THE BARTH IRON ORE DEPOSIT.

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In the final report of the Fortieth Parallel Survey¹ a remarkable hill of iron ore was noted about six miles west of the town of Palisade, Nevada. The deposit has since been acquired and developed by the American Smelting and Refining Company and is known as the West Iron Mine. Since the present owners began operating this mine about six years ago, over 240,000 tons of ore have been shipped to their smelters near Salt Lake City.

W. H. Emmons² visited the mines in 1907 and suggested that the deposit might have originated as a result of contact metamorphism. He considered the rock that encloses the ore to be a fine-grained diorite, and stated that he found a metamorphosed rock, presumably of sedimentary origin, in contact with the diorite a short distance south of the mine.

Several days were spent by the writer at the mine during the fall of 1911 in a study of the deposit, and his grateful acknowledgment of the courtesy of superintendent H. G. Wilson and consulting engineer G. B. Wilson is here recorded.

The mine workings consist of an open pit about 200 feet in diameter and eighty feet deep, sunk in the solid ore. About twenty feet above the bottom of the pit a series of cross-cuts and drifts have been run as the upper or "dry" level in an extension of the ore to the south and east. Two levels approximately fifty feet apart vertically and below the upper level have been opened up down the dip of the ore body and connect with an inclined shaft that follows the dip of the ore for 180 feet. In the accompanying map of the mine workings (Fig. 17) the outline of the pit and

¹ King, Clarence, "Geol. Exp. of the 40th Par.," Vol. II, pp. 585-6.

² Emmons, W. H., "A Reconnaissance of Some Mining Camps in Elko, Lander, and Eureka Counties, Nev.," Bull. U. S. Geol. Sur., No. 408, pp. 112-113.

the workings of the upper level are shown in solid lines. The lower level is shown in dotted lines, while the intermediate is in dashed lines. The chief production of the mine has come from the pit and the development work in the levels, although at the time of the last visit the upper level was being caved.

The topography of the surrounding area is characteristic of the Great Basin in which it lies. The Cortez Range, trending north and south, rises two to three thousand feet from the broad flat

FIG. 17. Mine map of the West Iron Mine. Workings of upper level shown by solid lines, lower level by dotted lines, intermediate level by dash lines.

valleys on either side. It is a rough-hewn block of andesites and rhyolites that has been faulted up to its present position. The Humboldt River, flowing westerly, cuts directly across the range

in a narrow steep-walled canyon known as the Palisades (Fig. 18).

The canyon walls rise rather abruptly from the river for a few hundred feet, then merge with the gentler slopes that cul-

FIG. 18. Outline map showing location of Palisade, Nevada.

minate in the Carlin peaks to the north and an unnamed ridge to the south. Radiating from these elevations, several ravines and small canyons have deeply incised the slopes and finally lead to the river. One of these, Safford Canyon (Fig. 19), originating on the ridge to the south and deepening to the northwest, joins the river near the western end of the Palisade Canyon.

The west rim of Safford Canyon is a low ridge, the northern spur of which is formed by the outcrop of the ore body. Here

the canyon walls are somewhat gentler and the surrounding hills have the mature aspect of long-continued erosion. A short distance to the west of the mine stands Eagle Rock, an oval spine

FIG. 19. Geological map of the vicinity of the West Iron Mine.

of rock deeply cleft at the top and rising precipitously from the water's edge, a landmark since the earliest days of trans-continental travel.

The slopes are thinly covered with coarse angular detritus that has resulted from the breaking up of the underlying rocks by the weather. As is common in arid regions, the mechanical disintegration is in advance of the chemical, and the soil is thin and scanty. Occasionally ledges and boulders of harder rock project from the débris in rather fantastic shapes and give a touch of variety to the otherwise barren surface of the hills.

In the vicinity of the mine the surface is formed from a thick andesitic flow. In the report of the Fortieth Parallel Survey

only the lower portion of the flow was called an andesite and the upper part was classified as a trachyte. At first sight this division of the rocks into two distinct parts seemed to be valid. The lower rock was darker and better crystallized than the more glassy rock that capped it, and there was a fairly definite line of contact between them. A close examination of the contact failed to show any evidence that the two parts were actually distinct flows, and as the microscope showed only such differences as usually occur in the different parts of a surface flow, the rocks may be considered as such.

The base of the flow is well exposed at the mine and near the railroad bridges across the river (see Fig. 19). In the latter location it stands 25 feet or more in a nearly vertical wall with a rude columnar structure. This phase is quite brittle and breaks easily into angular fragments. It is olive green in color, the surface broadly marked and subdivided by a network of dull red bands of iron oxide. Numerous greenish red phenocrysts, which were later proved to be altered olivine and hypersthene, speckled the darker ground mass of the rock.

Thin sections showed the rock to be porphyritic, the phenocrysts forming about 10 to 25 per cent. of the whole. The phenocrysts were euhedral olivine crystals, now completely altered to serpentine and hydrous iron oxide; fresh subhedral crystals of augite; lath-shaped crystals of plagioclase showing polysynthetic twinning and zonal structure and ranging in composition from andesine to andesine-labradorite; and occasional rectangular hypersthene crystals completely altered to fibrous serpentine. Rarely a rounded and embayed quartz-grain was found, and microscopic crystals of apatite occurred sparingly as inclusions in the feldspars. In contrast to the other phenocrysts, the feldspars graded in size down to the microscopic crystals in the ground mass.

The ground mass is formed almost entirely of small elongated crystals of a rather basic andesine. These are arranged in roughly parallel lines that suggest flowage and often bend around the larger phenocrysts. A smaller proportion of hypersthene

and occasional biotite crystals occur among the feldspars and are usually parallel to them. The remainder of the ground mass is made up of small flakes of hematite which sometimes have euhedral outlines suggesting them to be pseudomorphs after magnetite.

In places a more heterogeneous arrangement of the feldspars of the ground mass gives the rock a diabasic texture and again the individual crystals of the ground mass approach the magnitude of the phenocrysts and the rock has the appearance of a fine-grained norite. The latter phase is especially characteristic of the walls of the ore body. All of the rock is badly weathered, and even in the specimens obtained from drill cores two hundred feet below the surface, the texture is clouded and obscured by limonite, kaolin, and serpentine resulting from the partial decomposition.

The rock is an olivine-bearing hypersthene andesite. A representative specimen, collected near the railroad bridges, was analyzed by Mr. W. S. Palmer, of the Mackay School of Mines, the alkalies being determined by Mr. A. R. Merz, of the U. S. Bureau of Soils. The results were as follows:

ANALYSIS OF ANDESITE FROM BARTH, NEVADA.

SiO ₂	53.00
Al ₂ O ₃	14.32
Fe ₂ O ₃	12.00
MgO	2.88
CaO	8.44
K ₂ O	2.48
Na ₂ O	2.94
H ₂ O —	1.45
H ₂ O +	1.01
S	trace
CO ₂	1.14
P ₂ O ₅	.17
Cl	trace
Total	99.83

The rock was as fresh as could be obtained, but was somewhat weathered, as is indicated by the rather high percentage of carbon dioxide. As the ferrous iron was not determined for lack of

apparatus, it is not possible to calculate the norm exactly but it contains 16.5 per cent. of orthoclase, 26.9 per cent. of albite, 20.0 per cent. of anorthite, approximately 9 per cent. of quartz, and the remainder in the ferromagnesian minerals, calcite, apatite, etc. The rock belongs to the dosalane class of the quantitative system and to the subrang Shoshonose. The preponderance of the feldspar noted under the microscope is confirmed by the analysis and the excess of silica explains the occasional phenocrysts of quartz found. The high percentage of iron is the most noteworthy, however; possibly it throws some light on the origin of the ore.

The upper portion of the flow, the trachyte of the Fortieth Parallel Survey, is composed of much lighter-colored rocks. When felsitic they are of a light lavender color and are dotted with large white phenocrysts of altered feldspar. A few darker specks of biotite and hypersthene are found on the surface. The more glassy varieties are darker and fresher. They contain the same phenocrysts in about the same proportion. Under the microscope the larger phenocrysts were found to be basic andesine with inclusions of glass, apatite, and iron oxide. Smaller phenocrysts of hypersthene and biotite were common and occasional rounded and embayed quartz-grains. Usually the phenocrysts showed perfect crystal outlines, but they were often rounded and partially resorbed. The larger hypersthene were occasionally embayed and the cavities filled with crystallized ground mass. The ground mass was formed of a mass of microscopic crystals of feldspar and hypersthene in a matrix of glass which in the felsitic varieties was devitrified.

Except for the absence of olivine phenocrysts and the greater abundance of biotite in the upper beds, the relative proportions of the minerals are the same in both the upper and lower beds. The greatest difference lies in the texture and completeness of crystallization of the ground mass and this is the cause of the difference in the appearance of the rocks. In the absence of any evidence such as glass or baking or reddening of the lower beds at the contact, or other phenomena usually found at the contact of two flows, the two may be considered as one.

The only other formation, aside from the scant alluvium in the valleys, is a low terrace of bedded sands and gravels located at the northern edge of the river and well exposed in a cut of the Western Pacific Railroad (see Fig. 19). These probably belong to the terrace gravels deposited during the existence of Lake Lahontan.

The rocks in the vicinity of the mine have been gently tilted to the west as a part of the monocline forming the faulted block of the Cortez Range. Aside from a few minor faults of slight displacement and local extent noted in the ore body, there has apparently been no other displacement or diastrophic movement.

The ore deposit is located on the point of the spur marking the junction of Safford Canyon with the Palisade Canyon. A low silicified knob of andesite just west of the pit marks the original outcrop of the ore. At the surface the deposit is a thick lens about 100 feet in thickness and about 200 feet long, dipping 40° to the northeast. It is entirely surrounded by the andesite except where the gravels and sands of the stream beds rest upon its eroded surface to the north and east. The northern part of the foot wall as exposed in the pit is undulatory and lies in three benches as if step-faulted. To the south these are sharply truncated and the ore extends back to a nearly vertical wall of the andesite. While there has been some slight movement along the boundary of the ore body and slickensides are to be occasionally found, wherever there is a possibility of measuring the displacement, as in the case of the veins penetrating the foot-wall, the actual movement has been small. In no case was there sufficient movement detected to account for the step-faulting of the ore body as a whole and it is evident that the undulatory character of the foot-wall was produced at the time of the deposition of the ore.

The ore extends in anastomosing veins into the foot-wall, cementing the included fragments of the andesite into a breccia-like mass. While there is no gradation between the ore and the andesite, many of the included fragments of the latter show embayments and undulatory outlines, indicating their corrosion

and replacement by the ore-bearing solutions. Where the veins are especially thick and abundant, the fragments of andesite are changed in color to a deep green. A slide showed that the altered andesite was a mass of crystals of phlogopite lying in a fine-grained, indeterminate matrix deeply stained with iron oxide. Clusters of apatite radiated from the angles of the andesite fragments and phlogopite scales were especially abundant in their vicinity.

The hanging wall has been eroded except to the south of the pit where a fault of 10 to 15 feet has dropped it below the level of erosion. Here the ore has been caved for a considerable area and the hanging wall is well exposed. It is pitted and corroded, and although the ore does not penetrate it as in the foot-wall, it is decidedly undulatory on a much smaller scale. The three large undulations of the foot-wall are not repeated in the hanging wall although it is in a direct line with them.

In the lower levels of the mine the form of the ore body as developed shows a striking change from that in the pit. The large extension of the ore to the southwest is absent below and the ore pinches to a thin vein as the foot and hanging walls come together at the extreme south. From the latter point the ore rapidly widens until it is over a hundred feet thick at the north. This change of form is best brought out in the accompanying diagram (Fig. 20). The solid line represents the outline of the ore body at the upper level and pit. The dot and dash line is the form as developed on the intermediate level and the dotted line the form at the lower level. The levels are approximately 50 feet apart and the change in form from the irregular mass above to the elliptical lens below takes place in less than 100 feet in depth.

Three drill holes were put down to the east of the pit. Their location is shown on the map (Fig. 17). No. 2 is near the southern extremity of the ore body; No. 1 is in a direct line east of the inclined shaft; No. 3 is just south of the railroad spur that serves the mine. The following is the record of the strata passed through in drilling them.

LOGS OF DRILL HOLES AT BARTH, NEVADA.

South.	No. 1.	No. 2.	No. 3.	North.
Gravel.....	44'	42'	39'	
Andesite.....	90'	116'	8'	
Ore.....	60'	107'	157'	
Andesite.....	8'	9'	11'	
Total.....	202'	274'	215'	

It will be noted that the ore apparently thickens toward the north. There is a possibility that this may be due in part at least to a steeper dip of the ore body causing the drill to pass more obliquely through the ore at this point and so magnifying the width of the ore. Judging from the irregularity in the undu-

FIG. 20. Outlines of iron ore body. Outline on upper level and open pit shown by solid line, on lower level by dotted line, on intermediate level by dot and dash line.

latory boundaries of the ore body found in the mine, it is more likely that the increase in thickness is caused by the recession of the walls and that the ore body is actually larger toward the north.

The ore is massive and compact. Many fracture planes have been developed in it as a result of the diastrophic movements that formed the range. Some of these planes have been slickensided but the displacement has been very slight with the exception of the small step faults at the southern end of the upper level. The

irregular form of the ore body cannot therefore be explained by subsequent faulting and must have been produced either before or during the deposition of the ore.

The ore is massive hematite through which microscopic euhedral crystals of apatite are disseminated. It shows little variation throughout the ore body either in depth or towards the walls. It is somewhat magnetic and in parts of the mine will deflect a magnetic needle to a notable extent. Although no ferrous iron could be detected in any of the samples of ore analyzed, it is probable that some magnetite exists in the ore. All of the ore at present exposed has been subjected to the oxidizing effects of the circulating meteoric waters and judging from the present wetness of the mine it is certain that these have had free access to the ore. The magnetite that was originally deposited with the hematite has probably been largely oxidized, and it will be possible to obtain the correct composition of the original ore only when the mine workings have extended below the oxidized zone. A specimen obtained at the hanging wall contact on the lower level, showing the replacement of the andesite by the ore, contained much magnetite and it is probable that much of the original ore was magnetic.

The following analyses made by Mr. Palmer show the slight variation of the ore on the different levels.

ANALYSES OF IRON ORE AT BARTH, NEVADA.

	Upper Level.	Intermediate.	Lower Level
Insoluble.....	1.98	1.80	.45
Fe ₂ O ₃	95.15	89.19	98.44
FeO.....	none	none	none
Al ₂ O ₃	1.85	3.52	1.16
CaO.....	.43	1.94	trace
P ₂ O ₅	not det.	.69	not det.
Ignition.....	.44	2.53	.05
Total.....	99.85	99.67	100.10
Total Iron.....	66.54	62.37	68.84

The ore is of high quality and uniformity and were it not for the lack of cheap fuel and high cost of transportation, it would be used for the manufacture of iron and steel. The phosphorus content is above the Bessemer limit, yet it is much below that of

the Alabama ores. Possibly with the development of electric smelting, this as well as other deposits in the state can be utilized for the making of iron and steel.

Under the microscope the ore was found to be quite porous and many minute cavities were distributed throughout the slides. A determination made by boiling a 20-gram fragment of the ore in distilled water for an hour showed the pore space to be 11.3 per cent. The ore was remarkably fine and even grained, and aside from the apatite crystals contained only the hematite. The apatites were elongate and rectangular in shape and averaged a half millimeter in length. They were clear and for the most part had perfect outlines. The larger crystals frequently had many inclusions of hematite grains. These were usually arranged parallel to the longer axis of the crystals. Occasionally the crystals were embayed and with ragged outlines as though the hematite surrounding them had begun to crystallize before the crystals had ceased their growth. For the most part, however, the apatite had already formed before the matrix of hematite had begun to separate from the solutions.

There is no apparent variation in the ore towards the hanging wall. Near the foot-wall, however, the apatite has a tendency to segregate in small nodules and veins. In these segregations the individual crystals increase in size, occasionally reaching a length of four to five millimeters. They are greenish red in color. The crystals have no definite arrangement except a slight tendency to radiate structure. They are in a matrix of hematite that merges with the ore on all sides. A few minute grains of quartz occur in the ground mass and one of the larger apatites completely surrounds a large grain of quartz.

At the foot-wall there has been a freer circulation of the surface waters and the ore has been hardened and cemented for a width of five or more feet. This phase is known as the "steel" rock on account of the difficulty with which it is drilled. Assuming that the ignition is chiefly water, the analysis indicates that the "steel" rock contains nearly 20 per cent. of limonite. The streak of the "steel" rock is a yellowish brown in contrast

to the purplish streak of the ore from the main body, and from the slight change in the other constituents it is evident that the hardening is due to cementation by infiltrated hydrous iron oxide. The completeness of the cementation is shown by the slight amount of pore space (.01 per cent.) remaining in the "steel" rock.

The following analysis from the upper level shows the cause of this hardening of the ore.

	"Steel" Rock	Ore.
Insoluble	1.20	1.98
Fe ₂ O ₃	92.59	95.15
FeO	none	none
Al ₂ O ₃	.57	1.85
CaO	.57	1.43
P ₂ O ₅	1.07	not det.
Ignition	3.71	.44
Total	99.46	99.85

Narrow seams and vuggs of calcite are fairly common in the upper level and layers of calcite crystals frequently line the walls of the few cracks and cavities. Occasional gouge seams of a light yellow clayey material are found near the foot-wall on this level. This material was found to be chiefly minute scales of phlogopite. Associated with the phlogopite were a few crystals of apatite and quartz. The color is due to iron oxide that stains the mica flakes which form the matrix.

ORIGIN OF THE ORE.

It is evident from the large, irregular form of the ore body that it is either a magmatic segregation in the andesite or is a replacement deposit. There are many features that would suggest the former origin, but such a hypothesis is rendered untenable by the lack of gradation between the ore and the andesite, the absence of the rock-forming minerals even along the borders of the ore, and the penetration of the ore along fissures in the foot-wall, indicating that the ore was deposited after the solidification of the andesite.

On the other hand, the positive evidence of the replacement of

the andesite in the incomplete effacement of the andesite at points along the boundaries and the characteristic pitted and corroded walls clearly indicate that the ore has replaced the andesite and the deposit is a true replacement deposit.

The replacement of the andesite has been remarkably complete. It is only in favorable situations that any evidence of the stages in the process can be detected. Specimens were obtained from the

FIG. 21. Microphotograph of andesite showing manner in which solutions penetrated the rock along minute crevices.

foot wall that disclosed the manner in which the ore was deposited. The ore-bearing solutions penetrated the andesite along minute crevices, as is well shown in the accompanying microphotograph (Fig. 21). The walls of the fissure were attacked and the fissure broadened, as is indicated by the blunt termination of the veinlet of ore. The transparent acicular crystals in the dark-colored ore are minute apatites similar to those found in the mass of the ore. As the solution migrated from the fissure into

the bordering andesite, a narrow zone was developed along the fissure in which only the feldspars remained of all the minerals of the andesite. The feldspars were quite fresh and the last of the minerals to be replaced. In the process a fine indeterminate matrix was developed at the contact of the ore with the andesite and in one specimen only was the suggestion of the phlogopite scales to be recognized. Phlogopite is apparently one of the intermediate products of replacement and is only found at the borders of the ore. Calcite is particularly abundant in the incompletely replaced andesite and seems to be developed as the ore is deposited. From the high content of lime in the andesite this is not surprising, though the source of the carbon dioxide is not so certain.

The striking feature is the extremely narrow zone of partial replacement. At the hanging wall this zone is especially narrow and rarely is evident even in a microscopic examination. Professor Irving in his recent paper on "Replacement Ore Bodies"¹ has called attention to the fact that igneous rocks are rarely completely replaced. In the present instance, however, this has taken place with remarkable completeness and no trace of the former minerals or texture of the andesite can be found in the mass of the ore.

The Barth deposit belongs then to Irving's second class of replacement deposits, those that have sharp and abrupt boundaries between the ore and the enclosing rock. Of the criteria which he cites for the recognition of such deposits, the Barth deposit has the following:

1. The euhedral crystals of apatite developed in the andesite at the borders of the ore body.
2. The undulatory and corroded walls.
3. Complete absence of banded structure of crustification.
4. Blocks of unreplaced andesite completely surrounded by ore near the foot wall.
5. The extreme irregularity of form of the ore body.
6. Decrease in volume of the ore over that of the rock as shown by the increased pore space in the ore.

¹ *ECON. GEOL.*, Vol. 6, pp. 527-561, 619-669.

7. The large excess of the volume of the ore over the original pore space (5 per cent.) of the andesite.

The origin of the ore-bearing solutions is not so clear. The original minerals associated with the ore are hematite, magnetite, fluor-apatite, and phlogopite. Primary magnetite and hematite are characteristic of ore deposited under conditions of considerable heat and pressure.¹ Phlogopite is considered as characteristic of igneous and metamorphic rocks.² Apatite is found under all conditions, according to Emmons. Usually, however, apatite is considered as being most characteristic of igneous and metamorphic rocks. Synthetic production of apatite has been possible only under conditions of considerable heat and pressure. Cameron and McCaughey³ indicate that apatite is not formed at temperatures usually found at the earth's surface. Cameron⁴ states however that chlor-apatite has been obtained by heating a solution of di-calcium phosphate and calcium chloride to a temperature of 200° Centigrade in a closed tube. Though apatite has been found in sedimentary rocks, its origin is not definitely known.

Occurrences of apatite that have apparently been deposited from surface solutions have been described. Bischof⁵ notes an occurrence of apatite crystals in small drusy cavities in phosphorite. Eakle⁶ recently noted in the ores of Tonopah, Nevada, minute crystals of apatite of undoubted secondary origin. Yet it is a striking fact that neither fluorine nor chlorine could be detected in either of these occurrences.

Rogers⁷ in examining a similar mineral from Tonopah found that the haloids had been replaced by the carbonate radical and that the supposed apatite was in reality dahlite.

The apatite contained in the ore at Barth is of the fluor variety

¹ Emmons, W. H., "A Genetic Classification of Minerals," *ECON. GEOL.*, Vol. 3, pp. 611-627.

² Iddings, J. P., "Rock Minerals," 1906, p. 434.

³ "Apatite and Spodiosite," *Jour. Phys. Chem.*, Vol. 15, pp. 463-470.

⁴ Personal communication.

⁵ *Chem. and Phys. Geol.*, Vol. 2, p. 23, 1855.

⁶ *Univ. Cal. Pub. Dept. Geol.*, Vol. 7, p. 16.

⁷ *Am. Jour. Sci.*, 4th Ser., Vol. 33, pp. 475-482.

and as far as known this has never been found or produced under conditions such as rule at the surface. Consequently it is believed that the apatite at Barth could not be formed from the cold oxidizing waters of the surface.

On the other hand, there is a conspicuous lack of any of the silicate minerals that are characteristically produced under condition of great heat and pressure such as distinguish deep-seated and contact deposits. The alteration of the andesite is very slight even at the ore contact. There are no garnets, pyroxenes, or epidote, that are abundant where rocks have been intruded by deep-seated igneous rocks.

There is a lack of the bleaching and leaching of the andesite such as is common around hydrothermal deposits, yet there is a small amount of bleaching and silicification at the outcrop as if there had been some action of this character. The minerals forming the ore body indicate that they were deposited under conditions of some heat and pressure, and from the lack of extensive metamorphism of the andesite we are forced to conclude that the ore-bearing solutions were not very hot. They may have been about 200° to 300° Centigrade. These solutions must have been associated with some igneous rock to acquire the necessary heat. The rocks that form the Cortez Range are the latest igneous rocks in the vicinity and the andesite is a part of the series. Perhaps the best that can be said at present is that the solutions came either as an after effect of the flow of andesite or as a basic splitting of the magma that gave origin to the following rhyolites that cap the andesite.

Of the occurrences of iron ore deposits which have been described, that at Iron Springs, Utah,¹ most nearly resembles Barth. There an ore of a similar mineralogical composition occurs along the contact of andesite and metamorphosed limestone as well as in veins in the andesite. The ore was deposited after the metamorphism of the limestone and its origin is believed by Leith and Harder to be due primarily to igneous after effects of the intrusion of the andesite.

¹Leith and Harder, "Iron Ores of Iron Springs Dist., Utah," U. S. G. S. Bull. 338, 1908.