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required in the mapping of any other formation in the Archæan regions. Where cañons occur in the granite their walls are more rugged, less precipitous and higher than in the porphyry, and the waterways are broader.

Closely associated as they are, the crystallines and the Cambrian ledges exhibit the contact of the two formations in many places. In some portions of the region it is not uncommon to find sandstone more closely accompanying the granites; limestone, the porphyries. Dikes are found more commonly in the granite. Iron ores are found mainly in the porphyry, while the lead ore in the crystallines is confined largely to the granite.

Specimens from many localities show an almost continual change in the hue, if not in the texture, both of the granites and porphyries. Between fifty and one hundred hues are represented in the former, while in the latter about two hundred distinctly different hues are shown, each in the corresponding number of specimens collected.

Associated as a dike rock in the granite, olivine diabase is also found, making up a few areas of considerable size. These have a topography much like that of the smaller granite fields. Limited areas of so-called syenite occur; also other forms of crystallines, rocks which will not here be mentioned.

OCCURRENCE OF ZINC IN NORTHEASTERN IOWA.

BY A. G. LEONARD.

In the Upper Mississippi valley for a considerable period after the mines began to be operated much more lead than zinc was produced. It was not until 1860 that the latter metal came into market. Since then the zinc production has rapidly increased. During the ten years previous to 1882 the output of zinc more than doubled that of lead, while in 1889, according to the last federal census report the proportion between the two was as 13 to 1 for the entire region.

On account of their increasing importance the zinc deposits will be especially described in this paper, but as the two metals are so closely related in occurrence what is said of one will, in many cases, apply equally well to the other.

Not until the year 1880 were the Iowa mines worked for zinc carbonate or "dry bone," as it is called by the miners. Up to that time the carbonate, though found in many of the mines, was thought to have no special value and had been thrown away as worthless, or when found in the diggings the latter were abandoned.

In the fall of 1880 two wagon loads of zinc were taken to Benton, Wisconsin, by Mr. William Hird and sold for $16.00 per ton. So far as known this was the first zinc ore sold from the mines of the State, and from this time on the carbonate has been mined in rapidly increasing amounts. The

first mine to be worked for zinc was the McNulty, often called the "Avenue Top" mine, at the head of Julien avenue, Dubuque. This had previously been operated for lead and $25,000 worth is said to have been taken from it. The galena gave out in the crevice and a short distance beyond the zinc carbonate began to appear. It is estimated that this mine has yielded not less than $50,000 worth of the latter. After the sale of the first dry bone many began at once to search for it and numerous mines were soon being operated. Old lead mines that had been abandoned were again opened and worked for zinc when the associated ore began to appear.

A slight examination of the great mining regions of the globe will show that they are situated in regions of disturbance in the earth's crust. The strata have been more or less tilted from their original horizontal position, or are fractured and igneous masses intruded into them. In other words, the ore deposits of the globe conform to the general law stated by Humboldt that "the deposits of the precious metals and of lead, zinc, and mercury are usually associated with intrusions of igneous rocks."

The zinc deposits of the Upper Mississippi form a notable exception to the above law. They occur in practically undisturbed strata which show no evidence of having been subjected to metamorphic agencies or of having any connection with igneous masses.

The manner in which these deposits occur is also unusual. They are not in true veins, filling fissures produced by some deep seated cause and extending to a considerable depth, but the zinc is found in crevices which have a comparatively limited extent downward, and show no evidence of having been connected with igneous masses below.

Whitney says, in connection with the Upper Mississippi region,* "These deposits approach most nearly in character to what have been designated as gash veins; but they are in some respects peculiar in character, no mining region exactly resembling this in mode of occurrence of its ores, having been observed by me in any part of the world, unless it be in the Missouri mines in which the conditions of the Upper Mississippi region are closely imitated although upon a somewhat limited scale." In Missouri the zinc ores occur in the sub-Carboniferous formation. There is in that region an apparent connection between the surface drainage of the country and the deposits.

Other occurrences for zinc are those of Kansas, New Jersey, Pennsylvania, Tennessee and Virginia. The principal foreign countries for the production of this ore are the Rhine District and Belgium, Silesia, Great Britain, France and Spain, The first named region has for years yielded more than the other four combined.

The zinc ore of Iowa is found in crevices in the Galena limestone. The strata of that region are cut by fissures, and it is in the expansions or openings of these that the deposits occur. There is a very noticeable uniformity in the direction of these crevices. With few exceptions they have either an east and west or north and south direction, the former being much the more common. Besides these two sets there are others, known as "quarterings," that cross the main ones at varying angles. The larger crevices and those carrying most of the deposits are the east and wests, while the north and souths are narrow, and, when occurring in them, the ore is in sheets. The

* Wisconsin Report, vol. 1, 1862.

latter set in many cases serve as feeders to the major clefts, and at their intersection large bodies of ore are apt to occur.

The zinc as a rule is found in what are called "openings." These are formed by the widening of the crevices due to decomposition or solution of the rock in these particular layers. These cave-like expansions usually include a number of strata which form more or less irregular walls of either side. At the surface the fissures commonly appear simply as a seam in the rock, which followed down probably contains little or no mineral until it suddenly widens out into the opening where the ore, if any, will be found to occur. The dimensions of these openings are very variable, their height being all the way from three or four to forty feet, and their width from one or two up to twenty and in a few instances even forty feet. They are commonly limited above by a hard persistent layer of limestone appropriately called by the miners the "cap-rock." The latter is almost invariably cut through by a seam which may be so small as scarcely to be distinguished, or by an open fissure of varying width that often carries ore. The opening frequently extends up above the main level of its roof, forming large cone-shaped or irregular cavities or "chimneys" as they are called. On the other hand it may widen out and form large rooms or "caves" filled with the zinc ore.

It is not uncommon for the ore-bearing cavity to be divided or almost blocked up by a large mass of limestone known as the "key-rock." This obstruction has probably been left because of its greater compactness, that has enabled it to resist the destructive forces that have removed the surrounding rock.

The expanded crevices often contain rounded blocks called "tumblers," that, like the key-rock, have escaped decomposition, their edges and corners worn away by air and water.

The term "opening" is liable to be misleading as conveying the idea of an open space. They are, as a matter of fact, usually filled with ore mixed with more or less clay and rock fragments. Even where large caves are formed these may be filled to the top with crevice material mixed with zinc carbonate. On the other hand openings are found empty or only partially filled with clay, and can be traversed for hundreds and even thousands of feet through passages where no work has been done to clear the way.

The ore-bearing crevices, when followed down, are found to widen out into several openings, one below the other. The upper one is called the "first" opening, the next below is the "blue rock" opening of the miners, and still lower is a third and fourth. In the mines of the Dubuque region, the first is the only one that has been largely operated, the water hindering progress at the lower levels. The second has, however, been worked when possible. In the Center Grove mines, two miles west of Dubuque, ore has been removed from the third and, in one case, from the fourth opening.

The ores of zinc found in the Iowa mines are the carbonate (Smithsonite), sulphide (Sphalerite), and, in comparatively small amounts, the silicate (Calamine).

The carbonate or dry bone is by far the most common. It occurs in a great variety of forms; in cellular masses; as botryoidal coatings; in earthy masses and impregnating the rock. It is found coating galena crystals and also entirely replacing the lead and forming pseudomorphs. Several inter-

esting specimens were seen in which fossils had been replaced by the carbonate. One of these was a slab of dry-bone on which were several large gasteropods, their substance changed over into the zinc ore, which had preserved their outline perfectly. The carbonate will contain on an average 35 to 40 per cent of zinc.

The sulphide or "black-jack" of the miners is not found so abundantly in Iowa mines as is the Smithsonite. This is doubtless due to the fact that the former has been largely altered into the latter as will be explained later. The ore contains considerable iron and is so dark colored as to resemble the galena on a cleavage face.

The silicate is rarely found. When occurring it forms coatings on the the Smithsonite. Some specimens collected had a banded structure and were not unlike quartz in appearance,

All the carbonate has without doubt been derived from the blende. Several facts indicate this to be the case: (1) It is not uncommon to find pieces, the outside of which are dry bone while the unaltered interior is composed of the sulphide. (2) In the lower levels and where it is below the water the ore occurs as the blende. This is the universal rule and would seem to be owing to the fact that the deposits beneath are not subjected to the alteration agencies at work nearer the surface.

The zinc ore may occur pure or mixed with more or less clay and rock. The carbonate is found coating the sides and top of the opening and covering the rock fragments in these. As before stated large masses of nearly pure dry bone occur filling large caves. In one of these great cavities the ore was so loosely deposited that a blow of the pick would cause tons of it to come tumbling down.

In their vertical distribution the lead and zinc ores of Iowa are unlike the occurrences in other parts of the region. Chamberlain makes the following statement concerning this:

"It is a law to which no noteworthy exceptions have yet been authentically reported, that lead predominates in the upper beds, but relatively decreases in the lower, while the zinc ores are very scant in the upper horizons, but relatively increase and often predominate below." This law does not hold good for the Dubuque region. There the zinc ore commonly occurs on the same level as the lead, and in some cases even above it. The zinc ore occupies the upper beds of the Galena limestone, few shafts reaching a greater depth than 120 feet, and then the upper portion of many is in the Maquoketa shales. It is doubtless true that the majority of the mines are in the upper one hundred feet of the Galena limestone, while in Wisconsin the zinc is confined mostly to the underlying Trenton. It often happens that the lead gives out in the crevices and, a short distance beyond, in the same opening, zinc ore will appear. Why the Galena should suddenly cease and the carbonate come in within a few yards, is a fact hard to explain. The two ores rarely occur mixed together, and where they are mingled the lead is in small quantities.

It will not be in place here to discuss at any length the theoretical questions connected with the zinc deposits. The subject is a difficult one, and sufficient data are wanting to prove, in a satisfactory manner, some of the theories advanced. But the questions connected with the origin of the zinc deposits are of much interest, both practically and scientifically and will

be stated briefly. They are best set forth by Whitney* and more recently, and in greater detail, by Chamberlain†.

First, then, as to the formation of the crevices. Extending east and west through the zinc region are numerous and abrupt undulations of the strata. These were caused by a horizontal pressure acting from the south resisted by a corresponding force from the north. To state it differently, the oscillations are due to lateral force from the Interior Sea to the south and resisted by the Archæan land area to the north. These flexures produced the crevices. As the strata were elevated the heavily bedded limestones were fissured parallel to the axis of elevation and more or less open crevices formed. In a direction at right angles little force was exerted and the beds were only fractured, producing north and south fissures.

As suggested by Whitney, the shrinkage of the rocks may account for some of the crevices, at least to their open character, though it is difficult to see how shrinkage could have the great influence attributed to it by that writer.

The ore receptacles having been formed, whence came the zinc to fill them? It will be necessary simply to mention here the rejected hypotheses, namely, those of sublimation, and of thermal waters. Facts are well nigh overwhelmingly against the idea that the fissures extend to any great depth, being confined chiefly to the Galena and Trenton limestones, and without such extension downwards either of the above theories are very improbable if not impossible. All the facts indicate that the zinc comes not from below, but from the limestones in which occur the crevices. It was deposited along with the sediments by the waters of the Silurian sea. The latter derived its metallic salts from the waste of the pre-existing land surfaces. Chamberlain describes in detail the cause of localization of the deposits to a few areas, ascribing it to the currents of the ancient sea, taken in connection with the precipitating agencies of organic matter.

After their deposition in the limestone beds the zinc was concentrated in the crevices by the action of drainage waters percolating through the metal-bearing beds. In this way the zinc was concentrated in the fissures where it is now found.

SATIN SPAR FROM DUBUQUE.

BY A. G. LEONARD.

Located less than six miles south of Dubuque and one and three-fourth miles due west of Massey station on the Chicago, Milwaukee & St. Paul Railroad are some curious "spar caves" as they are appropriately called. In these caverns are some occurrences of satin spar that are very unusual and of much interest. It is

*Geology Wisconsin, vol. I, 1862.
†Geology Wisconsin, vol. IV, 1873-1879.