift is directly on top of the glass rock and shows the oil rock to be 6 inches in thickness, with a hard blue shale bed, 2 feet in thickness, above the oil rock. The ore is disseminated blende, in large crystals one-fourth to one-half inch in diameter, and occurs in the blue shale bed above the oil rock. No other mineral is associated with the blende at this horizon, although galena has been found and worked at higher elevations.

The ore is passed through a horse-power crusher and then cleaned by hand jigs, giving a high-grade concentrate of zinc blende.

Eberle mine.—The Eberle mine is 1½ miles northeast of Beetown, Wis., in the SW. ¼ sec. 21, T. 4 N., R. 4 W.

Zinc blende has been found along an east-west crevice, and galena in a 50-foot drift along a crevice running N. 60° E. Along the east-west crevice a space has been worked between 150 and 200 feet long, with a height of from 6 to 17 feet and a width of from 8 to 15 feet. This drift is within the lower flinty beds of the Galena dolomite, 50 feet above its base. The crevice is tight throughout, the ore occurring in typical honeycomb form. Marcasite occurs in a thin sheet between the limestone and the blende.

There are two shafts, one 60, the other 100 feet deep, the working level being 60 feet below the surface. The mine is equipped with a 40-ton concentrating mill, erected in the fall of 1903.

Red Dog mine.—The Red Dog mine is located near the southeast corner of sec. 12, T. 3 N., R. 3 W., on the crest of a long east-west ridge, and is at an elevation of 975 feet above sea level.

The mine has been worked for several years at a horizon about 75 feet below the surface of the ground. At this horizon the ore is galena and smithsonite. Recently the shaft has been sunk 50 feet lower and has reached a second ore horizon, yielding blende and marcasite. The entire ore body is in the flinty beds which occupy the middle horizon of the Galena limestone.

Several large east-west crevices run through the mine and the greater part of the work has been carried along them, although north-south drifts have been run to connect. At the upper ore horizon the crevices have been widened out by solution, which seems to have been more effective here than above or below. So much of the dolomite has been dissolved that the unsupported strata have broken into angular blocks, which have frequently fallen out of place. The rock itself has been honeycombed by the solvent waters and the ore deposited in cavities. The rock has been reddened by oxidation and made so soft that it is reduced to sand by the blasting. The galena occurs as aggregates of cubes in the solution cavities, and is frequently associated with smithsonite, while considerable open space is left, which has evidently once been filled with blende, outlines of the crystal forms being left. The east-west crevices have been worked longitudinally for 150 feet and vertically for 5 to 30 feet. The area between the east-west crevices contains ore which is not rich enough for hand cleaning.

The upper ore horizon, as shown in the shaft, extends down to the lower, where typical honeycomb ore, containing blende and marcasite, but no galena, is found. There are no open cavities in this rock as in that above, the irregular solution cavities in the limestone having been filled by marcasite, blende, and calcite. Marcasite occurs as a thin film lining the cavities, the rest of the space having been filled by blende or calcite. At the bottom of the shaft the beginning of a pitch to the north has been developed.

An 85-ton concentrating mill has been erected, equipped with jigs and a concentrating table. Three air drills are to be used.

POTOSI DISTRICT.

Comparatively little mining has been done at Potosi for some years. A large number of old ranges, formerly worked, are described by Strong [a] and Chamberlin.[b] The present workings, as well as the geology and topography of the district, are shown in Pl. XV, a map

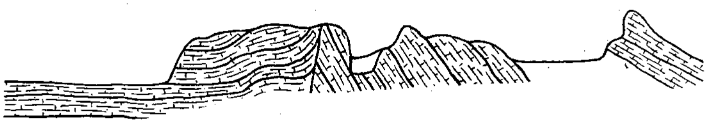


FIG. 44.—Small thrust fault near Potosi, Wis.

prepared from detailed surveys made by E. F. Burchard, A. W. Lewis, and J. R. Bannister. It will be noted that there is a long, narrow structural basin extending to the northeast from the southwest corner of the district. Near its eastern end, in sec. 36, is some of the most pronounced deformation in the region, a sharp little overthrust anticline being developed, as shown in fig. 44. This line of disturbance trends a little south of east and shows plainly in the two stream valleys that it crosses. Associated with it are several crevices which contain galena, and near them a small quantity of galena is disseminated through the rock.

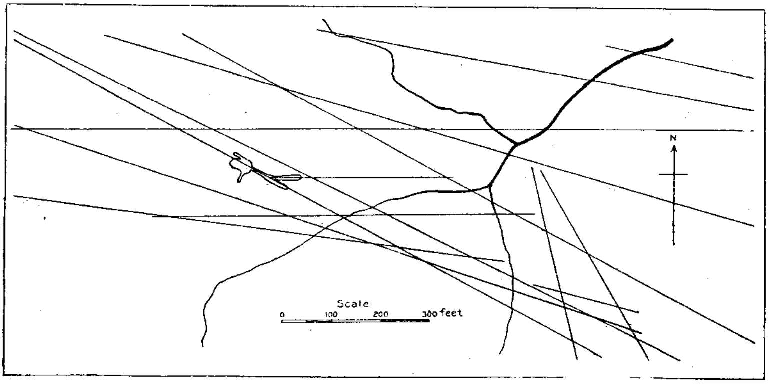


FIG. 45.—Map of principal crevices near Trego mine, Potosi, Wis.

The phenomena are notable, as this is the only place in the region where ore is known to be accompanied by such evidence of deformation. The amount of displacement is evidently very slight, since it is not enough to affect the position of 10-foot structural contours.

The Trego mine, No. 2, was located near the upper end of the syncline, in the area of local deformation. In fig. 45 the situation of the workings with relation to the known ranges of the region is shown from surveys made by Mr. Trego. The mine, which is now abandoned, was worked in the Galena formation some distance above the oil rock.

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[a] Strong, Moses, Geology of Wisconsin, 1873–1877, vol. 2, pp. 699–701.
[b] Chamberlin, T. C., Geology of Wisconsin, 1873–1879, vol. 4, 1882, pp. 447–448.

The Cardiff Company has two properties in the district—one not now being worked, in the vicinity of some old shallow mines in sec. 25, and a second in sec. 35. At the latter drilling has shown ore near the base of the Galena formation, and a shaft has been sunk to it. Drifting is now being carried on to develop the ore.

The Kroag and Webster mine, south of British Hollow, is apparently working in rock above the oil rock. The dump shows some good ore, but the property was idle when visited.

ORE IN THE PRAIRIE DU CHIEN FORMATION.

It has already been shown that the beds below the Platteville limestone, except the dolomitic strata of the Prairie du Chien or "Lower Magnesian," are generally unfavorable to the deposition of ore. In the latter formation ore has been found at a number of points, and the possibility of large bodies of ore at this horizon has such scientific and economic importance as to demand especial attention. For these reasons the following rather full abstracts are given of the most important literature on the subject. There is little to add to what has already been written, since for many years the search for ore in the dolomite has been practically abandoned.

Owen.—D. D. Owen first discussed the matter. In his final report he summarized[a] his observations as follows:

The Lower Magnesian limestone, as it presents itself north of the Wisconsin River, has many characters which indicate a metalliferous rock. It occurs, as we have seen, in thick and solid walls, massive and durable. It is traversed by rents and fissures of determinate course, of which the walls have but little disposition to crumble and give way. It is intersected by spars, crystallizations, and vein stones, such as usually accompany metallic ores. Along certain parts of its range it bears evident marks of considerable local disturbance, the signs of an adjacent axis of dislocation. It has, as already shown, many points of analogy with the Upper Magnesian limestone of the Mineral Point and Dubuque districts of Wisconsin and Iowa, a rock which has proved itself to be extraordinarily productive in lead ore and has afforded copper ore of excellent quality, which is now smelted, with profit, in the vicinity of the mines. The Lower Magnesian limestone may, in one respect, be considered more favorably situated than the upper as a mineral-bearing rock. It is an established fact in geology that, all other things being equal, the lower or older a rock is the more likely it is to be metalliferous, because nearer the sources from whence experience indicates that metallic materials find their way into its recesses; in other words, because in closer proximity to rocks of igneous origin. But it has been shown that the inferior beds of the Lower Magnesian limestone of the Upper Mississippi lie at least 300 or 400 feet below the lead-bearing beds of the Upper Magnesian limestone and are separated from the crystalline and igneous rocks by the lower sandstones only.

By reference to my former report in 1839[b] it will be seen that it was considered a remarkable circumstance that in a mining district so rich as that south of the Wisconsin River no basalt, greenstone, porphyry, or other intrusive or crystalline rocks had, up to the time of the survey of 1839, been observed there, since these are in general found in place in the vicinity of productive mining districts. But I then expressed my belief, based upon the abundance of metallic lodes in that lead region and upon the irregularities in the dip of the strata in some localities, that granite and trappean rocks could not be far off. This supposition has been fully verified by the present survey. One of the most interesting of its discoveries has been the establishment of the fact that the lowest beds of F. 1, previously described, rest either immediately on crystalline or trappean rocks, or there intervenes but an inconsiderable thickness of metamorphic beds.

There can be but little doubt that the whole mining region of the Mineral Point and Dubuque districts of Wisconsin and Iowa is based upon a syentic and granitic platform, which would, in all probability, be reached by penetrating to the depth of from 2,000 to 4,000 feet.

These facts, taken together, may be considered as favorable to the metalliferous character of F. 2. Fortunately I am able to bring several actual discoveries in corroboration of this inference.

He presents notes on the occurrence of galena at about a dozen localities in Wisconsin and Iowa, mainly upon the Kickapoo, Upper Iowa, and Turkey rivers. He closes the summary with the statement:

"The above instances abundantly prove that the Lower Magnesian limestone, as well as the Upper, is lead bearing; whether productively so or not can not be fully determined until the rock is scientifically mined.[c]

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[a] Owen, D. D., Rept. Geol. Survey Wisconsin, Iowa, and Minnesota, 1852, pp. 61-62.
[b] Senate Ex. Doc. No. 407, 28th Cong., 1st session, 1839, p. 30.
[c] Owen, D. D., op. cit., p. 64.

Percival.—Percival apparently believed that the lower strata would prove productive, as is shown by the following paragraph, quoted by Chamberlin[a] from his report of 1855:

If the mineral is interrupted in the upper sandstone it reappears in the Lower Magnesian. Numerous instances are stated of the occurrence of mineral in the Lower Magnesian in Owen's reports (1847, 1852), and several other localities have been mentioned to me by different individuals, near the Mississippi,and in the country between it and the Kickapoo, north of the Wisconsin. I shall, however, confine myself here to my own observations. I have not yet had time to explore the country occupied by the Lower Magnesian to any extent and have visited no other diggings in that rock but those in the vicinity of Blue River, known as Ohlerking's diggings. These, however, furnish satisfactory evidence that the mineral occurs in that rock in as proper openings, in as large masses, and arranged as regularly as in the Upper Magnesian. The diggings are in the sides of a ravine 60 to 70 feet deep, leading to Blue River, about 3 miles west of Franklin village. The Lower Magnesian occupies the sides of the ravine nearly to the summit, where it is overlaid by a low bluff of the upper sandstone. About three-fourths of the descent below the sandstone is occupied by a steep slope, formed by the softer upper bed of the Lower Magnesian, below which is another low bluff formed by the harder middle portion of the same rock. Three successive openings, one above the other, appear to occur here in the Lower Magnesian; one 8 to 10 feet below the sandstone, another just above the harder middle bed, and a third below the bottom of the ravine in the latter bed, and at a depth of about 70 feet in the Lower Magnesian. The openings appeared partly narrow and vertical, partly wide and flat, with appearances of decomposition and stain in the rock, deposits of clay and ocher, and arrangements of the mineral similar to those in the Upper Magnesian. Flint, such as is peculiar to the Lower Magnesian, is found in the openings, and is connected with the mineral in the same manner as has been noticed in the flint openings in the Upper Magnesian. The mineral in these openings generally appeared in more or less detached masses (chunk mineral), often very large, weighing more than 100 pounds; a few even more than 500 pounds. It is what is called pure mineral, free from iron and zinc ores, aud strongly resembled that found in the upper vertical openings in the Upper Magnesian. After examining this locality, I could not doubt that the Lower Magnesian is a good mineral-bearing rock.

Whitney.—Whitney has given the fullest consideration to the subject, and his views, also quoted by Chamberlin, are given below:

The advocates of deep mining bring forward several instances of the occurrence of lead ore in the Lower Magnesian, where the rock is exposed on the surface to the north of the lead region, from which they infer that it can be profitably mined in, by continuing the workings in the regular lead-bearing rock of the district down into the underlying formations. Now, it might be that the Lower Magnesian could be profitably worked in when it lies next to the surface, and yet that it would not pay to sink to it through a thickness of 100 feet or more of unproductive strata, when necessarily expensive machinery would be required to keep the mines free from water in addition to the increased expenditure for the machinery required for hoisting from a considerable depth. We will go further, and make the assertion, based on pretty extensive observation in the region, that if the present lead-bearing formation, the Galena limestone, were covered by 100 feet of unproductive rock, as difficult to sink through as the upper sandstone, the deposits of lead which it contains could only in very exceptional cases be worked with profit; and as these cases could not be known beforehand, the result, on the whole, would be unsatisfactory. Therefore, even if it be admitted that the Lower Magnesian does contain beneath the lead region as large and valuable deposits of ore as the Galena limestone, it could not be mined with profit except where it crops out in the valleys or is overlaid by only a thin stratum of other rocks. This statement is made, of course, with reference to the present condition of prices, wages, etc., in the lead region.

But on the other hand, we are not prepared to admit that the Lower Magnesian ever has been or is likely to be profitably mined in for lead, either when it comes to the surface or when it is overlaid by other rocks. For the purpose of determining this point, we have examined all the localities where galena has been reported as having been found in any noticeable quantity and are able to affirm that at the present time no profitable mining is carried on in the Lower Magnesian, and that none ever has been for any length of time; and further, that no well-developed crevices, or such as could be followed to any distance, have ever been found in it.

The principal localities which have been quoted and relied upon as affording evidence of the productiveness of the Lower Magnesian are the Kickapoo and Ohlerking's or Moosan's diggings, near Franklin, although neither of these has yielded as much ore or been as worthy of notice as those at New Galena, on the upper Iowa River in Iowa. The last-named diggings are thus described by me in the Iowa Report:

"Along the face of the bluff, in which a thickness of 120 to 150 feet of the Lower Magnesian limestone is exposed, a nnmber of drifts have been extended into the rock a little below its juncture with the sandstone, and considerable galena has been taken out. The limestone at this point is brecciated in its structure, appearing as if it had been partially broken up after its deposition and then recemented; portions of the rock have also a concretionary structure, and its whole appearance is that of a material which

[a] Geology of Wisconsin, vol. 4, 1882, p. 513.

has been subjected to both mechanical and chemical disturbances. The ore appears to be associated with irregular strings and bunches of calcareous spar, ramifying through the rock, but nowhere assuming a regular form, like that of a vein, or appearing to occupy a well-developed fissure. Sometimes a little decomposition of the rock has taken place, which has given rise to a sort of opening, but none were observed which were more than a few inches wide and a few feet long. It is said that between 50,000 and 100,000 pounds of ore had been obtained from these diggings; but it seems hardly possible that the operation should have been on the whole a profitable one; and, taking into consideration the hardness of the limestone and the very limited extent to which it has undergone decomposition in the vicinity of the mineral deposits, we see little to encourage further expenditure at this point."

Since the above was written we have had no further news from that quarter, but consider ourselves safe in presuming that all thoughts of doing a profitable business in the vicinity have been abandoned. Probably over $5 were expended there for every dollar's worth of ore taken out.

The Little Kickapoo diggings were visited by Doctor Kimball in the spirng of 1860, and from his notes I learn that they are occasionally worked by one person, but with no favorable results. A great number of shafts have been sunk for the purpose of proving the ground, some of them to the depth of 40 to 50 feet, and as there is no trouble from water, there is no difficulty in the way of following down the ore, if there were any to follow. There are fissures in the rock without a uniform direction, which lead down to a sort of opening in which the ore is found disseminated in large masses of flint. The material of the opening is ferruginous and sometimes soft, the whole appearance resembling that of the openings in the Galena limestone. The quantity of ore, however, which is found here is too small to repay the labor required to get it out; only about 20,000 pounds have been taken out in the ten years that the locality has been worked over, or about $60 worth a year. It appears, also, from descriptions given me by intelligent miners who had worked at these diggings, that the opening-like character of the rock only extended for a short distance into the bluff, and that on following the deposits beyond the point to which atmospheric agencies have had an opportunity of reaching, the strata became hard beyond all hope of profitable working. There can be no doubt that the locality in question is not one which can be adduced in favor of profitable mining in the Lower Magnesian.

More recently the occurrence of lead ore in this rock, near Franklin, has been made the subject of much comment and given rise to unbounded hopes of profitable deep mining. These diggings, which are known as Ohlerking's or Moosan's old diggings, are situated about 2 miles southwest of Franklin, on a branch of Blue River. The valley is narrow and closed by bluffs, which rise with a steep but grassed slope to a height of 230 to 250 feet, of which the lower 70 belong to the Lower Magnesian and the next 80 to the Upper sandstone, which is overlaid by 70 to 80 feet of Blue, with thin outlines of the Galena limestone on the summit. Doctor Percival says that three successive openings here occur—one 8 to 10 feet below the sandstone, another just above the harder middle bed, and the third below the bottom of the ravine in that bed and at the depth of about 70 feet in the Lower Magnesian.

On visiting this locality in 1859 I found only one person at work there, from whom a very dismal account of the prospect of mining in the Lower Magnesian was obtained. He had sunk a shaft 25 feet deep, from which he had raised about 10 pounds of ore; but I was unable to detect any sign of crevice or opening in theexcavation, and as no other was accessible my impressions were necessarily very unfavorable in regard to the prospects of mining in this formation, especially after listening to the vehement objurgations of this solitary miner against his own stupidity in continuing to "prospect" in so barren a rock. According to this individual the ore obtained here was all taken out "in the grass roots"—i. e., close to the surface—and no crevice had ever been found leading down to anything workable, a statement which agrees with all I have myself observed in the Lower Magnesian.

On the whole, it will be safe to say that no profitable mining has ever been carried on in this rock, and that it is entirely wanting in well-developed crevices or openings promising enough to justify expenditure in proving them. Of course it is not impossible that some locality may hereafter be discovered which shall be worked for a time with profit; but that the Lower Magnesian can be called, on the whole, a "good metalliferons rock" is what we are not, in view of the above facts, disposed to admit.

Murrish.—J. Murrish, in his report of 1871, cited a few localities at which lead had been found; and Strong[a] described several points at which more or less mining had been done.

Chamberlin.—Chamberlin[b] described the mines north of Highland and summarized the conditions up to 1880, as follows:

Mining operations having been recently prosecuted in the Lower Magnesian limestone, near Highland, by Mr. Ohlerking, an examination of the locality was made by the writer in September, and subsequently the drifts were carefully surveyed by Mr. Wilson, who located them upon the surface of the ground and made a topographical survey of the vicinity.

The mine is located on the slope of a ridge, the summit of which is formed by the Trenton and Galena limestones, the steep slope by the St. Peter sandstone, and the base by the Lower Magnesian limestone. The shaft penetrates 45 feet of the sandstone and about an equal depth of the Lower Magnesian limestone.

[a] Geology of Wisconsin, vol. 4, 1882, pp. 77–78.
[b] Ibid., pp. 516–517.

From near the base of this shaft a drift has been extended along an opening in a somewhat irregular course, as follows: In a direction of N. 1° E., a distance of 8 feet 8 inches; thence N. 45½° E. 17 feet; thence N. 82½° E., 31 feet 8 inches; thence N. 67½° E., 14 feet 8 inches, where it divides, one portion continuing on in a course N. 80° E., for 16 feet 6 inches, where the workings terminated at the time of our visit. The other portion extends N. 28° E. for 15 feet 4 inches, where it terminates.

A branch drift commences at 30 feet from the shaft and extends N. 50° E. for 15 feet 4 inches, when it turns to N. 13½° W. and continues 14 feet 8 inches, when it changes again to N. 16° E. for a distance of 16 feet, the limit to which it had been worked. An older drift has a direction, through about 90 feet of its course, of N. 16° E., connecting at its southern end with one extending 30 feet in a direction N. 63½° W. The entire extent of the drifts was about 280 feet. The opening was largely filled with clay and decomposing rock and contained considerable quantities of the reddish, slightly cohesive substance, known among miners in some localities as "joint clay." The wall rock is not well defined, the clay and decomposing material apparently graduating into the modified strata. At the extremity of one of the drifts there was an irregular space between the unmined clay and the arching roof of the opening, and I was informed that this was a common fact. That which is regarded as the cap rock consists of a layer of siliceous dolomite about 1 foot in thickness, over which lies a stratum of greenish blue clay shale, of somewhat irregular thickness, averaging perhaps 6 inches. The openings probably had their origin in fissures around which the rock has decomposed, giving rise to the present clay filling. The lead ore was mostly taken from within the clay, being neither at the bottom nor top. I extracted a piece, however, that was firmly embedded between two undisturbed layers of rock. The ore seen was chiefly in large cubes, considerably worn or corroded on the surface and often coated with the carbonate of lead.

Subsequently Mr. Ohlerking sunk to the depth of 175 feet, developing some further openings, not well defined, containing small quantities of large "chunk mineral." From the bottom of the shaft a boring with a common drill was extended downward to a depth of 84 feet, where the Potsdam sandstone was reached. Mr. Ohlerking is of the opinion, judging from the pulverized drillings, that oxide of manganese occurs in considerable quantity at about 35 feet from the bottom of the shaft to a depth of about 12 or 14 feet. The first 35 feet of the boring seemed to pass through a mass of limestone and flint irregularly mingled. Below this, down to the Potsdam, the formation seems to be limestone in regular layers, from 1 to 2 feet in thickness. The entire amount of ore produced up to 1880 is given at 10,000 pounds.

Calvin.—Calvin, in discussing the geology of Allamakee County, Iowa,[a] described the mine at Lansing, and made the following notes on the general occurrence of galena in the formation:

More or less galena of very excellent quality may be found in all the valleys cut in the Oneota limestone. In eroding the valleys the mineral was weathered out of pockets in the dolomite. Pockets and crevices containing galena are often met with in working quarries in the formation. Some of these have been brought to light by systematic prospecting, but with one exception the mineral has not been found in sufficient quantities to pay the expense of mining it. With the single known exception referred to the galena of the Oneota occurs in small pockets or fissures, a few inches wide, and at most from a few feet to a yard or two in length. There are no regular crevices, and the prospector finds, after penetrating a short distance from the face of the bluff, that the rock around the mineral-bearing cavities is solid and not decomposed by weathering. The work of mining, therefore, is difficult and the reward meager and uncertain.

Leonard.—Leonard reviewed the situation,[b] describing the Lansing mine and the old diggings on Mineral Creek as follows:

The only mine now being worked in this country is that of the Lansing Mining and Smelting Company, located 5 miles northwest of Lansing in T. 99 N., R. 4 W., sec. 10, NW. qr. This is of unusual interest on account of being in the Oneota limestone, in which ore had not previously been discovered except in small quantities. It was, indeed, considered practically useless to look for lead in this formation. Another remarkable fact in connection with this deposit is that it occurs as a vertical sheet in a north-and-south fissure. While these north-and-south crevices are not uncommon in the State, they are usually of limited extent and do not contain large bodies of ore. But here the sheet is an extensive one and does not yet show any signs of giving out. The mine was discovered in January, 1891, by Captain Turner, who had reached the conclusion that lead occurred in the Oneota and had done considerable prospecting at various points.

The location is on a hillside that slopes to the north and east. While the general direction of the crevice is nearly north and south (S. 10° E.), its course is not straight, but zigzags back and forth within certain limits, so that a shaft sunk on a general course of the fissure may be several feet out of the way.

The sheet has been followed 1,000 feet and its limits have not been reached either to the north or south. At the north end of the present workings the fissure is interrupted by a ravine and the sheet thus outcrops. There is reason for supposing that it will be found upon the other side. The main body of the

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[a] Iowa Geol. Survey, vol. 4, 1895, pp. 103–107

[b] Ibid., vol. 6, 1897, pp. 53–57.

sheet has a vertical extent of from 25 to 30 feet, and a width of from 3 to 4 inches. A shaft was sunk 113 feet to the St. Croix or Potsdam sandstone and galena was found in small quantities downward to within 4 or 5 feet of the latter. The bulk of the ore is, however, about 50 feet above the sandstone.

The sheet of lead is either imbedded in the crevice clay or fills the entire space between the rock walls. Where it extends south under the hill and has been little exposed to weathering agencies, the sides of the fissure have not undergone decomposition and the sheet is in contact with the rock. In other places where examined an inch or so of clay was found between it and the limestone, the crevice in this case being from 6 to 8 inches wide. Again, the fissure may open out until it has a width of 3 or 4 feet, and then be filled with clay, with the sheet of ore against the wall. In such a case the ore commonly lies against the east wall, or toward the lower side of the hill. The sheet does not extend vertically to the surface, but in the upper 8 or 10 feet curves over toward the east or down the slope. Evidently there has been a slipping of the hillside which has carried with it the top of the sheet, this bending being a result.

Most of the ore is taken out in pieces of considerable size. The galena is filled with many cavities, often lined with crystals of lead carbonate or cerusite, formed by the alteration of the sulphide. One sample showed 80.55 per cent of lead. The ore contains nearly 4 ounces of silver to the ton. At the present time (November, 1895) the production has reached 500,000 pounds with excellent prospects for the future.

Lead was formerly mined at one other locality in Allamakee County, on Mineral Creek (T. 99, R. 6 W., sec. 13), about 2½ miles south of where it empties into the Oncota. Near the confluence of the two streams a small town, New Galena, sprang up, and during the years 1856–57 prospecting and mining were actively carried on. The mines were in the upper part of the Oncota limestone, not far from its juncture with the St. Peter sandstone. Mineral Creek has cut its valley through this sandstone and well down into the underlying limestone, which here has an exposed thickness of more than 100 feet. This latter rock shows evidence of considerable disturbance, being more or less brecciated, and has been recemented by siliceous material. It is full of cherty, or flinty, matter and is very impure.

The mines were on a hillside and were worked by means of short drifts. Instead of being in crevices the ore occurred scattered through the limestone, necessitating considerable blasting. None of the drifts extended more than 40 to 50 feet from the surface, as the mineral-bearing rock did not reach a greater depth. To separate the mineral great heaps were constructed with wood intermingled with the rock. These were fired, and after the fire had done its work the heat was found to have been insufficient to melt the galena. It had only broken the rock into small pieces. Then this was washed and the mineral was separated. The latter was smelted in a furnace located at the mouth of Mineral Creek. During the two years that the mines were in operation 63 pigs were turned out and this trifling return represents almost the entire product of this district. When the locality was visited early in 1894 some prospecting was in progress, but with little chance of success. Float lead is found quite abundantly in the country, and the Oneota probably contains more or less of this mineral. But is it doubtful whether, as a rule, the ore occurs in well-defined crevices and in amounts sufficient to make the mining profitable.

Summary.—These citations have been given somewhat fully, since no work has been carried on in the Prairie du Chien for some years and it has been impossible to collect new notes on the occurrence of the ores. The fact that in a formation so well exposed and so excellently situated for the discovery of ores practically no ore has been found must argue strongly against any notion of its general productiveness. It is probable that some galena is indigenous, but there are no known reasons for expecting many or large ore bodies to be found. Certainly the ores found in the higher beds have no direct relations to those below, except as the latter have been derived from the former by downward and lateral transfer through erosion and reconcentration.

In areas where the Prairie du Chien is now exposed the Galena and Platteville were formerly present. If they were then mineral bearing, as they are now in the mining region, it is natural to suppose that as they were eroded some of their mineral content became segregated in the dolomite below.

It is impossible to say that further prospecting will not develop ore deposits in the Prairie du Chien. Indeed it is probable that more of such deposits will be found. So far as experience indicates, however, they will not be of the type found in the Galena-Platteville, but may be expected to be vein deposits such as that which was worked at Lansing, Iowa, or some sort of disseminated deposit such as occurs in southeastern Missouri. The hope of finding the latter is not strong, but the ore found on Mineral Creek is reported to have been of this character, and such bodies, even if found in the past, would not have been workable. Under present conditions any such deposit would be worthy of careful investigation.

GENESIS OF THE ORES.

HISTORICAL RÉSUMÉ.

Early references.—The earliest visitors to this region devoted apparently but little thought to the genesis of the ores. They were mainly concerned with their distribution and mode of occurrence. Aside from a vague reference or two in the writings of Featherstonhaugh and Schoolcraft, there is little of record. Apparently they accepted without special thought the then current dictum that ore deposits were the result of the action of deep-seated, ascending, waters. Owen, indeed, briefly discussed the problem and attached some significance to the presence of a "granitic and syenitic platform" at no great distance beneath the productive horizons. In this subsequent investigations have failed to sustain his views, since the pronounced unconformity above these pre-Cambrian igneous and metamorphic rocks was early seen to preclude any direct connection between them and the ore deposits.

Serious study of the genesis of the deposits was initiated with the work of Percival and Whitney. Both of these men began their studies of the region in connection with private mining companies, and each in turn later studied the field under the auspices of the State of Wisconsin. Whitney in addition prepared reports for the States of Iowa and Illinois.

While they began work in the region at about the same time and were both accurate, painstaking observers, they came to opposite conclusions. Percival believed in the deep-seated origin of the ores and referred them to ascending thermal waters acting along faulting fissures. This was the orthodox doctrine of his time. Whitney believed that the ores were concentrated from the surrounding rocks by the action of shallow, descending waters, and failed to find evidence of any considerable faulting. From the first, therefore, these two schools of thought have been represented among the investigators of this region and, while it is fair to say that for many years the consensus of opinion has favored the general theory typified by Whitney's view, there are even yet vigorous dissentients.

J. G. Percival.—In considering the views advocated by Percival it is proper to recall the fact that his studies were essentially preliminary. He died before his work was completed and his second report was issued after his death. It is idle to speculate as to the changes his views might have undergone had he gained a more complete knowledge of the district. His conclusions can be judged only as they are known to us. Percival was an unusually painstaking and accurate observer, and this fact gives importance to his belief in the presence of faulting in the region and its significance in relation to the ore deposits. His beliefs are perhaps sufficiently indicated by the following quotation: [a]

> The opinion expressed in my former report, that the mineral was derived from beneath, is strengthened not only by the general results of my observations in the diggings, but by the appearance of disturbance in the strata, particularly along the line of the great body of mineral traversing the middle of the district and by the relation in the bearing of that body to the extenive ranges of primary and metamorphic rocks toward the northeast, indicating that the mineral may have arisen from a mass of such rocks beneath the secondary strata.

Percival does not seem to have recognized the possible influence of inequalities in original deposition, nor does the fact then appear to have been recognized that differences in the lithology of the same bed could be due to differences in the depth to which dolomitization had extended. To these two causes, supplemented by gentle deformation, are referred the phenomena which he interpreted as faulting. So far as present observations go no faulting of more than a few inches is known in the region. This matter has already been discussed on page 43.

J. D. Whitney.—In sharp antithesis to Percival's belief in derivation of the ores from below, with localization along faulting fissures, stands the theory advanced by Whitney. As a result of studies, extending through several years, he concluded that the metals were originally precipitated from the sea at the time the surrounding rocks were formed and

[a] Ann. Rept. Geol. Survey Wisconsin, 1856, p. 63.

were later concentrated in their present situation by the action of ordinary underground water. He appealed to organic matter as the cause of the original precipitation and thought that the Ordovician seas contained unusual amounts of the metals. The localization of the deposits was explained as due, in part, to the presence of unusual amounts of organic matter and in part to opportunities for secondary concentration.

This was the first application to this region of the theory of lateral secretion, as it came later to be termed, and Whitney's main contribution was his recognition of the fact that the ores were derived from the surrounding rocks and concentrated by the circulation of ordinary underground water. The clear recognition of these facts at so early a period, and in the face of current opinion to the contrary, is notable. Whitney's explanation of the localization of the deposits has not appeared altogether convincing to subsequent workers, and he left many details of the processes of both original deposition and subsequent concentration to be worked out. The importance of the zinc deposits was almost wholly unrecognized, and his studies were necessarily confined almost entirely to the deposits found in crevices and openings. The considerable differences between them and the lower-lying bodies now being worked would seem to warrant inquiry as to whether the explanation offered by him applies to the whole of the deposits.

T. C. Chamberlin.—The second geological survey of Wisconsin devoted elaborate study to the lead and zinc region. Strong, who began the work, did not live to complete his study of the material collected and accordingly contributed little to the discussion of the theoretical questions involved. This work fell to Chamberlin, and in the paper already so frequently cited[a] he has given much the most complete consideration of this phase of the subject that has yet appeared.

In general, Chamberlin's conclusions are founded on those of Whitney and advance the theory of the latter to much greater precision of detail. On the fundamental question of the source of the material he agrees that the metals, originally derived from the crystalline rocks in the area to the northeast, were, during the process of sedimentation, disseminated through the Galena and Platteville beds. This conclusion he reached, as did Whitney, mainly by the elimination of other sources from consideration, but the result was checked by a calculation showing that the amount of material necessary to produce by concentration the richest known ore bodies was very small, "one fourteen-hundredths of 1 per cent."[b] The cause of the regional location of the deposits was found in the paleogeography of the Mississippi Valley and a hypothetical mapping of ocean currents such as to produce a shore current and large eddy in the region. This was thought to be favorable to the unusual accumulation of organic matter, particularly of plant remains, with consequent reduction and precipitation of the sulphides.

The minor localization of the deposits was explained by the observed fact of their occurrence in "synclines," which were held to be in part depositional and to have furnished favorable conditions not only for original precipitation but for later concentration.

The process of concentration was studied in detail and both the direction of underground flow and the nature of the chemical reagents and reactions involved were considered. The vertical order of the deposits, galena above and blende below, was noted and a suggestion was made as to its explanation through "selective chemical affinity."

Chamberlin's conclusions have stood the test of time remarkably well. In some particulars they have been criticised; in others additional information has brought greater certainty or more detail. The specific criticisms and changes involved will be discussed in detail later.

W. P. Blake.—In 1893 Blake, after spending two years at Shullsburg in the development of zinc properties, recurred to Percival's opinion regarding the presence of faults in the area.[c] He, however, followed Whitney and Chamberlin in believing that the ores were

[a] The ore deposits of southwestern Wisconsin: Geology of Wisconsin, vol. 4, 1882, pp. 365–571.
[b] Op. cit., p. 538.
[c] Bull. Geol. Soc. America, vol. 5, 1894, pp. 25–32; Trans. Am. Inst. Min. Eng., vol. 22, 1893, pp. 558–568; 621–635.

derived from the surrounding rocks rather than from below. He emphasized, without attempting to explain, the fact that the deposits were found in a driftless area. His main contribution was the pointing out of the importance and significance of the oil rock, though in explaining the presence of the hydrocarbons in it he had recourse to a theory of submarine exhalations of which there is no independent evidence and for which there is now no necessity.

W. P. Jenney.—At the same time that Blake wrote, Jenney discussed the region,[a] going back entirely to Percival's notion of derivation of the ores from indefinite depths, with localization along faulting fissures. His observations were mainly upon ore deposits in the Ozark region, though he spent a short time in the upper Mississippi region. His arguments were based upon analogy and certain broad generalizations regarding ore deposits in general.

Arthur Winslow.—Winslow, as a result of his studies in Missouri, arrived at the conclusion that the Ozark ores were altogether the result of secondary processes.[b] He believed them to have been concentrated in their present position as a result of the decomposition and erosion of overlying beds. He suggested that this theory might also prove applicable to the deposits in the upper valley. He called attention to the wide distribution of lead and zinc, and at his suggestion J. D. Robertson made a number of large quantitative analyses of the rocks of the Ozark region. The limestones, including evidently dolomites, showed an average content of .00198 pound of galena per cubic foot of rock and .0063 pound of blende. The largest percentages of the metals were found in the crystalline rocks, but the number of analyses was not considered sufficient to establish this as a rule.[c]

A. G. Leonard.—In 1896, as a result of studies of the Iowa deposits, Leonard pointed out difficulties in accepting Winslow's explanation arising from the presence over much of that area of the thick, impervious Maquoketa shale. He adopted Chamberlin's explanation both of the origin and localization of the ores, stating that "it furnishes, on the whole, the most plausible explanation yet offered for the localization of the upper Mississippi deposits."[d]

Calvin and Bain.—In 1900, after studying the Dubuque deposits, Calvin and Bain accepted in the main the conclusions of Whitney and Chamberlin. They checked the suggestion regarding the presence in the country rock of the metals in disseminated form by large quantitative analyses similar to those made by Winslow and called attention to the close association of the deposits with dolomite, suggesting that the conditions which produced regional dolomitization of the Galena were favorable to the original precipitation from sea water of the metals.

C. R. Van Hise.—At about the same time Van Hise discussed the general principles controlling the deposition of ores[e] and applied them to the deposits in this region. In this paper several important advances were made. The theory of the derivation of the ores from the surrounding rocks was accepted. Their localization was explained upon a wholly new basis, namely, that they were clustered round the outlets of an older artesian circulation which had first concentrated material that had been widely diffused through the region. The present ore deposits were held to be the result of a second concentration by downward-flowing waters that acted essentially as had been postulated by Chamberlin. The details of this process were elaborated and in particular the present vertical order of the deposits was explained as a result of the process now called "secondary enrichment." This paper attracted wide attention and greatly stimulated the study of ore deposition in the Mississippi Valley. Van Hise and Bain[f] worked out the application of the principles to the Joplin district and held them to be very probably applicable to the other districts in the Mississippi Valley.[g]

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[a] Trans. Am. Inst. Min. Eng., vol. 22, 1893, pp. 208–212.
[b] Missouri Geol. Survey, vol. 7, 1894, pp. 477–487.
[c] Op. cit., p. 482.
[d] Iowa Geol. Survey, vol. 6, 1896, p. 61.
[e] Trans. Am. Inst. Min. Eng., vol. 30, 1901, pp. 27–177.
[f] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, pp. 22-227.
[g] Inst. Min. Eng., London, 1902, reprint, p. 59.

U. S. Grant.—In 1902 Grant took up the restudy of the Wisconsin mines and in 1903 published a preliminary report in which he accepted Van Hise's conclusions regarding the genesis of the ores. In a second report attention was directed entirely to the distribution and structural features of the deposits under an arrangement whereby the further study of their genesis was taken up by the writer.

Résumé.—From this brief review of the opinions of earlier workers in this field it is apparent that in recent years the general disposition has been to concede that the ores originated through some phase, at least, of lateral secretion. The theory that the ores were derived from deep-seated sources has been appealed to only on the basis of analogy and general principles. The main difficulties in the way of accepting the doctrine of the genesis of the deposits through lateral secretion have grown out of the problem of the localization of the deposits. To meet these difficulties two sorts of hypotheses have been advanced; first, that the material was originally somewhat unequally distributed through the rocks as a result of varying conditions of sedimentation, and second, that the material was originally approximately evenly diffused and that present inequalities are the results of the manner and degree of later concentration. The views of Whitney and Chamberlin are typical of the first group; those of Van Hise and Winslow of the second.

STATEMENT OF THE PROBLEM.

Before entering upon a detailed account of the results of the present studies as they relate to the genesis of these deposits it may be helpful to review briefly the facts of occurrence which any satisfactory theory must take into account. These relate to (*a*) geographic distribution, (*b*) geologic position, and (*c*) mode of occurrence.

GEOGRAPHIC DISTRIBUTION.

By referring to the description already given it may be noted that there are two facts of geographic distribution which must be considered. The first is the limitation of the mining area to a certain definite part of Wisconsin, Iowa, and Illinois, and the second is the distribution of the deposits in camps or districts within this region. The reason for the major distribution is by no means obvious, since the Galena formation, in which the deposits mainly occur, has a wide extent through the other parts of the States concerned. For many miles to the southeast equivalent beds extend in characteristic development, with apparently abundant opportunity for secondary concentration of such ores as may be present, but without any such concentration having taken place. In eastern Wisconsin the Galena formation again appears well developed and without ore, and in Missouri, even where the same horizon is developed within a lead-zinc region, it is barren. If attention be directed to the underlying Platteville, much the same state of affairs is found. In the case of the Prairie du Chien it is true that ore occurs in equivalent beds in the Ozark region and that there are small scattered occurrences of lead and zinc minerals in much of the area north of the Wisconsin River. The fact, however, remains that outside the mining region this, as well as the Galena, is barren.

To say that the distribution is conditioned by the absence of the drift only partially satisfies the conditions, since there are broad barren areas of all these formations quite as free from drift as are the productive areas. This leads to a consideration of the second important fact of geographic distribution—the segregation of the deposits into definite districts and camps with barren areas between. This segregation, which was early recognized and which has become more and more defined as prospecting has gone forward, is one of the most difficult facts for any theory of genesis to explain.

GEOLOGIC POSITION.

To satisfactorily explain these deposits, account must be taken of their abundance in the Galena, their sparse distribution in the Prairie du Chien, and their practical absence in the Niagara, all of which are, in the main, lithologically similar rocks developed in the same region. The distribution of the ores from the top of the Galena even up to the actual contact with the Maquoketa down to the glass rock of the Platteville, their particular abundance in the upper Platteville and lower Galena, and their practical absence from the dolomite quarry beds in the lower part of the Platteville also call for explanation. The presence of the ore deposits mainly, at least, in the shallow basins or synclines which characterize the area and their practical absence elsewhere is probably also significant.

MODE OF OCCURRENCE.

The distribution of the ores in crevices, openings, pitches, and flats, particularly their relations to the latter unique form of ore body must be taken into account. The pitches and flats, so far as observation and reading show, constitute a form of ore body almost peculiar to this district. Certainly nowhere else is it so well developed or so common as here.

The association of the ores, their general freedom from gangue minerals, the simplicity of the association and the absence of the complex arsenides, antimonides, and sulpharsenides which mark similar ores in the West, the practical absence of silver and the entire absence of gold must all be taken into reckoning. The order of deposition, the relations of the sulphides to each other in the ore bodies, in vertical order and in relation to underground water, all these are important and significant. An explanation, to be satisfactory, must offer a rational cause for all. It is clear that the facts of distribution and occurrence may be accounted for by factors relating to the primary origin of the ores or to their secondary reconcentration or to both together. It will be helpful, therefore, to consider, first, the original source of the metal; second, the processes by which they have been concentrated to form ores, and, third, the details of the processes through which they have been altered and reconcentrated, if it proves that there has been more than one stage of concentration.

ORIGINAL SOURCE OF THE METALS.

OBJECTIONS TO THEORY OF DEEP-SEATED ORIGIN.

That the ores were concentrated from the surrounding rocks is now so generally conceded that it is necessary only to mention the principal objections to any hypothesis which would derive them from lower horizons. No veins in this district are known to attain more than a limited depth, despite the fact that mining has been carried on actively for nearly a hundred years. The veins worked have none of the usual characteristics of the "true fissure veins" of the West, slickenside and gouge being almost entirely absent, the ore shoots having their major axis in a horizontal rather than a vertical direction and the association of the ore minerals and gangue being strikingly different. It is believed to be significant that in those ore deposits of the Mississippi Valley which may be assigned with some confidence to a deep-seated source—those of southern Illinois and southwestern Arkansas—the association of minerals and the mode of occurrence are entirely different.[a]

It has been shown that there is practically no faulting in the upper Mississippi region and that igneous rocks are entirely absent. The region is an exception to mineral districts in general in the very slight amount of deformation which has taken place. It is true that, as a whole, it is within a warped area, and that the exact nature and cause of this post-Tertiary warping are as yet unexplained. This broad gentle deformation has no relation to the ore deposits which has yet been made out, and it is far from certain that it is to be correlated even with the shallow local synclines in which the deposits actually occur.

Aside from these negative objections, there are certain positive difficulties in the way of believing in a derivation of the ores from below. Their present position, as shown by the field evidence, indicates clearly that they came from above. The presence of stalactites of ore and the general disposition of the ore bodies to flatten out in broad sheets on top of every impervious bed admits of no other explanation. This, it is true, proves nothing as

[a] Bain, H. F., Fluorspar deposits of southern Illinois: Bull. U. S. Geol. Survey No. 255, 1905, pp. 61–67.

to the original derivation of the ores, since the last step in the process is ever the most evident one, but it may certainly be questioned whether the ores could have come up from below without somewhere showing evidence of the fact. There should be at least a reasonable number of segregations of ore under, as well as above, impervious beds, particularly in the lower-lying unoxidized beds, where later reconcentration has presumably been least effective. The accompanying descriptions of the mines will, it is believed, convince any one of the almost entire absence of such relations.

The lower portion of the Platteville, the "quarry beds," is a massive dolomite, similar in all essential particulars to the Galena. It is apparently well suited to contain ore bodies and is well exposed to observation. It is almost entirely barren, and on any hypothesis of derivation from below it is difficult to assign a cause for the transfer of the solutions through this favorable bed to higher horizons before deposition occurred.

Another difficulty is found in the presence beneath the district of the great aquifers of the Cambrian and the St. Peter sandstone. These porous beds are charged with artesian water, and it is difficult, if not impossible, to conceive any process by which heated ore-bearing solutions could rise through them without becoming diffused.

These various difficulties never have been met by any of the advocates of a deep-seated origin of the ores, and until they are met it is useless to appeal to any such hypothesis.

ULTIMATE SOURCE OF THE METALS.

For the original source of the zinc and lead we must doubtless look to the crystalline rocks of the Lake Superior region. It is from this region that the lime, magnesia, and sand now found in the formations of the zinc and lead region came. In Canada[a] and in northern Minnesota[b] there are scattered deposits of the ores of these metals in the older formations, which were exposed to erosion in Platteville and Galena times. During these epochs the region was apparently base-leveled and the drainage from a wide area reached the bordering seas. Mechanical erosion was at a minimum and solution was active. Magnesium, lead and zinc have many chemical reactions in common, and it would seem inevitable that where one of these metals was transported in quantity from the land to the ocean, the others would follow, and that certain amounts would be deposited.

ZINC AND LEAD IN CAMBRO-ORDOVICIAN ROCKS.

These entirely theoretical, though, it is believed, well-founded considerations, may be confirmed by a certain amount of direct evidence. It is very commonly true that the Cambro-Ordovician dolomites and limestones of the Mississippi Valley show the sporadic occurrence of lead and zinc. To a less extent the same thing is true of the other limestones and dolomites of the area. All of the productive deposits of the valley, except those in southwestern Missouri[c] and in the southern Illinois districts[d] are in this series of beds. These districts are believed to represent special cases.

This widespread occurrence of the ores can represent only an equally widespread distribution of the metals that enter into their composition. Many of the limestones and dolomites of the Mississippi Valley that lie far from any known body of mineral and are quite barren when examined by ordinary methods of analysis show notable percentages of both lead and zinc when tested by the large quantitative methods used by Winslow and Robertson.[e] In the following table the results of similar tests made by J. B. Weems on rocks occurring near Dubuque are given. While the percentage of the minerals is in no case large, the total amount by acre or square mile of the formation, assuming that the specimens represent average conditions, is sufficient to account for the largest leads in the region.

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[a] Rept. Ontario Bureau of Mines, 1903, p. 25; 1904, pp. 11, 87; Ontario Lead and Zinc Company's Rept. on property, by C. M. Boss, pamphlet, 15 pp., Duluth, 1903.

[b] Seventh Ann. Rept. Geol. and Nat. Hist. Survey Minnesota, 1878, pp. 14-21; Final Rept., vol. 5, 1900, p. 439.

[c] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, pp. 207-212.

[d] Bull. U. S. Geol. Survey No. 255, 1905, pp. 61-67.

[e] Missouri Geol. Survey, vol. 7, 1894, pp. 740-742.

Analyses of Dubuque limestones and dolomites. [a]

	Analysis No.	H_2O.	Insol.	CaO.	Fe_2O_3.	SO_3.	P_2O_5.	MgO.	CO_2.	Org.	Total.	Dolomite.	Limestone.	Excess CO_2.	Less CO_2.	PbO.	Pb.	ZnO.	Zn.	Rock No.
Blue rock from Halpin mine at depth of 40 feet in Galena....	37	0.06	1.55	30.23	0.82	1.52	0.45	19.39	45.19	1.42	100.63	88.89	5.83	0.09	......	0.00633	0.00587	0.00090	0.00072	304
Niagara, Cascade, Iowa........	38	.26	11.34	27.19	.81	......	.60	17.78	41.46	.82	100.26	77.13	8.80	.50	......	.00567	.00525	.00020	.00016	305
Lower buff beds, Sageville, Iowa	39	.10	1.08	30.78	.90	......	.64	18.34	44.37	3.41	99.62	84.39	9.14	......	......	.00501	.00465	......	......	306
Trenton limestone, Sageville, Iowa..........................	40	.04	7.63	50.15	.62	......	.61	1.21	39.56	.77	100.59	7.62	86.26	......	2.96	.00611	.00567	......	......	307
"Upper thin beds," section 33, Dubuque township...........	41	.06	5.23	28.95	1.15	......	.46	18.54	44.00	.96	99.35	83.01	7.61	.87	......	.00302	.00280	.00050	.00040	308
Niagara, Sherrills Mound......	42	.05	3.24	30.01	.74	......	.52	18.99	44.91	1.34	99.80	86.71	6.75	.45	......	.00065	.00060	......	......	309
Galena below cap rock (first opening), Tibey quarry......	43	.05	3.33	34.56	1.26	......	.37	15.30	43.34	1.25	99.46	76.08	19.07	......	1.65	.00109	.00101	......	......	310
Lime-burning rock, Eagle Point	44	.02	2.15	30.72	.82	......	.60	19.90	45.91	.13	100.25	94.14	2.47	......	.08	.00155	.00143	......	......	311
Nonlime-burning rock, Eagle Point..........................	45	.04	8.63	28.86	.85	......	.51	18.82	42.08	1.07	100.86	84.13	6.92	......	1.29	.00221	.00204	.00170	.00136	(?)
	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	Avg.	.00326	......	.00029	......
	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(b)	.00376	(c)	.00043	......

[a] Analyses by J. B. Weems, Iowa Geol. Survey, vol. 10, 1900, p. 567. [b] Average PbS. [c] Average ZnS.

NOTE.—1 cubic foot rock weighs 170 pounds: 2,269,664 tons rock per square mile 1 foot thick. Galena, 95.33 tons per square mile 1 foot thick. Blende, 9.76 tons per square mile 1 foot thick. Galena, 19,066 tons per square mile 200 feet thick. Blende, 1,952 tons per square mile 200 feet thick.

The presence of the metals in the rocks in widely disseminated and minute quantities is obviously susceptible of two interpretations. In all mineral districts, even those where the veins are most persistent and most sharply defined, the ore has a greater or less tendency to spread out from the veins proper and impregnate the country rock. In a region much cut up by veins the country rock may become so thoroughly mineralized that it may itself be an ore.

It is clear that the action of circulating waters may tend either toward dissemination or toward concentration of a particular substance, and that the effects of this action will depend upon a number of factors, including the chemical character of the substance, of the solution, and of the country rock, and the rate, direction, constancy, and duration of flow, and the temperature and pressure of the circulating solution. A set of conditions under which ore occurring in definite veins might become thoroughly disseminated is so possible that doubtless much ore, even in the region under discussion, has been so distributed. It is not, however, believed that this is true of the bulk of the ore bodies. In order to make such a conclusion valid it would be necessary, first, to demonstrate that the vein fillings were themselves of deep-seated origin and were not due to lateral segregation, since the process of concentration is as common and easy of occurrence as that of dissemination. If it be definitely proved that the vein deposits of this or any other ore district had their origin in deep-seated causes, then the probability is that any disseminated ore has been carried out from them, and in such a case it would be expected that the quantity of ore so found would regularly decrease with increase of distance from the vein. In any other case the burden of the proof is upon those who hold the widely disseminated and minute quantities of the metals to be wholly secondary. Against such a view there are certain objections which may be justly urged.

DEPOSITION OF ZINC AND LEAD FROM THE SEA.

It is a well-established fact that minute quantities of all the common metals occur in sea water. A few years ago J. R. Donn[a] investigated this question afresh and confirmed the earlier findings. If the metals occur in minute quantities in the sea it is difficult to understand why they should not be supposed to occur in minute quantities in sedimentary rocks which are formed in the sea. If calcium and magnesium, which occur in larger though still small quantities in ordinary sea water, can be deposited either by chemical or other agencies, why not lead, zinc, and iron? The mere statement of the case is sufficient to show the inherent probability of its occurrence. Again, in some of the analyses quoted and in others given by Winslow and Robertson,[b] the metals are found in rocks miles from any known or probable vein deposit. In ordinary field work nothing is more common than to find small quantities of metallic sulphides in undisturbed rocks, wholly outside known mineral regions. Such an instance is the occurrence of blende and of millerite, as reported by Keyes[c] at Keokuk, and of blende in the limestone of Van Buren County, Iowa, and elsewhere. Blende occasionally occurs in the septarian nodules of the Coal Measures; and iron sulphide is one of the most widely distributed of minerals. To assume that all of these occurrences are due to a wandering of ore from some vein deposit requires better proof than has yet been given. It may be impossible to prove that the metallic sulphides are absolutely original rock constituents, except where they form the basic constituents of pyrogenetic rocks, yet something must be allowed to probability, and up to the present it would seem that the evidence may justly be interpreted to mean that, except when found in definite association with veins of known or probable deep-seated genesis, disseminated metals are probably original. So far, therefore, as this evidence goes it would seem to warrant belief in the widespread distribution in the common sedimentary rocks of those metals which characterize ore deposits found in such rocks—iron, lead, zinc, and, to a less extent, copper.

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[a] Trans. Am. Inst. Min. Eng., vol. 27, 1897, pp. 612–621.
[b] Missouri Geol. Survey, vol. 7, 1894, pp. 479–482.
[c] Iowa Geol. Survey, vol. 1, 1893, p. 187.

It has been common to assume that zinc and lead, so far as they are disseminated through the sedimentary rocks, exist largely as sulphides, though Winslow specifically disclaims any knowledge on this point.[a] The assumption is apparently based upon the facts that the most minute quantities with which we are familiar in the unoxidized rocks occur as sulphides, and that the conditions of precipitation along the sea bottom very largely favor the throwing down of the metals in this form. Whether the metals be brought to the ocean as sulphates, in which form they are particularly soluble, or as carbonates, chlorides, or in other combinations, the decaying organic matter present in the sea bottom of certain areas would seem likely to transform them to sulphides. It is known that some forms of marine life contain zinc and lead in their tissues, but in the main it is probable that these metals are precipitated directly by the ordinary chemical reactions involved in reduction and sulphurization. This would require that at any given point the sea water should be saturated, for those particular conditions, with the metal to be thrown down, and that it should remain saturated until the particle precipitated was sealed up in the rock.

While there are some reasons for believing that the composition of sea water differs notably in various portions of the ocean, even when there are no land barriers, we have no evidence that sea water over a wide area has ever become actually saturated, as that term is commonly understood, with the metals concerned. Such concentration has been calculated by Fuchs and De Launay to require the evaporation of 49,000 kilometers of sea water per square meter of surface in order to produce a layer of zinc sulphide 1 centimeter thick.

It is a common statement that the sea is not even saturated with either calcium or magnesium, both of which are much more abundantly present in it than the metals under discussion, and both of which are commonly deposited from it by some process or combination of processes. According to the laws of physical chemistry the sea, until saturated, should be capable of taking the various elements into solution when in contact with them, rather than throwing them out. It is, however, a fact of observation that broken masses of coral, originally secreted from sea water, are cemented together by calcium and magnesium carbonate. This would seem to show that the conditions of saturation of sea water are not well understood, and that much less material need be present to permit precipitation than ordinarily is thought. Certainly any process which tends locally to increase the amount of material or to decrease the amount of water present would be favorable to precipitation. Such locally acting agencies might, in conjunction with other processes, lead to the deposition of material which would have remained in solution had either been operating alone.

CONCENTRATION IN ORIGINAL SEDIMENTS.

Whether the material was widely and evenly diffused or somewhat locally and unevenly gathered in certain areas of rock seems incapable of direct determination by means of the data available. Sedimentary processes, taken as a whole, seem well adapted to bring about the segregation of similar material. The silica, calcium, and magnesium widely distributed through rocks are brought together and form sandstone, limestone, and dolomite. Sedimentary rocks in general are much simpler in composition than igneous rocks; that is, the bulk of a sedimentary rock is usually made up of fewer constituents than the bulk of an igneous rock. If, therefore, the sedimentaries be derived from the igneous the process must be one of sorting and segregation. There is independent evidence of this in the case even of one of the heavy metals. The Clinton iron ores of the eastern United States seem to have resulted directly from sedimentary processes. The iron widely scattered through the rocks tributary to the Clinton seas was, through erosion and deposition, concentrated even to the extent of forming workable ore bodies. The black-band ores of the Carboniferous afford another illustration, and even the lean, cherty iron carbonates from which the Lake Superior iron ores were concentrated themselves represent concentrations brought about in the process of sedimentation.

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[a] Missouri Geol. Survey, vol. 7, 1894, p. 483.

It would seem, therefore, that in those cases where direct proof is available sedimentation tends toward the concentration of particular minerals in locally favorable areas.

In the present case it is entirely possible that there may have been such an original unequal distribution of metallic minerals, notwithstanding the fact that this has not been made evident by the analyses so far made. No very certain plan of sampling and analysis has yet been formulated for testing this matter. If the locus of the present ore bodies be that of rock originally richer in the metals, the concentration which produced the ore bodies should have impoverished the country rock. Since, further, it is highly improbable that considerable amounts of the metals should have been precipitated in favorable areas without at least some having been precipitated in less favorable ones, it would seem that at present the originally rich but now lean ore near the deposits might either equal, surpass, or fail to equal in metallic content the originally leaner ore between. It is furthermore so difficult to eliminate entirely the possibility of any secondary concentration that the exact condition of the rock sampled is not always certain. The best which may be hoped for is to determine whether any areas offered conditions that might be thought particularly to favor such precipitation.

Attention has already been called to the fact that the Galena formation, in which most of the ores occur, is a dolomite, and the conditions under which it was formed have been discussed. It is believed that these conditions—shallow sea water, warm and probably somewhat concentrated by evaporation—were favorable to the precipitation of the zinc and lead, as they undoubtedly were to the precipitation of magnesia.

These general conditions were, however, operative, so far as can be determined, in southeastern as well as southwestern Wisconsin, and, in fact, at various times and in many places in the Mississippi Valley. The conditions must therefore be thought of as widely acting and as contributory to the final result rather than as determinative, and it remains to inquire whether field evidence affords any clue to a local agency which might have affected the original distribution of the metals. The inherent probability of such agencies has been already suggested.

LOCALIZATION OF THE ORE DEPOSITS.

ORIGINAL INEQUALITIES OF DEPOSITION.

The present ore bodies are believed to have been formed mainly by the reduction of sulphates to sulphides as a result of the mingling of solutions and reactions between ore-bearing solutions and organic matter in the country rocks. To a subordinate degree the sulphurization of carbonates has probably taken place. It seems altogether likely that the original precipitation of the materials from the sea water occurred through the same reactions. If this be true, any original localization of material may have been due to—

(a) Local abundance of the metals in solution.

(b) Local abundance of the organic reducing matter.

(c) Locally peculiar organic matter, leading to particular efficiency in producing deposition.

Local abundance of the metals in solution.—Since lead and zinc are doubtless unequally distributed in the crystalline rocks to the north, it is entirely possible that drainage reaching the Ordovician seas might have brought more of the metals in solution to certain portions of the coast than to others. The composition of river water varies greatly,[a] and it is entirely possible that one or two streams tributary to the sea in the present mining region brought down unusual amounts of lead and zinc. This hypothesis is wholly unverifiable from present data. The only direct evidence favoring it is the fact that the structural basins in which the ores now occur are suggestive in shape of embayments at the mouths of streams or drowned river valleys. The presence within them and not generally elsewhere of considerable amounts of mechanical sediment deposited during a general period of base leveling is, furthermore, suggestive of nearness to rivers. These rivers, because of their

[a] Chamberlin and Salisbury, Geology, vol. 1, 1904, table opposite p. 102.

long, linear courses, would show, in the bringing in of mechanical sediment, the effect of uplift at any point in a wide area.

It may therefore be noted that such slight evidence as is available confirms rather than opposes the notion that there were originally rich and lean patches of rock.

Local abundance of organic matter.—It is to the local occurrence of organic deposits that Whitney and Chamberlin have appealed for an explanation of the localization of the ores. Whitney evidently had in mind the organic matter due to the decay of animals such as form the ordinary fossils found in the rocks, though the agency of long branching sea weeds was also called into requisition.[a] The notion that abundant animal life first appeared about the time those deposits were formed, causing the precipitation of metals from a "primeval ocean," was long ago proved to be incorrect. It is furthermore a fact that the ore deposits within the district do not show that close relation to the more fossiliferous rock which the theory would seem to demand. It is also true that, so far as these forms of life are concerned, the Galena and other formations of this region seem equally fossiliferous entirely outside the ore-bearing area.

Chamberlin appealed to local abundance of fossils of the ordinary type, of seaweeds, and of fucoids.[b] He mapped the sea currents of the Ordovician in such a way as to show the possibility of the formation of a sargasso sea in the region, but did not deem the latter essential.[c] His most important suggestion was that the irregularities of the sea bottom would lead to the accumulation of organic matter in the basins. These depressions were judged to be—

> more favorable to the life and growth of average marine species than the more exposed elevations of the sea bottom. But, however that may be, it is altogether certain that the movable remains of dead organisms would be mainly accumulated in the depressions, and that all floating material would find lodgment there. So that the depressions of the original ocean bottom were the areas in which were concentrated the organic matter to whose agency the removal of metalliferous solutions from the ocean is to be attributed.[d]

The importance of this observation arises from the fact that these original basins became later the locus of deformation and are the present "synclines" within which the ores are found. That this is a true cause can hardly be doubted, but it by no means follows that there were not other causes, contributory if not actually coordinate in importance.

Local abundance of peculiar organic matter of particular efficiency in producing deposition.—"Organic matter" is a loose general term covering a very large variety of compounds. These have markedly different efficiencies in the reduction of sulphates to sulphides and in other reactions. Jenney[e] has devoted particular study to this matter and has calculated what he calls the relative reducing power or duty of equal weights of a considerable number of organic and inorganic compounds. In his table hydrogen oxidized to water is taken as a standard and to this is given a value of 100.

A few of the more important values are given below:

Relative reducing power of various elements and compounds.

Hydrogen, oxidized to H_2O	100.00
Marsh gas (CH_4), oxidized to $H_2CO_3+H_2O$	50.00
Petroleum (C_nH_{2n+2})	43.36
Carbon, oxidized to CO_2	33.33
The "humus acids" ($C_mH_nO_p$)	18.04
Carbon, oxidized to CO	16.67
Sulphureted hydrogen (H_2S), oxidized to H_2SO_4	23.53
Pyrite and marcasite (FeS_2), oxidized to $Fe_2O_3 3H_2O$ and S to SO_3	12.50
Blende (ZnS), oxidized to ZSO_4	8.25
Carbon monoxide (CO), oxidized to CO_2	7.14
Galena (PbS), oxidized to $PbSO_4$	3.35

[a] Geology of Illinois, vol. 1, 1866, p. 199.
[b] Geology of Wisconsin, vol. 4, 1882, p. 536.
[c] Op. cit., p. 533.
[d] Op. cit., p. 537.
[e] Jenney, W. P., The chemistry of ore deposition: Trans. Am. Inst. Min. Eng., vol. 33, 1902, pp. 445–498.

It is evident from this table that it is very material in what form the organic matter is present. The rate of decomposition is also important. If very slow, the amount of material available at any one time may be so small as to produce no appreciable effect. If very fast, the whole of the material may be given off as a gas or light oil, precipitating only the small amount of metal present at one time in the sea. If neither too fast nor too slow, the escaping gases and oils may rise through the sea and even through a considerable thickness of sediment, continuing indefinitely to precipitate such suitable metallic solutions as come within their sphere of contact.

In the scattered irregular bodies of oil rock we have an agency eminently suited to this rôle. Chamberlin mentioned the carbonaceous shale "in the lower part of the Galena and upper part of the Trenton"[a] as one of the precipitating agents. It remained, however, for Blake to recognize the preeminent importance of this material. So impressed was he with its petroliferous character that he suggested the possibility of submarine exhalations of petroleum to account for its richness, or of submarine fresh-water outflows to kill suddenly large numbers of animals, and so give rise to the excess of organic matter. Neither of these ingenious hypotheses proves to be necessary, since David White's microscopic investigations show the oil rock to be made of minute, probably unicellular algæ. These are not only organic, but had, seemingly, the power to collect hydrocarbons from the water and store them in their cells. Upon decomposition these hydrocarbons would be given off both as a gas and as oil. This material even now is capable of giving off 57 volumes of gas, as shown by Mr. Rollin Chamberlin's test, and the analysis of the gas indicates that it consists largely of hydrogen, marsh gas (CH_4), and light hydrocarbons of the sort which have a high reducing power.

It already has been shown that the oil rock, so far as it occurs in any thickness at all, has a very patchy distribution. It is practically confined to the structural basins in which the ore deposits occur, and is at least generally absent from the barren areas between. Whether it occurs in the surrounding region is not certain. It is present at Freeport, Ill., but beyond that nothing is known of its distribution. For present purposes it is sufficient to note that within the zinc and lead region it has an irregular distribution, coinciding with the irregular distribution of the ores, and that it is material eminently suitable to reduce and precipitate sulphides of the metals as well as furnish sulphur to unite with their carbonates.

At the writer's request, Mr. F. F. Grout has kindly tested the reducing power of oil rock from the Dugdale prospect with the following results:

To one-fourth gram of air-dried oil rock and 100 cubic centimeters of water was added .005 gram of iron as ferric sulphate. This was acidulated with 5 grams H_2SO_4, and a similar portion was rendered alkaline with .1 gram KOH. After standing a week the amount of iron present as a ferrous salt was determined with $KMnO_4$. It was found that in the acid solution the amount was .0035 gram and in the alkaline .0012 gram.

If even now this material has such a prompt reducing action it may well be supposed that when first formed this action was much more important.

That the oil rock has suffered loss of a large amount of its volatile matter is indicated by phenomena already discussed. The small interbanded layers of limestone have been broken and brecciated and in places the oil rock becomes almost a breccia in appearance, with slickensided surfaces indicating movement of the particles against one another. Individual pieces of oil rock are bent and recurved, and the softer material has been squeezed in and around the harder fragments. The whole mass is ordinarily finely laminated, like a shale or slate, and has every indication of having yielded to the vertical pressure of the overlying beds. In microscopic sections normal to the bedding the algæ appear in cross section as flat, closely compressed disks, whereas they were no doubt originally spherical in form.

The amount of decrease in bulk which the rock has suffered can not be determined absolutely. If it be assumed that the loss has been as great as that which has occurred in the formation of ordinary bituminous coal, a settling of 2 to 14 feet of the overlying beds might

[a] Geology of Wisconsin, vol. 4, 1882, p. 536.

have occurred. This is more than enough to account for the flats which are found vertically over the oil-rock patches, and such settling would very likely produce the peculiar pitching crevices that encircle these flats and lead down to the oil rock. The sag between these pitches is, on this theory, in part the expression of preexisting inequalities in the bottom and in part the unequal settling due to difference in thickness of the oil-rock layer. It is to be remembered that the material ordinarily occurs in several beds rather than in one and is commonly thicker near the center of the sag than at its edges.

In these irregular patches of oil rock we have, then, (1) a locally abundant supply of suitable reducing matter distributed concordantly with the ore deposits; (2) a material peculiarly suitable to the reduction of sulphates and the sulphurization of carbonates; (3) a supply which was not only abundant when the beds were laid down but which is even yet highly efficient; (4) a material which is both qualitatively and quantitatively adequate to account for the most puzzling structural features of the deposits. These facts would seem to warrant the conclusion that the original distribution of the metals in the Platteville and Galena was irregular and that the present ore deposits are found within areas which were originally richer.

SECONDARY INEQUALITIES DUE TO PROCESSES OF CONCENTRATION.

However great may have been the original inequalities in the distribution of the metals in the rock secondary processes have been of first importance in producing the present ore bodies. The amount of metal originally present in the most favored localities is quite uncertain. It may have been large, but most probably was small. Certainly there has been very marked concentration, and even reconcentration, within recent times. Before considering the question of just how much concentration has occurred it will be well to review the process in general and the chemical reactions involved.

CHEMICAL PROCESSES INVOLVED.

The sulphate cycle.—The sulphides of zinc, lead, and iron readily alter to sulphates, in which form they are soluble in ordinary ground water. Sulphates of zinc and iron are common in the region and sulphate of lead is reported. In this form, then, the disseminated matter, if it be in sulphide form, may be transported from the areas in which oxidation occurs to those in which reduction is dominant. Precipitation of the sulphides from sulphate solutions may be brought about at ordinary temperatures by various organic compounds, by other sulphides, by hydrogen sulphide, or by calcium carbonate.

It has already been shown that the oil rock is now capable of giving off marsh gas, acetylene, hydrogen sulphide, and various other carbon compounds. It has further been shown that the sulphur in the rock is, at least in part, indigenous and not due to intermixed particles of pyrite.

These various substances would react upon the sulphates, among other ways, as follows, only the reactions for lead being written:

$$(1)\ PbSO_4+H_2S=PbS+H_2SO_4.$$

In the presence of limestone the sulphuric acid would promptly react with the wall rock to produce gypsum according to the reaction

$$H_2SO_4+CaCO_3+2H_2O=CaSO_4+3H_2O+CO_2.$$

$$(2)\ CH_4+PbSO_4=PbS+H_2O+H_2CO_3,$$

or

$$CH_4+PbSO_4=PbS+2H_2O+CO_2.$$

A large number of other reactions are possible between the sulphates and the material from the oil rock, but in each case the end products include the sulphides and carbon dioxide. The former are the main constituents of the ore bodies. The latter is the most important element in increasing the solvent power of underground water toward the wall rock.

The reactions of the sulphides on each other may be written as follows:

$$(1)\ PbSO_4+ZnS=PbS+ZnSO_4.$$
$$(2)\ ZnSO_4+FeS_2+O_2=ZnS+FeSO_4+SO_2.$$

According to these reactions lead sulphate will be reduced by zinc sulphide and zinc sulphate by iron sulphide. Since the latter is left in the form of a sulphate with SO_2 as a by-product, it is evident that further reactions between these materials and the organic matter and wall rock will occur. In the end there is a formation of sulphides and of CO_2, as in the other series of reactions, so that the transfer of the oxygen from one sulphate to the other may be regarded as a minor phase of the main cycle. If the relative reducing power of the various materials concerned be kept in mind, it will be evident that the carbon compounds will promptly rob the sulphate of its oxygen. For this reason it is not believed that sulphates are transported far through rocks charged with organic compounds. Where they travel long distances, they must pass through rocks from which the available carbon has already been extracted or through beds, such as sandstone, that are practically free from it.

As an example of the perfection of this protective action the specimen illustrated in fig. 13 and described on page 58 may be cited. In this the galena has been precipitated and is replacing the dolomite. The latter is very light colored and was carefully tested by Mr. Grout, who found that the combined water and carbonaceous matter in it together amounted to only 0.14 per cent. If it be assumed that this is the most active carbon compound, it is, nevertheless, evident that a very small amount is ample to produce precipitation of the galena.

So far, therefore, as the metals were transported as sulphates, they can not be assumed to have traveled far through the ordinary country rock of the district.

The sulphide cycle.—While sulphides are probably largely altered to sulphates prior to transportation, this alteration is not indispensable. Sulphides, as such, may, under proper conditions, be dissolved, transported, and precipitated. Van Hise[a] has summarized existing information regarding this process. It appears from the work of C. Doelter that measurable quantities of pyrite, galena, sphalerite, and other sulphides are soluble in pure water. The conditions under which in nature they go into solution and are precipitated out of solution are not understood and demand further study.

Becker has especially studied the solubility of the various sulphides in the presence of alkaline sulphides and carbonates.[b] He finds that the sulphides of iron, zinc, antimony, copper, and some other metals are readily soluble in both alkaline sulphides and in natural waters containing alkaline carbonates and hydrogen sulphide. They may be transported in such solutions and precipitated by mere dilution, by decreasing heat or pressure, or by any reaction that would destroy the solvent. The alkalies are widely distributed in small quantity in the rocks of the zinc and lead region. A possible source for the hydrogen sulphide has already been indicated and ample means of precipitation would be present wherever alkaline waters of long course underground met in crevices the short-course, oxidizing, and generally acid waters. So far the cycle seems well suited to explain the concentration that has taken place. There is, however, one difficulty. Becker found that galena was, so far as his tests went, entirely insoluble in solutions of sodic sulphide or of sodic sulphydrate, or in solutions of sodic carbonate partially saturated with hydrogen sulphide.

Since galena forms an essential and widespread constituent of these ores, it is difficult to conceive a process which would concentrate only the blende and pyrite and leave the galena untouched. So far, then, as concentration through the sulphide cycle is concerned, there is only the solubility of material in water to depend on, and no means have yet been devised for determining how important or unimportant this has been in this region.

The carbonate cycle.—Lead, zinc, and iron readily form carbonates which are soluble in

[a] Treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1905, pp. 1106-1110.

[b] Becker, G. F., Quicksilver deposits of the Pacific slope: Mon. U. S. Geol. Survey, vol. 13, 1888, pp. 432-434.

underground waters. Probably the process consists of first oxidizing the sulphides to sulphates and then reacting with the wall rock as below:

$$PbSO_4+CaCO_3+2H_2O=PbCO_3+CaSO_42H_2O.$$
$$ZnSO_4+CaCO_3+2H_2O=ZnCO_3+CaSO_42H_2O.$$

The frequent presence of lead carbonate and the abundance of zinc carbonate in the upper portion of the ore bodies show that these reactions have commonly taken place. The occasional presence of crystals of gypsum or selenite is an interesting confirmation. The carbonates are so soluble that in the main they are carried down to contact with sulphides or hydrogen sulphide where reactions similar to the following occur:

$$PbCO_3+ZnS=PbS+ZnCO_3.$$
$$ZnCO_3+FeS_2+O_2=ZnS+FeCO_3+SO_2.$$
$$ZnCO_3+H_2S=ZnS+H_2O+CO_2.$$

Sulphides formed in this way, if sufficient oxygen be present, will be changed to sulphates with eventual reduction and the usual formation of the end products—sulphides and carbon dioxides. The carbonate cycle is therefore closely related to the sulphate cycle. It results in the same end products, and the ores go into and are thrown out of solution under much the same conditions.

Minor cycles.—Chamberlin has called attention[a] to the possible effect of various other reagents, including particularly humic and other organic acids. These have been but little investigated in this connection; but here is an open, interesting, and possibly fruitful field. So far as present observations go, however, the organic matter present in the rocks seems to have operated altogether as a reducing agent. Above the level of the ground water decaying vegetable matter may have aided in bringing the metals into the condition of carbonates by the formation of the humus acids, but even this is uncertain. At the oil-rock horizon it would require the presence of oxygen to form the organic acids which might take the material into solution. This in itself limits the zone within which the action probably took place. Furthermore, metallic salts of these organic acids would probably be almost immediately decomposed by the limestone and in the end there would be the familiar precipitation of metallic sulphides and carbon dioxide.

A study, then, of the possible methods of solution and transportation of the material leads to the conclusion that the major concentration, at least, has been effected by waters having a local circulation only. An effective wide-reaching circulation is not impossible, so far as the chemical reactions involved are concerned, but, on the whole, would seem improbable. This would confirm the conclusion drawn from the study of conditions of sedimentation—that in the main the ores were derived from limited areas within which the rock was originally richer in metals than elsewhere.

GENERAL PROCESSES OF CONCENTRATION.

There are two elements in the underground circulation which must be taken into account in explaining the concentration of the ores. The first is the water which makes its way to the crevices by long and devious courses. The second is that which flows into them after a short course through rock mainly above ground-water level. The former is believed to afford the reducing element to the reaction. The latter is oxidizing or carries oxidized salts. The two mingle in the crevices and produce the ore bodies by precipitation.

In many of the mines it may be observed that while the sulphides in the pitches and crevices are fresh and untarnished the wall rock back of them has been considerably oxidized. In fact, it is common to find the first effects of oxidation along the thin band of marcasite which separates the ore from the wall rock.

These facts seem to indicate that the level of oxidation is slightly lower in the country rock than in the cavities, and that the latter are filled quite up to the water table with

[a] Geology of Wisconsin, vol. 4, 1882, pp. 540-542.

waters that are reducing in character. The source of the reducing matter is undoubtedly the lower-lying oil rock and the unleached dolomite and limestone below water level. Accordingly, the waters within the crevices are, on the whole, slightly ascending and strongly reducing in character. The cause of their ascending course will be understood when it is remembered that the deposits occur in synclines or basins. These are 1 to 3 miles wide and as much as 9 miles long. Their depth is sufficient to give considerable artesian head where, as in the Ida-Blende, Gruno, and other mines, the glass rock and clay bed form an impervious stratum. One element in the underground circulation is therefore water which falls at various points on the sides of the basin, descends through the pores and minor crevices to the oil rock horizon or other impervious bed, flows laterally to a crevice, and ascends to the level of outflow. This water is, in the crevices, reducing in character because of its long contact with organic matter—that in the oil rock especially. If it contributes any ore to the deposits the material must be transported in the form of sulphides or salts of organic acids.

The second element is that portion of the water which, after passing through the rock above the water table, travels laterally along it and into the crevices from above or from the side in the upper portion of the openings. It is this current which is believed to have brought in the main burden of ore.

If an area of unaltered dolomite, containing sulphides of zinc, iron, and lead, and an excess of organic matter, be exposed to the action of descending waters by depression of the water level, oxidation begins at the upper surface and progresses downward. It does not, however, operate equally on all the constituents of the rock, but first attacks and removes the organic matter. Until this be done the various sulphides are effectually protected. After a period of time, therefore, there will be, above, a zone in which the sulphides are present without any organic matter. Next the iron sulphide goes into solution, and so there is formed a shallower belt, from which it has been removed, leaving only the galena and blende. At still a later stage a belt is developed free even from blende, though still showing galena. At this time there would then be from the surface downward—

(*a*) A belt containing galena only.

(*b*) A belt containing galena and blende.

(*c*) A belt containing galena, blende, and marcasite.

(*d*) A belt containing the sulphides and an excess of organic matter.

Waters passing laterally out of belt *d* into a crevice would carry mainly CO_2, which would lead to the enlargement of the crevice. From belt *c* would come waters carrying iron sulphate, which would deposit iron sulphide upon the walls of the crevice as far as the water was able to make headway downward. From *b* would come waters mainly carrying zinc sulphate, but with minor amounts of lead and iron sulphate. These would form sulphides in crusts on top of the marcasite. Finally, from *a* would come waters bearing lead sulphate and eventually lead carbonate, which would deposit their load as galena coating the other material.

According to this conception the waters which leach the rock above the water table pour into the upper portion of the crevices and make such headway as they can downward against the reducing waters. In areas where there is a rough topography and erosion has cut deep they may make their way well down to the oil rock. In general, this forms an impervious bed, limiting the circulation below. The actual mingling of the waters takes place through a vertical range of 100 or more feet, if one may judge by the extent of the deposits below water level. Allowing for difference in head in different crevices, there is no inherent difficulty in supposing the mingling to extend through even a greater vertical range, but on this point there is little positive data.

Van Hise has argued for a somewhat different circulation. According to his conception there was an earlier or first concentration of the ores produced by a wide-reaching artesian circulation, followed by a second concentration, substantially as outlined above.

Before the Lancaster peneplain was developed the zinc and lead region was covered by the Maquoketa shale. To the northeast the Platteville and Galena formations were exposed, and rain water falling on them doubtless traveled downward along their dip, accumulating artesian pressure, as water now does in the deeper lying Cambrian. If at any time prior to the complete removal of the shale erosion cut through it at some point in the southwest, opportunity would have been afforded for the rise and escape of the water. At present Platte, Grant, and Mississippi rivers cut down into the St. Peter in areas where the Maquoketa remains in patches on the peneplain. If it could be assumed that these streams had in the past been equally in advance of general degradation of the surface, it is clear that their channels would have afforded conditions for the escape of artesian waters. At such places the salts carried in solution would doubtless have been largely deposited, and as the points of outlet would have been few as compared with the points of inlet in such a circulation, the average result would have been a concentration of the material in a few favored localities. This ingenious explanation would satisfy the requirements of the case as regards the localization of the deposits in a way not otherwise possible on the basis of differences in the conditions of concentration. There are, however, difficulties in the way of accepting this explanation.

The difficulties arising from the form in which the material is presumed to have been mainly taken into solution and transported have already been discussed. It has also been indicated that the field evidence shows the immediate formation of the deposits to have been by descending waters, and while this is far from conclusive, it is thought that there should be some cases, at least, of deposition under rather than over impervious beds if deep ascending currents furnished the material. The few exceptions known are all clearly cases where oxidizing waters are present in abundance, and these could hardly have made a long traverse through the rocks.

It is difficult to make sure as to where the shale was first cut through in the southwest. The winding course of the Fever and other rivers is interpreted as meaning that they are superimposed streams. This should mean that their present courses are inherited from an older cycle of erosion. The Mississippi at and above Dubuque has a broad, very shallow basin, in the bottom of which is the present gorge. This is deep enough to cut away the shale where it would otherwise be present, as is shown on the map of the Lancaster quadrangle. So far the general conditions would seem to have been favorable to such conditions as Van Hise has suggested. When, however, they are examined in detail the results are less satisfactory. If the present streams be taken as a test each would have cut through the shale first in the anticlinal areas. It is in such places that they now cut deepest into the formations, and there is no known reason why the same should not have been true when the shale was first cut through. It has already been indicated that the anticlinal areas are exceptionally barren. It would accordingly be necessary to suppose that the material first concentrated in their vicinity by the artesian circulation was later removed to the adjacent synclinal or basin areas by local circulation. On the whole this seems improbable and, in view of the other difficulties already mentioned, the writer would hold that the wide-reaching artesian circulation probably had little, if any, effect in producing the ore bodies of the area. This, it may be frankly confessed, is a return to earlier views and a reversal of an opinion held in 1902[a] when, largely on the basis of analogy with the Joplin deposits, Van Hise's opinion of those of the upper Mississippi Valley was adopted. Though this interpretation of the Joplin deposits has since been questioned,[b] it is believed that the discrepancies are entirely explainable[c] and that the hypothesis of an early concentration through the action of wide-reaching artesian circulation is good for that area. It is possible that further advances in knowledge of the chemistry of the process may minimize the difficulties in the way of applying it to the mines of Wisconsin and that, in the end, the broader circulation may prove to have had a greater influence than is now thought possible. The

[a] Van Hise, C. R., and Bain, H. F., Lead and zinc deposits of the Mississippi Valley, excerpt from Trans. Inst. Min. Eng. (London), 1902, pp. 35–46.

[b] Buckley, E. R., and Buehler, H. A., Geology of the Granby area: Missouri Bureau Geology and Mines, 2d ser., vol. 4, 1906.

[c] Siebenthal, C. E., Structural features of the Joplin district: Economic Geology, vol. 1, 1905, pp. 119–128; discussion, ibid., 172–174.

recognition, however, within the area of other and adequate causes of the peculiar localization of the deposit undoubtedly removes the main objection to the alternative hypothesis of concentration by local circulations.

ALTERATION OF THE ORES.

That the ores originally consisted of sulphides is now generally conceded. That these sulphides were somewhat intimately intermingled is probably, but not necessarily, true. At present there are, however, four well-defined types of ores described as—(1) galena ores, (2) zinc carbonate ores, (3) zinc sulphide ores, (4) iron sulphide or sulphur ores. These occur commonly in a corresponding vertical order, the galena ores being at the top. To a large extent this is believed to be a result of alteration and reconcentration of the first formed ore bodies, in which it is thought that there was less separation of the sulphides.

The galena ore is found above water level under conditions of great oxidation. The zinc carbonate ore, including some galena above and some blende below, is found about at the level of underground water. The carbonate is clearly a product of alteration from blende according to reactions already given. Blende is dominant at lower levels except in certain places where marcasite is more abundant or where a crossing crevice disturbed the equilibrium by causing an unusual precipitation of galena.

The general nature of the process by which this orderly vertical arrangement of the ores has been brought about has been already indicated. It has been discussed in especial detail by Van Hise.[a] There are reasons for thinking that this vertical order may, in places, have been original; that the upper Galena may have contained much more lead sulphide than the lower Galena and less blende. Certain of the mines—the Skene at Elizabeth, for example—showed, when examined, large deposits of galena without any direct evidence that blende had been formerly present. In other places drilling under old and rich lead diggings has failed to show the blende deposits which should theoretically occur. It is possible that the galena is in these places in a secondary position and had been transported some distance before deposition. The extreme practical importance of the matter warrants the consideration of any suggestion, however vague, of another origin.

If the theory outlined on pages 133–136 be correct—that the zinc and lead were originally deposited in the Ordovician seas in locally rich areas because of the buried masses of remains of algæ—it is necessary to believe that these masses effected precipitation from the sea water even after burial under 250 feet of dolomite. This follows from the fact that even the uppermost beds of the galena yield ore bodies where conditions are favorable for concentration. The solid carbon in the buried material could not do this, but it does not seem beyond the powers of volatile hydrocarbons, either liquid or gaseous, such as are even yet present. These would rise to the surface by the most direct route through such cracks and pores as were available. As the cover increased in thickness and cementation became more perfect the amount of such material reaching the surface would grow less and less. That it did not all escape is made clear by the facts of the field. Under these conditions it is entirely supposable that in the closing stages of galena deposition only enough hydrocarbons reached the ocean bottom to precipitate the relatively insoluble sulphide of lead and not enough to affect the more soluble sulphides of iron and zinc. It is therefore by no means certain that the common vertical order, galena above and blende below, is entirely the result of secondary action.

GEOLOGIC DISTRIBUTION.

According to the hypothesis here outlined the ores were deposited mainly in the upper Platteville and the Galena strata. So far as they are found below these horizons they are believed to have been mainly carried down during periods of later erosion. The conditions at Dodgeville, discussed by Mr. Ellis, seem to favor the view that the ore in the glass rock

[a] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, pp. 41-46; Mon. U. S. Geol. Survey, vol. 47, 1904, pp. 1147-1153.

was derived from the Galena above. North of Dodgeville and Highland, where ores have been formed in the Prairie du Chien, it does not seem unlikely that their home was originally in the higher formations. Elsewhere, as at New Galena and Lansing, Iowa, the ore may have been indigenous to the Prairie du Chien. It has already been suggested that the amount of such ore is small.

RÉSUMÉ.

The ores of this region are believed to represent concentrations of material originally disseminated through the surrounding rocks, particularly the Galena and upper Platteville beds. It is believed that the zinc and lead originally present in the crystalline rocks of the Lake Superior district was delivered by rivers to an especially favorable portion of the Ordovician coast, where in warm, shallow waters it was partially concentrated by evaporation and was locally precipitated in quantity. The agents of precipitation were hydrocarbons or hydrogen sulphide, or both, derived from decaying masses of algæ of a peculiar type irregularly accumulated within certain shallow basins on the sea floor. The rising hydrocarbons continued to be effective throughout the period of deposition of the Galena dolomite.

As the algæ matter became compressed the beds above broke and settled, leaving open spaces of peculiar form for the ultimate reception of the ore bodies. The beds were slightly deformed, whereby the basins were accentuated and deep joint cracks were developed. The area was subjected to peneplanation and later to gorge cutting, whereby the overlying shale was cut away and a vigorous underground circulation was brought about. This circulation resulted in a concentration of the disseminated material, and with the fall of ground-water level the ores were successively reconcentrated until the present type was produced.

ECONOMIC CONSIDERATIONS.

GUIDES FOR PROSPECTING.

Old workings.—This region has been so thoroughly prospected and so long under development that the important mineral-bearing localities are rather definitely known. On Owen's original map nearly all the sections of ground upon which ore has since been found are indicated as mineral lands. Amost every deposit so far located has given some surface indication, either by float mineral or otherwise. This is entirely in accord with the notion of the genesis of the deposits by concentration from the surrounding rocks through shallow circulations and is an interesting confirmation of it. A few deposits recently found by drilling showed no surface indications, but all such deposits were near old lead diggings and are probably related in some way to deposits earlier worked.

The surface indications of a lead deposit were so well understood by the earlier miners of the region that they seem to have left little for their successors to discover. For many years such lead ore as has been found has been discovered by following known deposits or crevices into deeper or laterally adjacent ground. It is entirely probable that a considerable amount of lead ore may yet be discovered by the same methods. This work is best pursued by the small tributer, or leaser as he is locally called, who invests little but labor in his test pits and drifts along the random of the openings. The larger companies now coming into the field are not likely to find such deposits profitable, and they must base their hope of gain mainly on the large bodies of ore below water level.

The location of the known old diggings is shown on Pl. VII, and a more detailed map will be found in the atlas of the older Wisconsin Geological Survey.[a] These old diggings are now generally marked by dumps, pits, and other evidences of the disturbance of the surface. It is often possible to obtain fairly accurate maps of the crevices which they followed. These crevices bear no certain relation to the pitches and flats below, but a vertical,

[a] Atlas of the Geological Survey of Wisconsin, pl. 31.

so situated as to be favorable to the movement of underground water, and hence extensively acted upon by solution and depositions, is apt to be paralleled through part of its course by pitches equally well situated. The vertical crevice is an important factor in that it has afforded communication between the descending surface waters and the deeper waters of the oil-rock horizon.

If several vertical crevices are present they may throw important light on the situation by their relations. Crossings of crevices are well known to favor deposition of ores by allowing the mingling of somewhat different solutions. This is illustrated in the eastern part of the Rowley mine, where an intersecting quartering crevice is marked by a notable increase of galena.

If mining is carried on along a vertical crevice and a pitch to the right or left is encountered, it is to be expected that a corresponding pitch on the opposite side will be found. There are a few apparent exceptions to this, notably the Doll and Empire mines, but it is on the whole probable that further development will show north pitches even here.

It is not to be expected that all pitches will be equally mineralized or even that a single pitch will be mineralized along its whole extent. In any mine any portion of its ore may come wholly from a single pitch. It should be remembered, too, that a pitch does not have an indefinite development in a single direction. It is believed that instead the two pitches usually developed are only portions of a long ellipse, and that the ore body will be bounded by pitches longitudinally as well as laterally. The lateral pitches, being in the course of the main flow of underground water, will probably be much better developed and much richer.

The major importance of the old workings lies in the fact of the common vertical order of the deposits, lead ore above and zinc ore below. According to this the lead diggings above water level are over, or approximately over, the zinc ore bodies yet to be worked below that level. It can not be doubted that as a general rule this is true, and accordingly the old workings become very valuable guides to the deposits yet to be won. It is, however, a rule with exceptions, and, furthermore, the zinc is not always immediately below the old lead workings. In the secondary concentration of the ores some of the lead seems to have been moved considerable distances and deposited under wholly new conditions. In other cases probably it was the blende which wandered before deposition. In still other cases one or the other may never have been deposited. Lead sulphate and sulphide are so much more insoluble in ground water than zinc sulphate and sulphide that it is quite possible that it would be precipitated in places and under conditions where the precipitating agency was too feeble to act on the zinc solutions. It is a fact of general experience that galena is more widely distributed than blende, and this may be the explanation. Again, Buckley and Buehler[a] have shown that there are notable differences in the action of these substances, according as they are in acid, neutral, or alkaline solutions. While, therefore, the field evidence indicates clearly that in the main the two substances were transported and deposited under the same conditions, it is not necessary to believe that this has been true in every case. Reasons already have been given for believing in an originally greater deposition of galena in the upper beds, and it should be remembered that while the old lead diggings usually point to lower-lying bodies of blende the certainty of it in a particular case can be determined only by drilling.

Synclinal areas.—The fact that the ore bodies are located, mainly, in synclines or basins seems fully established. The reasons for this, arising from conditions during original deposition and subsequent concentration, have already been discussed. The location of many of these basins is shown on the accompanying plates and on the large-scale maps of the Wisconsin Geological and Natural History Survey. Very little of the area has yet been surveyed in this detail, and in many places the data available do not allow the accurate drawing of contours. In all future work the depth to oil rock should be carefully noted and a record preserved, so as to allow the extension and revision of the maps. Not all the

[a] Buckley, E. R., and Buehler, H. A., Geology of the Granby area: Missouri Bureau of Geology and Mines, 2d ser., vol. 4, 1906, pp. 88–93.

old lead workings are known to be in basin areas, but so much of the territory is unsurveyed that no argument can be founded on that fact. So far as present experience goes there is no known exception to the rule that all the important zinc mines are located within structural basins.

Thick oil rock.—It has been separately pointed out that thick oil rock has not been found away from the mines. Reasons have been given for believing that the reverse relation holds—namely, that ore deposits will not be found except in areas of thick oil rock. Since this is easily recognized in drill cuttings, it becomes a valuable supplementary guide in prospecting. It is important to have more data on this point in order to test the matter thoroughly. It may be frankly stated that at present the suggestion is based largely upon theory.

Topographic slope.—The relations of the ore bodies to topography already have been discussed. It is not certain that the lower lying deposits will prove to be as closely related to topography as those in the crevices and openings. Since, however, they are the result of the action of underground water, they should show dependence upon topography so far as it controls the circulation. Other things being equal—a well-developed structural basin, thick oil rock, and numerous old workings on crossing crevices—topographic slope ought to influence the deposition of the ore. The lower portion of the slope, a portion neither under the valley bottom nor yet upon the peneplain, would seem to afford the maximum favorable position for the proper mingling of the solutions. It may be noted that many though not all of the good mines are so situated.

Underground-water level.—The relations of the ore deposit to the underground-water level determine its character and, to some extent, its type. A deposit of carbonate of zinc in an opening above water level and a deposit of blende, as honeycomb ore, below water level, are believed to have been originally the same thing.

Immediately below water level the maximum favorable conditions for deposition seem to have obtained. It is impossible to say, however, how far below they were favorable. If the water level at a given point be determined by relations to overflow from that particular basin, it would seem that convection currents would be mainly upward and there would be little opportunity for the oxidizing solutions to travel downward. What headway diffusion would make against convection is somewhat problematical, but the amount seems, on the whole, likely to have been small. In such situations the ore will probably be found to be rather sharply limited in depth.

Where, however, the underground-water level merely represents local excess over the capacity of the cavities in the rocks below to allow it to travel—where, in fact, it is stagnant or moving slowly downward—there is a better opportunity for oxidizing waters to penetrate by convection and for oxidized salts to be carried down by diffusion. Under such conditions the belt of deposition might be materially deepened. No data are now available to determine which case represents the facts in this field, though the basin structure of the areas in which the deposits are found would seem to indicate the first set of conditions.

METHODS OF PROSPECTING.

Test pitting.—The early lead diggings were nearly all located by test pitting. There are areas which have been so completely worked over in this way that there is hardly a level patch in the whole field. Shafting on the crevices with drifts along the openings were the favorite means of exploration of the upper ground. Under present conditions, where the ore is sought below water level and at greater depth, these methods are too slow and expensive and have been generally abandoned.

Churn drilling.—At present churn drilling is the favorite method of prospecting. As the depths are not great—200 feet or less—a light rig only is needed. Gasoline engines are generally used for power, and over 100 drills are now at work in the district. Drilling is done by contract at a cost of 75 cents to $1 a foot and is rapid, cheap, and effective in locating the pitches and flats. The drillings should be carefully collected and examined, as mistakes are easily made. The drill holes should be put at one side of the crevice rather than on it, to allow for the spread of the pitches in depth.

Diamond drilling.—The presence of considerable flint and of many open cavities in the rock has made it difficult and expensive to use the diamond drill. The mechanical difficulties have all been overcome, and some work has been done on contract in the region. The rates have been high as compared, for example, with the low costs in southeastern Missouri, and opinion is divided as to whether the added certainty of results is sufficient to warrant the extra cost. Wheeler estimates that by using a small bit—2 to 2½ inches—the cost might be brought down to 75 cents from $1.50 a foot,[a] but this is much less than the work has so far cost

METHODS OF MINING.

Manner of opening.—The mines are generally opened by vertical shafts. In the past adits or levels have been used to some extent, though mainly for drainage purposes. The ground now being worked lies, in the main, too low to be opened except by shafts. The latter are generally sunk on one of the vertical crevices for economy in sinking, and this necessitates crosscuts from the bottom to the pitches on either side. Since the core between the pitches is rarely mineralized sufficiently to warrant milling as a whole, it is a question whether inclined shafts meeting on one hoisting platform and following down each pitch would not be more economical when the conditions permit such shafts to be sunk. Here, as at Joplin, it is customary to deliver from more than one shaft to a single mill, though many of the mines are able to furnish from one enough ore to keep the mill running. The underground work, as is usual in zinc mining, is carried on by a form of underhand stoping.

Mining is done usually with air drills, and it is customary to break down 100 tons of mill dirt per shift with four drills. The rock, while not hard, does not drill quickly. The dolomite crumbles down and powders or packs in the holes, so that the amount of drilling per man per shift is not greater, and is often less, than in regions where much harder rock is encountered.

Tramming.—Very little timbering is necessary, though the openings are usually large. Tramming is done by hand. The ore is hoisted in tubs or buckets, being shoveled below and dumped at the crusher floor.

Equipment.—The plants now being built in the district generally employ steam for power, though gasoline is used at a number of points. The pumps are usually Cornish lift pumps of cross-head pattern, which are simple and effective down to depths of 200 feet. They are too light, as now built, for greater depths. The amount of water handled probably does not exceed 2,000 gallons per minute at any place and is usually 1,000 or less. It is found in practice that the water problem is much less serious than was expected. It is probable that as larger mines are opened up, better and more economical pumping plants will be built.

Steam or electric hoists are commonly employed, and many of the mines are lighted by electricity. The buildings are substantial and are fully inclosed so as to permit uninterrupted work through the cold winters. There are well-equipped machine shops and foundries throughout the region, and at Galena and Platteville there are companies which make a specialty of building and erecting mining and milling plants complete.

Labor.—Most of the laborers are of Cornish or American descent and have come mainly from farms. There are no unions. In the mines the shift is eight hours long. Surface laborers work nine hours and mill men ten. The mines usually run two shifts and the mill one. Hand miners are paid from $1.50 to $2 per shift; machine men, $2.25 to $2.75; helpers, $1.75 to $2.25; trammers, $1.60 to $2.25, except where paid by the tub; jig men, $3; engineers, $2.50; firemen, $2.25; common laborers, $1.30 to $1.60. The conditions of life are good,

[a] Mines and Minerals, March, 1906, p. 371.

with good food, wholesome surroundings, and good schools for the children. Recently there has been a shortage of both men and houses, owing to the rapid growth of the industry.

Royalties.—Mining is usually done on the leasing system, very few of the mining companies owning their fees. The first royality is 10 per cent, except in dry mines, where 12½ per cent is sometimes exacted. In the case of subleases 15 per cent or more is asked, depending on conditions. Royalties on lead and zinc are the same now. The lead is leased in lots of various sizes, generally from 5 to 40 acres. In the towns the leases on a number of building lots are usually collected by a single company.

Costs.—Costs are generally estimated at $1 to $1.25 per ton of mill dirt, with milling at 25 to 35 cents per ton. In one case, where approximately 4,500 tons of concentrates had been sold, the average total cost was found to have been very nearly $15 per ton of concentrates. In another, where nearly 5,000 tons had been marketed, the cost had been about $17. These figures are very nearly accurate, though it is impossible to make them exactly so on account of differences in ore reserves developed, depreciation in plant, etc. The cost also varies notably with the amount of water to be pumped, the distance from the railway, and the necessity or not of roasting or magnetically treating the concentrates. In the second case above part of the ore was so treated. These cases represent rather typical conditions.

METHODS OF MILLING.

Grade of the ore.—There are marked differences in the grade of the ore handled. The carbonate ores are usually dressed to yield 20 to 40 per cent of zinc without milling. The crude mill dirt is rarely sampled accurately enough to permit correct averages to be obtained. In one mine, where the blende was free enough to be salable without roasting and magnetic concentration while the ore of the pitches only was being run, the mill yield of concentrates amounted to about 22 per cent. The same mine, under another management, when the rock between the pitches was being handled, gave a yield of 12½ per cent. Another mine gave 17 per cent, and still another 20 per cent. All these figures must be corrected to allow for losses in re-treating the concentrates to separate the blende from the iron sulphide. Wheeler estimates that the crude ore will yield 4 to 8 per cent of zinc in final concentrates, and thinks that careful work would bring it up to 5 or 10 per cent. These figures seem to represent as fair a statement as can be made from the data at hand. The larger figures commonly quoted either fail to take any account of mill losses or of the iron sulphide which goes with the zinc in ordinary milling. In small works, with hand dressing, much higher grades of ore only are handled.

Hand work.—At the smaller mines, particularly those producing zinc carbonate, the ore is hand dressed, and the finer sizes are treated on hand jigs. Formerly it was customary, in order to reduce freight charges, to roast the carbonate in furnaces somewhat like limekilns This has been generally given up, though occasionally small lots are roasted.

Steam mills.—Concentrating mills of the Joplin type are now used throughout the region. (Pl. XVI.) A few close-sizing mills were formerly operated, but they have all been reconstructed or abandoned. A 50-ton mill is usually built with a single bank of jigs; the 100-ton mills commonly include 3 banks with 7 cells each. In several of the mills concentrating tables are also used to re-treat the tailings.

The concentration work is rather well done. The softness of the rock permits finer crushing at the same cost than is practiced in Missouri, and by the use of long jigs the ore is well cleaned. As is usual in such mills, the actual saving is not definitely known and probably varies somewhat from time to time with the richness of the dirt.

Mr. Benjamin Hodge conducted a test of the Enterprise mill while it was running on 17 per cent dirt which indicated a saving of 86 per cent. This was based on a three days' run with samples of the crude ore taken at the crusher every ten minutes. It is hardly likely that the average saving in the district is as good.

Much of the ore after ordinary concentration requires re-treatment to free it from the iron sulphide or "mundic" present. This is generally accomplished by roasting and magnetic concentration.

Roasting.—The roasting is ordinarily done in a rotary cylindrical furnace made of steel and lined with fire brick. It has a slight pitch, so that the ore travels through it in two to three hours. From 20 to 30 tons of ore are handled in twenty-four hours, with a fuel consumption of 1½ to 2 tons. The ore is roasted to a point when a portion of the iron is converted to the oxide, but the kernels of the larger pieces still show sulphur. Mr. F. H. Trego, of Platteville, has been experimenting with a lighter and simpler furnace, but it is not yet on the market.

Magnetic separation.—The roasted ore is treated on a magnetic concentrator to clean the blende. The usual machine is the Cleveland-Knowles. In this type the roasted concentrates are fed on a horizontal traveling belt, which carries them under two vertical revolving magnets. These pick up the iron and carry it to one side, where it is removed by scrapers. The current used is weak—3 to 4 amperes at 110 to 220 volts. There are considerable mechanical losses both in the roasting and concentrating. The average results of the week's run at one plant in regular work are given below:

Results of magnetic concentration.

	First week.			Second week.		
	Zn.	Fe.	Pb.	Zn.	Fe.	Pb.
Unroasted concentrates	35.3	18.35	0.37	36.1	16.4	0.5
Magnetic concentrates	57.2	4.50	.58	57.4	4.45	.73

The iron product from the magnetic machine at this time ran 4.5 to 5.6 per cent zinc. In certain cases ore running 60 per cent zinc and 3 per cent iron has been produced here.

In general at this mine the crude mill dirt yields about 12½ tons of concentrates to 100 tons of mill dirt, and approximately one-third to one-half the concentrates are thrown out in the iron product from the magnets. It is generally stated that the loss during roasting and magnetic treatment amounts to 10 to 25 per cent of the zinc, and the cost is approximately $2 per ton of concentrates. These recleaning plants as now built cost $8,000 to $10,000 and are usually separate from the main mill.

In this process of treatment there is not only the loss of zinc to contend with, but the marcasite is a total loss. Since when clean it is salable at $3 to $6 a ton, many attempts have been made to treat the ore without roasting. At the Empress mine a Blake-Morscher electrostatic plant was in operation for some months in 1903 and produced some very high-grade concentrates. Mr. A. M. Plumb, who had charge of the plant, has given an account of its operation,[a] from which the following statement of results is taken:

Blake-Morscher concentrates.

	Zn.	Pb.	Fe.
Crude concentrates	29.15	5.16	20.90
Zinc product	58.4	.23	2.16
Iron product	5.07	8.40	38.88

The material was zinc middlings from jigs and was 6 mesh.

Various other machines have been or are being tried, including the International and the Lang. In a few cases after roasting, the material is cleaned by rejigging instead of treating with magnets.

[a] Mining Magazine, vol. 11, 1905, pp. 515–519.

This was the method devised and used by W. P. Blake, who was the first to successfully handle these ores.[a]

While the mills now in operation are successful in that they produce a commercial product from ores not otherwise merchantable, they are wasteful and expensive, and it is hoped that better methods may be devised.

MARKETING THE ORES.

Lead ores.—Formerly all the lead ore was reduced in local furnaces of the Scotch hearth type. Such furnaces are still in operation at Dodgeville, Galena, and Dubuque, but do not run steadily. The bulk of the lead ore now goes to the smelters of the St. Louis district, but some finds its way to Pittsburg and Chicago. The ore is very clean, running 70 to 82 per cent lead, and is in good demand.

Zinc-carbonate ores.—This ore is marketed mainly at Mineral Point, Wis., where it is used by the Mineral Point Zinc Company (affiliated with the New Jersey Zinc Company) to manufacture zinc white. A little is occasionally sold to the zinc smelters of the St. Louis district.

Blende ores.—The Matthison-Hegler Zinc Company, at La Salle, Ill., and the Illinois Zinc Company, at Peru, are the main buyers of the higher grade of zinc ores. The lower grades are sold mainly to the Mineral Point Zinc Company, which is prepared to handle especially low-grade ore in its plant. A small spelter plant is maintained by the same company at Waukegan, Ill., and the New Jersey Zinc Company is just completing a very fine plant at Depue, Ill. A new zinc smelter is also being built at Danville, Ill. Formerly the Indiana gas smelters drew on this field, but they have dropped out of the market. Occasionally a little of the ore is shipped to the Kansas-Missouri smelters and to the Collinsville and Sandoval, Ill., plants. At Galena, Ill., a concentrating plant is maintained for treating the ores of mines not equipped with mills. A considerable business is done in retreating zinc concentrates high in iron and, by roasting and magnetic treatment, raising their grade. The Joplin scale of prices prevails in the district, with a $1 penalty per unit of iron and a 60 per cent zinc basis. Ore is bought on assay and paid for in the car. High prices have prevailed the last few years, and the region has been undergoing rapid development.

[a] Blake, W. P., The separation of blende from pyrites; a new metallurgical industry: Trans. Am. Inst. Min. Eng., vol. 22, 1893, pp. 569-574.

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