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The Ore Deposits of Magdalena, New Mexico

Hematite and Zinc Blende Are Found Associated at the Ground-water Level, Creating a Zone of Impoverishment Instead of One of Enrichment

BY PHILIP ARGALL*

Magdalena, a town of about 1200 inhabitants, is connected with the main line of the Sante Fe railroad by a branch running up from Socorro, N. M., while a spur track about three miles in length extends from Magdalena to the Graphic smelter near the village of Kelly, the heart of the mining district. Kelly is situated on the western slope of the Magdalena range at an altitude of 7500 ft. The ore deposits extend along the slope of the range both north and south from Kelly; my knowledge of them, however, is limited to the exposures in the two principal mines of the district, both lying north of the village of Kelly.

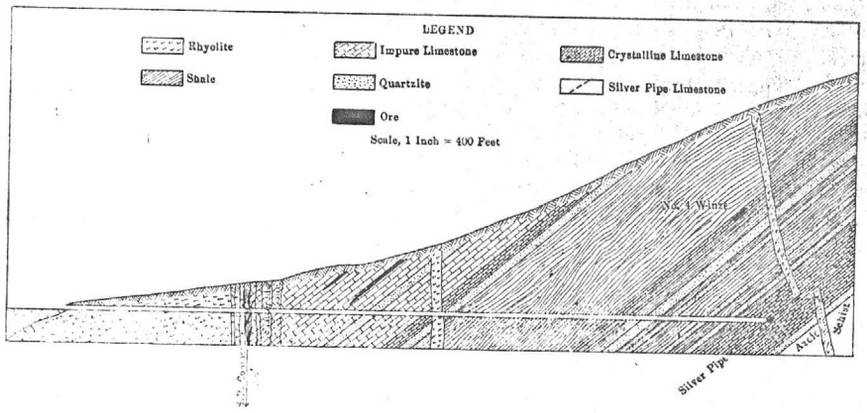

FIG. 1. SECTION OF GRAPHIC MINE THROUGH WALDO TUNNEL

Historical

The mines were first worked for lead carbonate discovered by Col. J. S. Hutchison, who located both the Graphic and the Juanita claims early in 1866. The easily reduced lead carbonates were shortly after that date smelted in adobe furnaces (Mexican fashion) and the resulting pig lead was shipped over the old Santa Fe trail by ox teams to St. Louis, Mo. Some years later other pioneers conducted smelting operations in adobe furnaces, at a point close to Kelly, known as South camp, where also the first water-jacket furnace erected in the district was put in operation in 1880. As active developments were carried out large bodies of lead carbonate were discovered in the Kelly and in the Graphic claims in 1878-9, when it might be said the district took on its first boom.

The Rio Grande smelter at Socorro was built in 1881 by the late Gustave Billings who, having previously purchased the Kelly mine, was also largely instrumental in having the railway extended in order to facilitate shipping the Kelly ores to his furnaces. The Rio Grande smelter was successfully operated for several years, obtaining a supply of silicious ores from various mining camps tributary to the Santa Fe system. The plant, however, was not sufficiently well located either as regards ore supply, fuel, or fluxes to compete successfully with the large and well established plants in Pueblo and elsewhere, particularly when the local carbonate supplies began to fall off materially in their production and quality; hence, after the practical exhaustion of the lead carbonates of the Kelly mine, coincident with the depression of 1893, the Rio Grande smelter closed down and has not since been operated. A smelter of about 100 tons daily capacity was erected at the Graphic mine in 1896, but inasmuch as an ample supply of profitable silicious ore was not obtainable in the Magdalena districts, a smelter there would be compelled to obtain its profits from smelting lead-carbonate ores, or from the importation of silicious ores at heavy freight rates on a mountain road with an uphill pull on fuel and supplies. This plant was, as one would expect, short lived. The suspension of smelting operations at the Graphic plant may be said to mark the closing of the lead-carbonate period at Magdalena, and with the exhaustion of the large bodies of these ores, mining in the district came practically to a standstill. As usual, however, the mines were leased, so that the gleanings from the old stopes and workings might be harvested, and peradventure some new bodies discovered by the intelligent work of the leasers. The leasers here were destined, as in so many other cases, to bring the district in a short time from a state of suspended animation to one of vigorous activity.

The Beginning of the Zinc Industry

In 1893 some leasers recognized the zinc carbonate ores so abundant in the zone of oxidation in close association with the lead-carbonate ores; they were equally fortunate in being able to secure a market for them in Wisconsin and in Missouri (Joplin) where smithsonite ores were for some time in high favor with the zinc-pigment manufacturers. Active prospecting opened up large bodies of zinc carbonate in both the Kelly and the Graphic mines, from which heavy shipments were made for several years. The smithsonite ores, however, gave place at a shallow depth to mixed oxide and sulphide of iron ore carrying zinc blende in varying quantities (a peculiar combination to be described later), and at moderate depth passed into solid sulphides in the Kelly

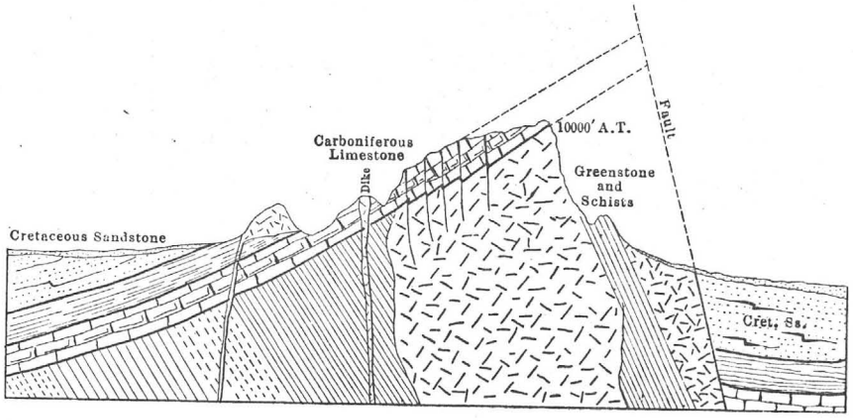

FIG. 2. GEOLOGICAL CROSS-SECTION OF THE MAGDALENA MOUNTAINS, NEW MEXICO

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mine, and doubtless will also do so in the Graphic when developed below the ground-water level.

This brings us to the last, or sulphide, period which was ushered in by the development, from 1904 to 1906, of large deposits of mixed iron oxide, zinc blende and pyrite, with some galena and chalcopyrite disseminated in small bunches throughout the deposit, in both the Graphic and the Kelly mines. The Kelly mine made quite heavy shipments during the latter year, while the Graphic company pushed development, to the extent, it is said, of developing about 100,000 tons of mixed oxide-sulphide ores, the zinc contents of which is not high enough to be valuable as a spelter ore; hence some method of eliminating the iron oxides and sulphides is necessary in order to raise the ore to the spelter tenor.

Geology

The Magdalena mountain range extends in a northerly direction from Kelly. The basal visible rock is an exceedingly compact schist, greenish in color and called by the miners "greenstone." This rock appears to form the principal mass of the mountain range and extends along its western flank, dipping about 30 deg. to the west and forms the floor of what we may call the ore measures. There is seldom any clean line of demarkation between the bottom bed of the crystalline limestone and the schists. They usually merge into each other, but in places in the Graphic mine a thin bed of quartzite occurs near the base of the crystalline limestone; in other places in both the Kelly and the Graphic mines a thin bed of pyritic material, carrying some copper, occurs adjacent to but above the quartzite. The copper oxides, on exposure, make a verdant coloration that excites the imagination of the miners, who invariably predict a rich copper deposit in depth, notwithstanding the fact that the ore deposits, confined to the limestones, are replacement deposits and that this particular cupreous pyrite bed is the lowest mineralization known in the ore measures. Some workings that have penetrated the underlying schists have, however, shown insignificant veinlets carrying chalcopyrite, but they lack continuity in both strike and dip and are simply gashes in the schist, which were probably filled from above.

The ore measures are well shown in Fig. 1, a section on natural scale through the Waldo tunnel of the Graphic mine. It will be noticed that the crystalline limestone is separated into an upper and lower series by a thin band called the "silver-pipe" limestone, a fine-grained, fossiliferous limestone about 6 ft. thick. This band is of such regularity and persistence throughout the district that it is invariably followed as a sort of indicator in the development of the mines, and because it has in places formed the plane of a bedded fault giving loose and better ground in which to drift.

The main ore deposits occur close to the silver-pipe stratum mostly in lower crystalline limestone in the Kelly mine, with the silver pipe forming the roof; and on both sides of the silver pipe in the Graphic; the formation is, however, mostly below it, but always in the crystalline limestone. This silver-pipe limestone has been but seldom attacked by the solutions that deposited the primary sulphides, yet strange to say, many acres of it have been replaced by the menstruum that circulated in the zone of oxidation; atom for atom, as it were, all structural details in this impure limestone are reproduced in the ore. Crinoid stems and shells of mollusks are found perfect in detail, but in zinc carbonate instead of the original lime carbonate. At the point where the Waldo tunnel intersects the silver pipe there is a well-pronounced bedded fault that can be traced almost to the end of the development north and south of the tunnel, a distance of 2000 ft. The throw, as I determined it at the dike which I fortunately located in a raise above the tunnel, is 40 ft. The ore measures on the line of this section, Fig. 1, are barren, while 800 ft. north on the strike of the silver pipe the upper and lower crystalline limestones have been almost entirely replaced by ore, while the silver pipe is either absent or included in the mineralization.

Overlying the upper crystalline limestone, Fig. 1, alternating beds of shale and quartzite occur, ending with a thin bed of limestone, mineralized in places (No. 4 winze). Next follows a thick bed of black carboniferous shale which brings us to what the miners call the "outer lime," an impure earthy limestone containing one, or perhaps two, horizons of mineralization which have been worked in several places in the oxidized zone. The ore is, however, of low grade and occurs in quite irregular deposits replacing the limestone metasomatically. This limestone is cut off on our line of section by the eruptive marked "rhyolite," a sort of granite porphyry called rhyolite in the field. Irregular deposits of blende and galena with pyrite occur in the shattered zone adjacent to this eruptive.

Positions of Ore Deposition

The positions of ore deposition in this formation which I have called the ore measures can now be summarized:

(1) The cupreous pyritic bed near the foot of the lower crystalline limestone; (2) the main and, so far, only important deposit, immediately above or below the silver-pipe stratum, sometimes on both sides of it; (3) the thin bed of crystalline limestone underlying the massive bed of carbonaceous shale; (4) the irregular deposits in the outer limestone. All four are metasomatic replacements of the limestone by the solutions that deposited the primary sulphides; (5) the vein-like deposit in the crushed and shattered zone between the outer limestone and the intrusive eruptive. It will be noticed that the Waldo tunnel penetrated this eruptive for about 400 ft. before reaching the shattered limestone zone; very little development has been conducted to open up the exposed ore at the contact, which consists of zinc blende, pyrite and galena, occurring in small lens-like deposits in soft porphyry and which forms a vein paralleling the outline of the eruptive. There are also some small and quite irregular replacement deposits in the shattered limestone. The eruptive porphyry is quite massive and in

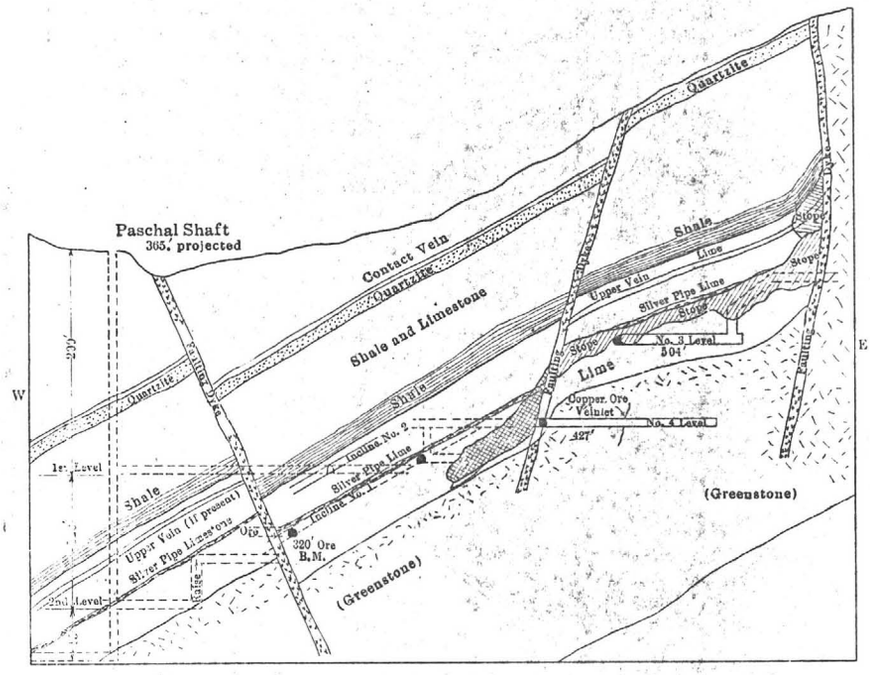

FIG. 3. SECTION SHOWING "SILVER PIPE" AND FAULTING DIKES

all probability extends across the valley and forms part of the western mountain mass. If so, it effectively cuts off the ore measures on their westerly dip.

Faulting at the Kelly Mine

Another section, Fig. 3, is taken through the most productive part of the Kelly mine. It shows three faults each filled with a dike. These I have called faulting dikes, the eastern one is a down-throw of something like 250 ft. The middle faulting dike results in a western down-throw of about 60 ft., while the western faulting dike is an up-throw of 25 ft. toward the west. The ore measures have been eroded east of the section, possibly to the top of the mountain, leaving the schists exposed. It will be noticed that almost the entire thickness of the upper and lower limestone has been stoped at the first faulting dike, while an upper vein has, in places, been indicated. Furthermore, the ore appears to have been continuous between the faulting dikes, and to have been mostly lead carbonate; the silver-pipe stratum was extensively mined for zinc carbonate. The workings varied from 8 to 20 ft. in hight, were in a dangerous condition at the time of my visit (1905), and collapsed shortly afterward. The silver-pipe stratum wherever visible showed replacement by zinc carbonate to more or less extent, and was in many places in a decidedly leached condition, having a honeycombed or loose, granular structure, usually quartzose. The "transition zone" may be said to begin at the bottom of the 60-ft. down-throw, but is, of course, irregular; some sulphides occur at the top of the down-throw and oxides are found 50 ft. below the bottom of it, notably in the chamber, indicated in hatched lines on the section, which was filled with impure smithsonite. Between the second and third faulting-dike, No. 1 incline follows the silver-pipe contact for 250 ft. through solid limestone without indication of mineral; but on nearing the up-throw faulting dike the rock became softened, stained with oxide and contained some ore at the dike, while north of the plane of section a large deposit of ore occurred. Another incline showed somewhat similar conditions, the most persistent ore near the dikes thinning out and disappearing in the intervening ground and indicating a close relation between the dikes and the ore deposits. These dikes in the Kelly faults corresponded to the main north and south faults that extend parallel with the main uplift of the mountain range and appear to me to antedate the ore deposits. There is another system of cross-faults, east and west, apparently of recent origin; in some cases they occurred possibly later than the main oxidation period, but mostly they were formed prior thereto. These, with the north-south faults, block out the ore measures in rough parallelograms. According to Charles R. Keyes,[1] the Magdalena range is one of the oldest in the basin region of New Mexico. It is, he says, a huge tilted block from which 5000 ft. of sedimentaries have been almost entirely removed, down to the Cambrian complex. Over the greater part of the range, the sedimentaries have been entirely eroded, leaving the schists to constitute the main mass of elevation while the ore deposits are situated on "one of the enormous plates of limestone that have been able to resist the attack of the elements." Fig. 2 shows "the general geotechnic features of the Magdalena range," with a main fault to the east of "not less than 5000 feet." Keyes considers the schists and granites to be Protezoic; the lower part of the limestone sequence, early Carboniferous; the upper limes late Carboniferous; while the north-south faults, in the mineralized area, are approximately parallel with the great fault, producing the mountain block, but of much later date. Be that as it may, I am inclined to the opinion that the faulting dikes are of the same period as the massive granite-porphyry eruptives that cut off the ore measures on their western dip (Fig. 1) and that the ore deposition is subsequent to both.

Confining my observations to the Kelly mine, I noticed the faulting dikes were in places practically filled with vein quartz, blende and sulphide ore; that is to say, they had been in part changed by circulating waters from eruptive dikes to mineral veins by the removal of some of the rock constituents and the deposition of quartz, pyrites, etc., in their stead. This occurred, however, only in the region of the large ore deposits. At most places the dikes are straight granite-porphyry eruptives with no particular evidence of mineralization. They vary in thickness from a few inches up to 10 ft.

Irregularities of Ore Deposition

Owing to the extensive oxidation near the dikes I could not find any primary sulphides from which deduction might be drawn regarding the order of ore deposition or faulting. Briefly, however, my observations in the Kelly mine show:

(1) That the ore is found in larger quantities and of greater value adjacent to the north-south faulting dikes; (2) the crystalline limestone at the silver-pipe contact is not uniformly replaced by ore from one faulting dike to another, but the ore becomes thinner and more irregular as it is followed away from a given dike, finally ceasing at a moderate distance along the dip of the beds; (3) the primary sulphides, as seen in the deeper workings, point conclusively to metasomatic replacement of the lower crystalline limestone, immediately below the silver-pipe stratum, by iron, zinc and lead sulphides in lens-like deposits; (4) the oxidation has extended, in the deeper workings, from the faulting dikes, both up and down, along

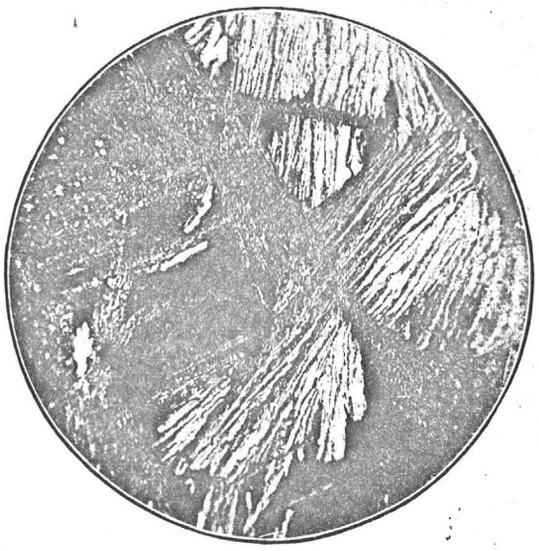

FIG. 4

FIG. 5

BLENDE AND HEMATITE

[1] *Mining Magazine*, Aug., 1905, p. 109.

the bedding plane of the limestone, showing that the faulting dikes are even now water channels or at least planes of permeability favoring the descent of meteoric waters.

For these reasons I am rather inclined to the theory that the ore deposits of the Kelly mine were formed by solutions which circulated in the north-south faulting-dike fissures.

The ore deposits in the Graphic mine appear closely related to dikes and faults, but as the workings are mostly in the oxidized zone and to a large extent abandoned, I could not obtain any data (May, 1907) on the exact relation of one to the other. The mine superintendent, however, informed me that he had not observed dikes to occur in the north-south faults in the Graphic mine. The large mass of mixed sulphides occurring on the eighth and ninth levels, north of the Waldo tunnel, show several small north-south faults, but no dikes that I could detect. Faulting along the plane of the silver-pipe is, in the Graphic mine, everywhere in evidence, and this bedded fault has carried oxidation to great depths.

Ores and Minerals

The commercial ores are cerrussite, smithsonite, zinc blende, galena and oxidized copper ore, together with some native copper. Owing to the great variety of minerals found in the oxidized zone, these mines have long been famous for their rare mineral specimens. Zinc occurs as smithsonite with its variations, hydrozincite and monheimite in various colors, green, brown, yellow, pearl and gray with several intermediate shades. A beautiful green variety much sought after for jewelry was analyzed by Prof. W. P. Headden, with results as follows: CO_2, 35.12 per cent.; ZnO, 60.97; CuO, 3.48; CdO, 0.16; CaO, 0.44; FeO, PbO, and MnO, traces. Aurichalcite, the basic carbonate of zinc and copper, and chalcophanite, the oxide of zinc and manganese, are both rare minerals, but are not uncommon at Kelly.

Copper occurs in the native state, sometimes in masses of several tons while as scales and veinlets, penetrating the smithsonite deposits, it is quite common. Cuprite and azurite occur in beautiful crystals lining cavities. Malachite and other oxidation products of copper are of common occurrence; in fact, I believe a close examination of the Magdalena ore deposits would disclose nearly all the oxidized zinc and copper ores known, while a close study of the zone of oxidation in which all these secondary minerals occur would throw a flood of light on a subject that has not received the attention its importance would appear to demand.

Primary, Secondary and Tertiary Ore Deposits

The primary ores are undoubtedly mixed sulphides; that is to say, iron pyrites, zinc blende and chalcopyrite occurring quantitatively in the order given. I have seen them only in two places in the Kelly mine, and possibly one place in the Graphic where a drift on the ninth level, passing out of the faulted zone, entered massive and solid sulphides inclosed in marbleized limestone.

Between the zone of complete oxidation and the sulphide zone, there occurs in the Kelly mine, and to a much greater extent in the Graphic mine, a zone of mixed oxides and sulphides in which the predominating mineral hematite—chiefly of the specular variety—is difficult to distinguish from zinc blende in the mines; the red streak, however, first called my attention to the combination while sampling the Kelly mine about two years ago.

I am indebted to Prof. William Campbell, of Columbia University, for an examination of this peculiar ore, and for the micrographs that accompany this paper. His description follows: "The principal mineral is hematite, which is shown as rosettes in Figs. 4 and 5; the black ground-mass is chiefly blende, and is, therefore, much later, I believe. Fig. 6 shows rounded and fractured grains of pyrite, seemingly eroded before the hematite came in. Fig. 7 is similar, but some chalcopyrite occurs around the pyrite, though the print does not show it. Fig. 8 shows more blende, which constitutes the black ground-mass. Fig. 9 shows fractured, dull grains of pyrite, a bright irregular mass of chalcopyrite opposite and to the left, and black blende. The rough matrix is hematite as before. The apparent order is pyrite, hematite, chalcopyrite and blende."

The order of deposition is somewhat peculiar, inasmuch as zinc blende, usually the first sulphide to pass into solution in the zone of oxidation, is the last to be reduced in the region of secondary sulphide deposition; but there is a possible explanation for this as I shall presently show.

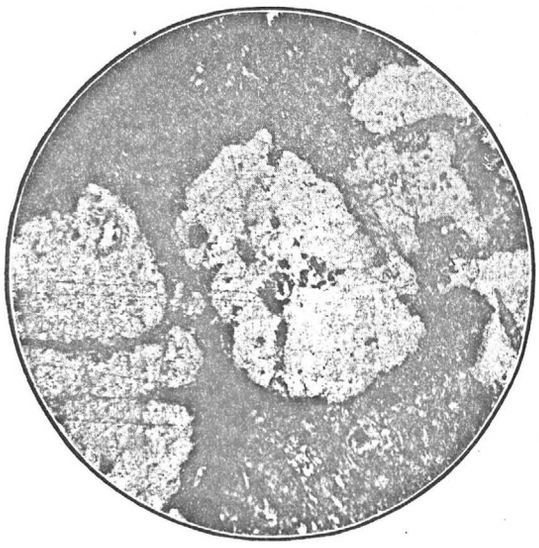

FIG. 6

FIG. 7

PYRITE AND HEMATITE

The mixed oxi-sulphide ores described by Professor Campbell, occur practically at the ground-water level. The main oreshoot contains numerous small pipes of oxidized ore within its mass, while many of the larger joints and faults are also filled with iron ochre. In a word, it is a transition deposit lying between the principal zones of oxides and sulphides, merging on following upward, into the thoroughly oxidized deposits; no doubt it will pass into the zone of primary sulphides when followed to depth below the groundwater level; thus it belongs in part to both zones and for distinctness we will call it the "transition zone."

In the Kelly mine I have traced the ore deposit from the zones of oxidation, through that of transition into what is undoubtedly the zone of primary sulphides. Here galena appeared to favor the footwall portion of the deposit, pyrite being more plentiful near the walls or at

the beginning or termination of an oreshoot. Both the mixed sulphide ores and the crystalline limestone have been subject to extensive corrosion in this transition zone. In one place I noticed a white, amorphous, zinc carbonate (evidently a chemical precipitate) filling an irregularly corroded channel or water-course, in the mixed sulphides and hematite ores of this zone. This zinc carbonate assayed: Zinc, 41.20 per cent.; lime, 0.40; insoluble, 12.60; sulphur, 0.51. In other places similar, white carbonate marked the bedding plane in these ores, while channels or pipes of corrosion, partially filled with oxide of iron or entirely with an impure partially crystalline smithsonite, are of common occurrence. I examined one cavern in this crystalline limestone, in the Kelly mine, out of which was mined about 15,000 to 20,000 tons of semi-crystalline smithsonite averaging about 34 per cent. zinc. This ore crystallized in a pre-existing cavity. In fact all the crystalline smithsonite is "cave ore;" that is to say, it crystallized in open cavities, which usually occur in crystalline limestone.

In the Graphic mine, from which the specimens examined by Professor Campbell were obtained, the transition zone is much broken and contains many open joints resulting from a bedded fault and some small vertical faults. The great mass of the developed preshoot, however, consists of a mixture of hematite, zinc blende, pyrite, etc., which is shown in the micrographs. Beyond the influence of the faults, where the ore occurs in solid, unaltered limestone as in the 9th level, northeast Waldo, the formation is mostly pyrite, with resin blende, second in order of abundance; these are followed by galena, which forms about 4 per cent. of the sulphides, and chalcopyrite constituting less than 2 per cent. These I believe are the primary ores, and they are largely pyritic and it is safe I believe, to assume that the present "transition zone" has been subjected to much corrosion from circulating solutions through which the finer blende particles have been removed with the more soluble sulphides, leaving spaces for the deposition of secondary minerals, with pyrite as one of the reducing agents.

The complex faulting with the shallow rock cover over the ore deposits presented ideal conditions for oxidation. The climate was arid in all probability, as at present, and the oxidizing menstruum was very limited, resulting in strong solutions and intense corrosion. The metals probably did not travel far, zinc sulphate becoming fixed as carbonate replacing the lime in the silver-pipe stratum and, in part, the crystalline limestone. Copper salts were reduced to the higher oxides or to metallic copper close to the point of oxidation, while galena, the last sulphide to oxidize, is found as carbonate in cave-like deposits near the point of oxidation, not unlike the Leadville lead-carbonate deposits. Thus it would appear that iron salts alone moved downward in relative abundance toward the ground-water level and became deposited in the corroded veins as hematite, to be later augmented by chalcopyrite and zinc, the base iron forming the greater mass of the secondary deposit. The usual zone of enrichment in mineral veins becomes here a *zone of impoverishment* so far as the pay ores, zinc and lead, are concerned. The Leadville and the Magdalena deposits are both in the Carboniferous limes and are mineral-bearing at Red Cliff, Aspen, Leadville and elsewhere. The Leadville deposits were doubtless oxidized in the presence of an abundance of water which washed out nearly all of the zinc, and much of the iron. Whereas, the Kelly deposits are, I presume, typical of arid-climate oxidation with the zinc and copper fixed close to the point of oxidation, but in another form. The possible deposition (I can see no other way to account for it) of the hematite in such abundance at the ground-water level, reversing the usual order of things and creating a zone of impoverishment where there is usually one of enrichment, is something novel.

Conclusions

On the foregoing tentative assumption the oxidation might be considered to progress somewhat as follows: (1) Oxidation of zinc sulphide, the resulting sulphate replacing certain limestones as zinc carbonate (secondary ore), the lime passing into solution. (2) In part contemporaneous with the first; pyrite oxidizing; descent of corrosive solutions and iron salts; formation of caverns, water courses, etc.; and deposition of hematite in the vein near the ground-water level. (3) Leaching of the secondary zinc carbonate ores (bedded deposits) formed, during the first oxidation period, possibly by carbonated waters and the crystallization of the soluble zinc carbonate in the previously eroded caves, water courses, etc., adjacent to the ground-water level; these formed the so-called "tertiary ores." Part of the zinc carbonate was doubtless deposited as sulphide (zinc blende) in the vein matrix during this period. (4) Moisture permeating these tertiary smithsonites emerges in places as highly concentrated solutions of zinc carbonate and these deposit in cavities, or as linings of geodes, crystalline smithsonite of great purity, but strained with copper and other metals. The semi-precious smithsonite might perhaps be called a Quarternary ore.

FIG. 8

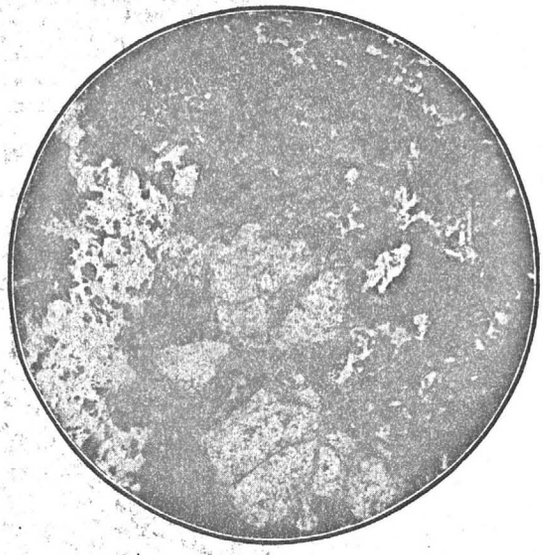

FIG. 9

PYRITE, BLENDE AND HEMATITE

Owing to shortage of labor some of the gold mining companies of Brazil, according to the *Brazilian Engineering and Mining Review*, are negotiating with the Japanese minister to Brazil for the importation of Japanese to supply the shortage.

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The complex faulting with the shallow rock cover over the ore deposits presented ideal conditions for oxidation. The climate was arid in all probability, as at present, and the oxidizing menstruum was very limited, resulting in strong solutions and intense corrosion. The metals probably did not travel far, zinc sulphate becoming fixed as carbonate replacing the lime in the silver-pipe stratum and, in part, the crystalline limestone. Copper salts were reduced to the higher oxides or to metallic copper close to the point of oxidation, while galena, the last sulphide to oxidize, is found as carbonate in cave-like deposits near the point of oxidation, not unlike the Leadville lead-carbonate deposits. Thus it would appear that iron salts alone moved downward in relative abundance toward the ground-water level and became deposited in the corroded veins as hematite, to be later augmented by chalcopyrite and zinc, the base iron forming the greater mass of the secondary deposit. The usual zone of enrichment in mineral veins becomes here a *zone of impoverishment* so far as the pay ores, zinc and lead, are concerned. The Leadville and the Magdalena deposits are both in the Carboniferous limes and are mineral-bearing at Red Cliff, Aspen, Leadville and elsewhere. The Leadville deposits were doubtless oxidized in the presence of an abundance of water which washed out nearly all of the zinc, and much of the iron. Whereas, the Kelly deposits are, I presume, typical of arid-climate oxidation with the zinc and copper fixed close to the point of oxidation, but in another form. The possible deposition (I can see no other way to account for it) of the hematite in such abundance at the ground-water level, reversing the usual order of things and creating a zone of impoverishment where there is usually one of enrichment, is something novel.

Conclusions

On the foregoing tentative assumption the oxidation might be considered to progress somewhat as follows: (1) Oxidation of zinc sulphide, the resulting sulphate replacing certain limestones as zinc carbonate (secondary ore), the lime passing into solution. (2) In part contemporaneous with the first; pyrite oxidizing; descent of corrosive solutions and iron salts; formation of caverns, water courses, etc.; and deposition of hematite in the vein near the ground-water level. (3) Leaching of the secondary zinc carbonate ores (bedded deposits) formed, during the first oxidation period. possibly by carbonated waters and the crystallization of the soluble zinc carbonate in the previously eroded caves, water courses, etc., adjacent to the ground-water level; these formed the so-called "tertiary ores." Part of the zinc carbonate was doubtless deposited as sulphide (zinc blende) in the vein matrix during this period. (4) Moisture permeating these tertiary smithsonites emerges in places as highly concentrated solutions of zinc carbonate and these deposit in cavities, or as linings of geodes, crystalline smithsonite of great purity, but strained with copper and other metals. The semi-precious smithsonite might perhaps be called a Quarternary ore.

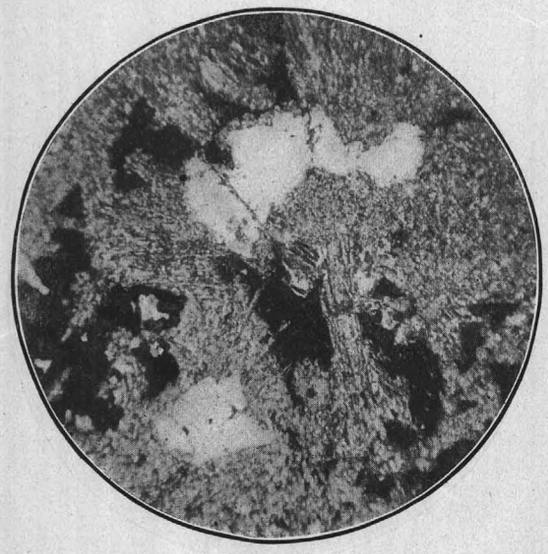

FIG. 8

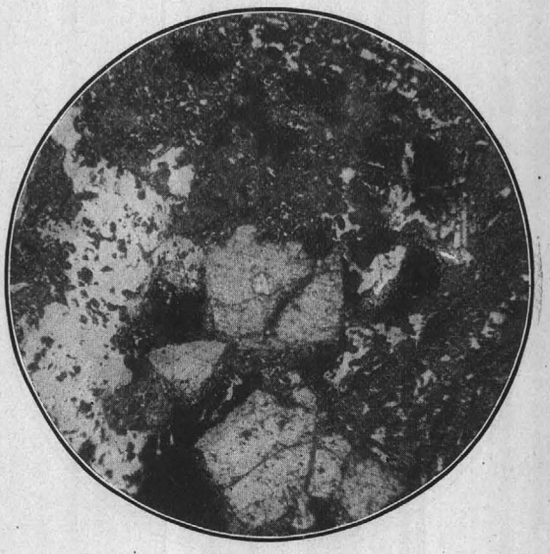

FIG. 9

PYRITE, BLENDE AND HEMATITE

Owing to shortage of labor some of the gold mining companies of Brazil, according to the *Brazilian Engineering and Mining Review*, are negotiating with the Japanese minister to Brazil for the importation of Japanese to supply the shortage.

the bedding plane of the limestone, showing that the faulting dikes are even now water channels or at least planes of permeability favoring the descent of meteoric waters.

For these reasons I am rather inclined to the theory that the ore deposits of the Kelly mine were formed by solutions which circulated in the north-south faulting-dike fissures.

The ore deposits in the Graphic mine appear closely related to dikes and faults, but as the workings are mostly in the oxidized zone and to a large extent abandoned, I could not obtain any data (May, 1907) on the exact relation of one to the other. The mine superintendent, however, informed me that he had not observed dikes to occur in the north-south faults in the Graphic mine. The large mass of mixed sulphides occurring on the eighth and ninth levels, north of the Waldo tunnel, show several small north-south faults, but no dikes that I could detect. Faulting along the plane of the silver-pipe is, in the Graphic mine, everywhere in evidence, and this bedded fault has carried oxidation to great depths.

Ores and Minerals

The commercial ores are cerrussite, smithsonite, zinc blende, galena and oxidized copper ore, together with some native copper. Owing to the great variety of minerals found in the oxidized zone, these mines have long been famous for their rare mineral specimens. Zinc occurs as smithsonite with its variations, hydrozincite and monheimite in various colors, green, brown, yellow, pearl and gray with several intermediate shades. A beautiful green variety much sought after for jewelry was analyzed by Prof. W. P. Headden, with results as follows: CO_2, 35.12 per cent.; ZnO, 60.97; CuO, 3.48; CdO, 0.16; CaO, 0.44; FeO, PbO, and MnO, traces. Aurichalcite, the basic carbonate of zinc and copper, and chalcophanite, the oxide of zinc and manganese, are both rare minerals, but are not uncommon at Kelly.

Copper occurs in the native state, sometimes in masses of several tons while as scales and veinlets, penetrating the smithsonite deposits, it is quite common. Cuprite and azurite occur in beautiful crystals lining cavities. Malachite and other oxidation products of copper are of common occurrence; in fact, I believe a close examination of the Magdalena ore deposits would disclose nearly all the oxidized zinc and copper ores known, while a close study of the zone of oxidation in which all these secondary minerals occur would throw a flood of light on a subject that has not received the attention its importance would appear to demand.

Primary, Secondary and Tertiary Ore Deposits

The primary ores are undoubtedly mixed sulphides; that is to say, iron pyrites, zinc blende and chalcopyrite occurring quantitatively in the order given. I have seen them only in two places in the Kelly mine, and possibly one place in the Graphic where a drift on the ninth level, passing out of the faulted zone, entered massive and solid sulphides inclosed in marbleized limestone.

Between the zone of complete oxidation and the sulphide zone, there occurs in the Kelly mine, and to a much greater extent in the Graphic mine, a zone of mixed oxides and sulphides in which the predominating mineral hematite—chiefly of the specular variety—is difficult to distinguish from zinc blende in the mines; the red streak, however, first called my attention to the combination while sampling the Kelly mine about two years ago.

I am indebted to Prof. William Campbell, of Columbia University, for an examination of this peculiar ore, and for the micrographs that accompany this paper. His description follows: "The principal mineral is hematite, which is shown as rosettes in Figs. 4 and 5; the black ground-mass is chiefly blende, and is, therefore, much later, I believe. Fig. 6 shows rounded and fractured grains of pyrite, seemingly eroded before the hematite came in. Fig. 7 is similar, but some chalcopyrite occurs around the pyrite, though the print does not show it. Fig. 8 shows more blende, which constitutes the black ground-mass. Fig. 9 shows fractured, dull grains of pyrite, a bright irregular mass of chalcopyrite opposite and to the left, and black blende. The rough matrix is hematite as before. The apparent order is pyrite, hematite, chalcopyrite and blende."

The order of deposition is somewhat peculiar, inasmuch as zinc blende, usually the first sulphide to pass into solution in the zone of oxidation, is the last to be reduced in the region of secondary sulphide deposition; but there is a possible explanation for this as I shall presently show.

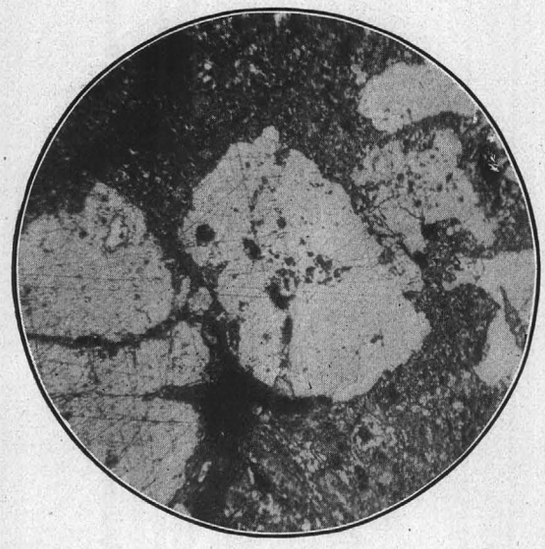

FIG. 6

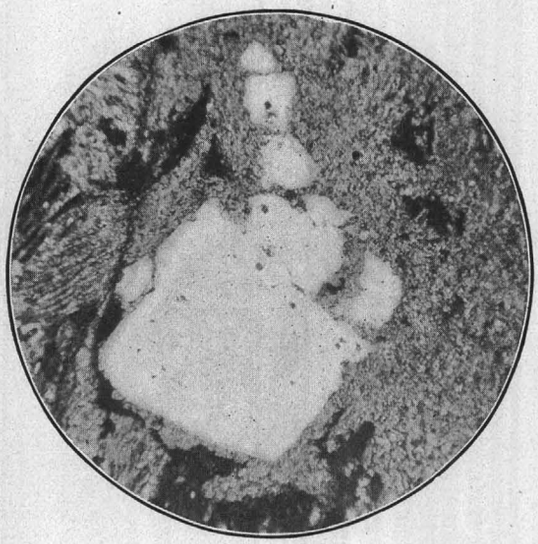

FIG. 7

PYRITE AND HEMATITE

The mixed oxi-sulphide ores described by Professor Campbell, occur practically at the ground-water level. The main oreshoot contains numerous small pipes of oxidized ore within its mass, while many of the larger joints and faults are also filled with iron ochre. In a word, it is a transition deposit lying between the principal zones of oxides and sulphides, merging on following upward, into the thoroughly oxidized deposits; no doubt it will pass into the zone of primary sulphides when followed to depth below the groundwater level; thus it belongs in part to both zones and for distinctness we will call it the "transition zone."

In the Kelly mine I have traced the ore deposit from the zones of oxidation, through that of transition into what is undoubtedly the zone of primary sulphides. Here galena appeared to favor the footwall portion of the deposit, pyrite being more plentiful near the walls or at

all probability extends across the valley and forms part of the western mountain mass. If so, it effectively cuts off the ore measures on their westerly dip.

Faulting at the Kelly Mine

Another section, Fig. 3, is taken through the most productive part of the Kelly mine. It shows three faults each filled with a dike. These I have called faulting dikes, the eastern one is a down-throw of something like 250 ft. The middle faulting dike results in a western down-throw of about 60 ft., while the western faulting dike is an up-throw of 25 ft. toward the west. The ore measures have been eroded east of the section, possibly to the top of the mountain, leaving the schists exposed. It will be noticed that almost the entire thickness of the upper and lower limestone has been stoped at the first faulting dike, while an upper vein has, in places, been indicated. Furthermore, the ore appears to have been continuous between the faulting dikes, and to have been mostly lead carbonate; the silver-pipe stratum was extensively mined for zinc carbonate. The workings varied from 8 to 20 ft. in hight, were in a dangerous condition at the time of my visit (1905), and collapsed shortly afterward. The silver-pipe stratum wherever visible showed replacement by zinc carbonate to more or less extent, and was in many places in a decidedly leached condition, having a honeycombed or loose, granular structure, usually quartzose. The "transition zone" may be said to begin at the bottom of the 60-ft. down-throw, but is, of course, irregular; some sulphides occur at the top of the down-throw and oxides are found 50 ft. below the bottom of it, notably in the chamber, indicated in hatched lines on the section, which was filled with impure smithsonite. Between the second and third faulting-dike, No. 1 incline follows the silver-pipe contact for 250 ft. through solid limestone without indication of mineral; but on nearing the up-throw faulting dike the rock became softened, stained with oxide and contained some ore at the dike, while north of the plane of section a large deposit of ore occurred. Another incline showed somewhat similar conditions, the most persistent ore near the dikes thinning out and disappearing in the intervening ground and indicating a close relation between the dikes and the ore deposits. These dikes in the Kelly faults corresponded to the main north and south faults that extend parallel with the main uplift of the mountain range and appear to me to antedate the ore deposits. There is another system of cross-faults, east and west, apparently of recent origin; in some cases they occurred possibly later than the main oxidation period, but mostly they were formed prior thereto. These, with the north-south faults, block out the ore measures in rough parallelograms. According to Charles R. Keyes,[1] the Magdalena range is one of the oldest in the basin region of New Mexico. It is, he says, a huge tilted block from which 5000 ft. of sedimentaries have been almost entirely removed, down to the Cambrian complex. Over the greater part of the range, the sedimentaries have been entirely eroded, leaving the schists to constitute the main mass of elevation while the ore deposits are situated on "one of the enormous plates of limestone that have been able to resist the attack of the elements." Fig. 2 shows "the general geotechnic features of the Magdalena range," with a main fault to the east of "not less than 5000 feet." Keyes considers the schists and granites to be Protezoic; the lower part of the limestone sequence, early Carboniferous; the upper limes late Carboniferous; while the north-south faults, in the mineralized area, are approximately parallel with the great fault, producing the mountain block, but of much later date. Be that as it may, I am inclined to the opinion that the faulting dikes are of the same period as the massive granite-porphyry eruptives that cut off the ore measures on their western dip (Fig. 1) and that the ore deposition is subsequent to both.

Confining my observations to the Kelly mine, I noticed the faulting dikes were in places practically filled with vein quartz, blende and sulphide ore; that is to say, they had been in part changed by circulating waters from eruptive dikes to mineral veins by the removal of some of the rock constituents and the deposition of quartz, pyrites, etc., in their stead. This occurred, however, only in the region of the large ore deposits. At most places the dikes are straight granite-porphyry eruptives with no particular evidence of mineralization. They vary in thickness from a few inches up to 10 ft.

Irregularities of Ore Deposition

Owing to the extensive oxidation near the dikes I could not find any primary sulphides from which deduction might be drawn regarding the order of ore deposition or faulting. Briefly, however, my observations in the Kelly mine show:

(1) That the ore is found in larger quantities and of greater value adjacent to the north-south faulting dikes; (2) the crystalline limestone at the silver-pipe contact is not uniformly replaced by ore from one faulting dike to another, but the ore becomes thinner and more irregular as it is followed away from a given dike, finally ceasing at a moderate distance along the dip of the beds; (3) the primary sulphides, as seen in the deeper workings, point conclusively to metasomatic replacement of the lower crystalline limestone, immediately below the silver-pipe stratum, by iron, zinc and lead sulphides in lens-like deposits; (4) the oxidation has extended, in the deeper workings, from the faulting dikes, both up and down, along

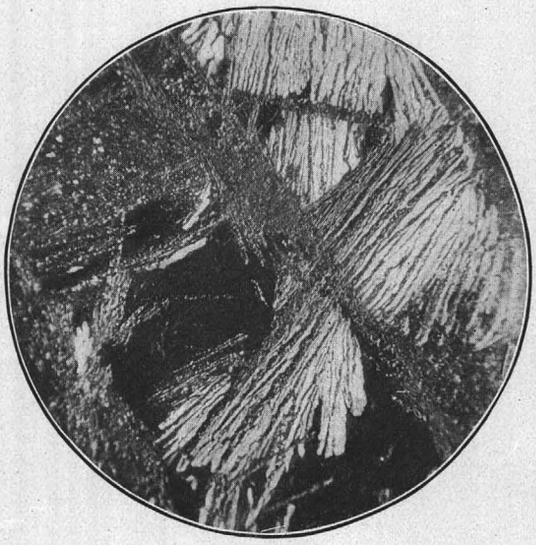

FIG. 4

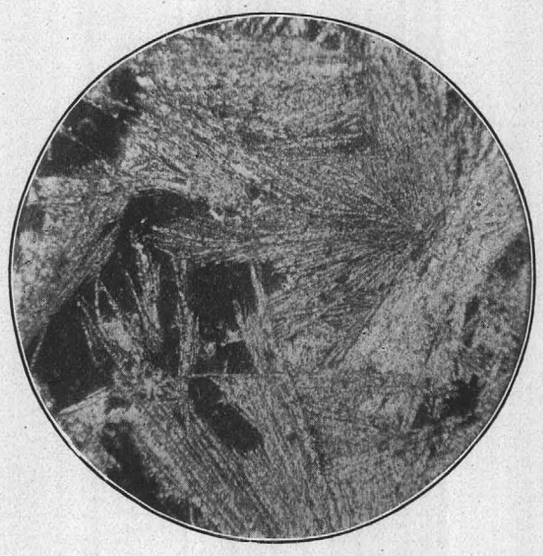

FIG. 5

BLENDE AND HEMATITE

[1] *Mining Magazine*, Aug., 1905, p. 109.

mine, and doubtless will also do so in the Graphic when developed below the ground-water level.

This brings us to the last, or sulphide, period which was ushered in by the development, from 1904 to 1906, of large deposits of mixed iron oxide, zinc blende and pyrite, with some galena and chalcopyrite disseminated in small bunches throughout the deposit, in both the Graphic and the Kelly mines. The Kelly mine made quite heavy shipments during the latter year, while the Graphic company pushed development, to the extent, it is said, of developing about 100,000 tons of mixed oxide-sulphide ores, the zinc contents of which is not high enough to be valuable as a spelter ore; hence some method of eliminating the iron oxides and sulphides is necessary in order to raise the ore to the spelter tenor.

Geology

The Magdalena mountain range extends in a northerly direction from Kelly. The basal visible rock is an exceedingly compact schist, greenish in color and called by the miners "greenstone." This rock appears to form the principal mass of the mountain range and extends along its western flank, dipping about 30 deg. to the west and forms the floor of what we may call the ore measures. There is seldom any clean line of demarkation between the bottom bed of the crystalline limestone and the schists. They usually merge into each other, but in places in the Graphic mine a thin bed of quartzite occurs near the base of the crystalline limestone; in other places in both the Kelly and the Graphic mines a thin bed of pyritic material, carrying some copper, occurs adjacent to but above the quartzite. The copper oxides, on exposure, make a verdant coloration that excites the imagination of the miners, who invariably predict a rich copper deposit in depth, notwithstanding the fact that the ore deposits, confined to the limestones, are replacement deposits and that this particular cupreous pyrite bed is the lowest mineralization known in the ore measures. Some workings that have penetrated the underlying schists have, however, shown insignificant veinlets carrying chalcopyrite, but they lack continuity in both strike and dip and are simply gashes in the schist, which were probably filled from above.

The ore measures are well shown in Fig. 1, a section on natural scale through the Waldo tunnel of the Graphic mine. It will be noticed that the crystalline limestone is separated into an upper and lower series by a thin band called the "silver-pipe" limestone, a fine-grained, fossiliferous limestone about 6 ft. thick. This band is of such regularity and persistence throughout the district that it is invariably followed as a sort of indicator in the development of the mines, and because it has in places formed the plane of a bedded fault giving loose and better ground in which to drift.

The main ore deposits occur close to the silver-pipe stratum mostly in lower crystalline limestone in the Kelly mine, with the silver pipe forming the roof; and on both sides of the silver pipe in the Graphic; the formation is, however, mostly below it, but always in the crystalline limestone. This silver-pipe limestone has been but seldom attacked by the solutions that deposited the primary sulphides, yet strange to say, many acres of it have been replaced by the menstruum that circulated in the zone of oxidation; atom for atom, as it were, all structural details in this impure limestone are reproduced in the ore. Crinoid stems and shells of mollusks are found perfect in detail, but in zinc carbonate instead of the original lime carbonate. At the point where the Waldo tunnel intersects the silver pipe there is a well-pronounced bedded fault that can be traced almost to the end of the development north and south of the tunnel, a distance of 2000 ft. The throw, as I determined it at the dike which I fortunately located in a raise above the tunnel, is 40 ft. The ore measures on the line of this section, Fig. 1, are barren, while 800 ft. north on the strike of the silver pipe the upper and lower crystalline limestones have been almost entirely replaced by ore, while the silver pipe is either absent or included in the mineralization.

Overlying the upper crystalline limestone, Fig. 1, alternating beds of shale and quartzite occur, ending with a thin bed of limestone, mineralized in places (No. 4 winze). Next follows a thick bed of black carboniferous shale which brings us to what the miners call the "outer lime," an impure earthy limestone containing one, or perhaps two, horizons of mineralization which have been worked in several places in the oxidized zone. The ore is, however, of low grade and occurs in quite irregular deposits replacing the limestone metasomatically. This limestone is cut off on our line of section by the eruptive marked "rhyolite," a sort of granite porphyry called rhyolite in the field. Irregular deposits of blende and galena with pyrite occur in the shattered zone adjacent to this eruptive.

Positions of Ore Deposition

The positions of ore deposition in this formation which I have called the ore measures can now be summarized:

(1) The cupreous pyritic bed near the foot of the lower crystalline limestone; (2) the main and, so far, only important deposit, immediately above or below the silver-pipe stratum, sometimes on both sides of it; (3) the thin bed of crystalline limestone underlying the massive bed of carbonaceous shale; (4) the irregular deposits in the outer limestone. All four are metasomatic replacements of the limestone by the solutions that deposited the primary sulphides; (5) the vein-like deposit in the crushed and shattered zone between the outer limestone and the intrusive eruptive. It will be noticed that the Waldo tunnel penetrated this eruptive for about 400 ft. before reaching the shattered limestone zone; very little development has been conducted to open up the exposed ore at the contact, which consists of zinc blende, pyrite and galena, occurring in small lens-like deposits in soft porphyry and which forms a vein paralleling the outline of the eruptive. There are also some small and quite irregular replacement deposits in the shattered limestone. The eruptive porphyry is quite massive and in

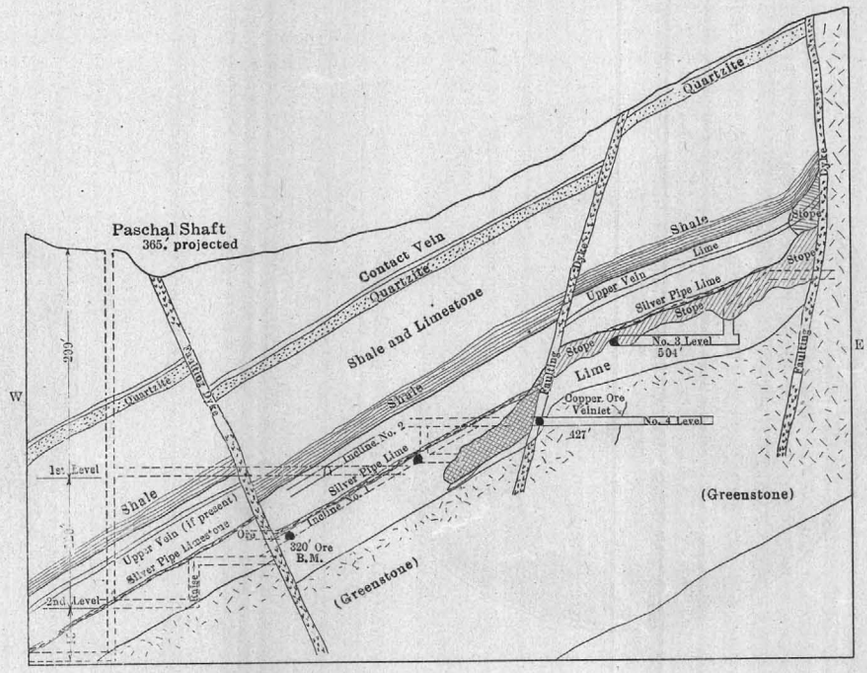

FIG. 3. SECTION SHOWING "SILVER PIPE" AND FAULTING DIKES

The Ore Deposits of Magdalena, New Mexico

Hematite and Zinc Blende Are Found Associated at the Ground-water Level, Creating a Zone of Impoverishment Instead of One of Enrichment

BY PHILIP ARGALL*

Magdalena, a town of about 1200 inhabitants, is connected with the main line of the Sante Fe railroad by a branch running up from Socorro, N. M., while a spur track about three miles in length extends from Magdalena to the Graphic smelter near the village of Kelly, the heart of the mining district. Kelly is situated on the western slope of the Magdalena range at an altitude of 7500 ft. The ore deposits extend along the slope of the range both north and south from Kelly; my knowledge of them, however, is limited to the exposures in the two principal mines of the district, both lying north of the village of Kelly.

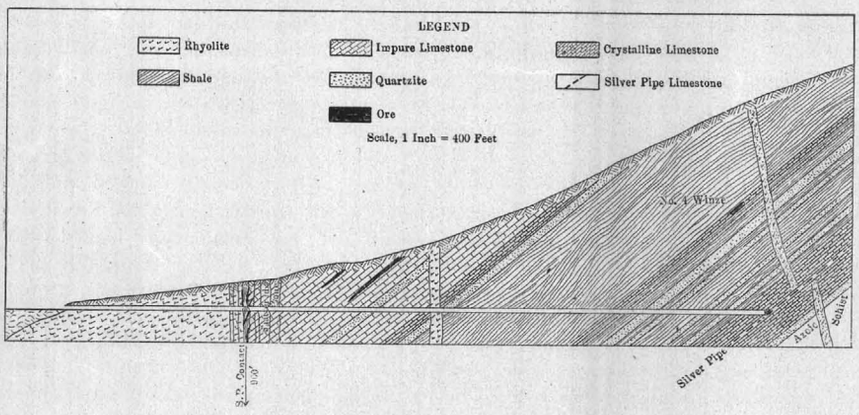

FIG. 1. SECTION OF GRAPHIC MINE THROUGH WALDO TUNNEL

Historical

The mines were first worked for lead carbonate discovered by Col. J. S. Hutchison, who located both the Graphic and the Juanita claims early in 1866. The easily reduced lead carbonates were shortly after that date smelted in adobe furnaces (Mexican fashion) and the resulting pig lead was shipped over the old Santa Fe trail by ox teams to St. Louis, Mo. Some years later other pioneers conducted smelting operations in adobe furnaces, at a point close to Kelly, known as South camp, where also the first water-jacket furnace erected in the district was put in operation in 1880. As active developments were carried out large bodies of lead carbonate were discovered in the Kelly and in the Graphic claims in 1878-9, when it might be said the district took on its first boom.

The Rio Grande smelter at Socorro was built in 1881 by the late Gustave Billings who, having previously purchased the Kelly mine, was also largely instrumental in having the railway extended in order to facilitate shipping the Kelly ores to his furnaces. The Rio Grande smelter was successfully operated for several years, obtaining a supply of silicious ores from various mining camps tributary to the Santa Fe system. The plant, however, was not sufficiently well located either as regards ore supply, fuel, or fluxes to compete successfully with the large and well established plants in Pueblo and elsewhere, particularly when the local carbonate supplies began to fall off materially in their production and quality; hence, after the practical exhaustion of the lead carbonates of the Kelly mine, coincident with the depression of 1893, the Rio Grande smelter closed down and has not since been operated. A smelter of about 100 tons daily capacity was erected at the Graphic mine in 1896, but inasmuch as an ample supply of profitable silicious ore was not obtainable in the Magdalena districts, a smelter there would be compelled to obtain its profits from smelting lead-carbonate ores, or from the importation of silicious ores at heavy freight rates on a mountain road with an uphill pull on fuel and supplies. This plant was, as one would expect, short lived. The suspension of smelting operations at the Graphic plant may be said to mark the closing of the lead-carbonate period at Magdalena, and with the exhaustion of the large bodies of these ores, mining in the district came practically to a standstill. As usual, however, the mines were leased, so that the gleanings from the old stopes and workings might be harvested, and peradventure some new bodies discovered by the intelligent work of the leasers. The leasers here were destined, as in so many other cases, to bring the district in a short time from a state of suspended animation to one of vigorous activity.

The Beginning of the Zinc Industry

In 1893 some leasers recognized the zinc carbonate ores so abundant in the zone of oxidation in close association with the lead-carbonate ores; they were equally fortunate in being able to secure a market for them in Wisconsin and in Missouri (Joplin) where smithsonite ores were for some time in high favor with the zinc-pigment manufacturers. Active prospecting opened up large bodies of zinc carbonate in both the Kelly and the Graphic mines, from which heavy shipments were made for several years. The smithsonite ores, however, gave place at a shallow depth to mixed oxide and sulphide of iron ore carrying zinc blende in varying quantities (a peculiar combination to be described later), and at moderate depth passed into solid sulphides in the Kelly

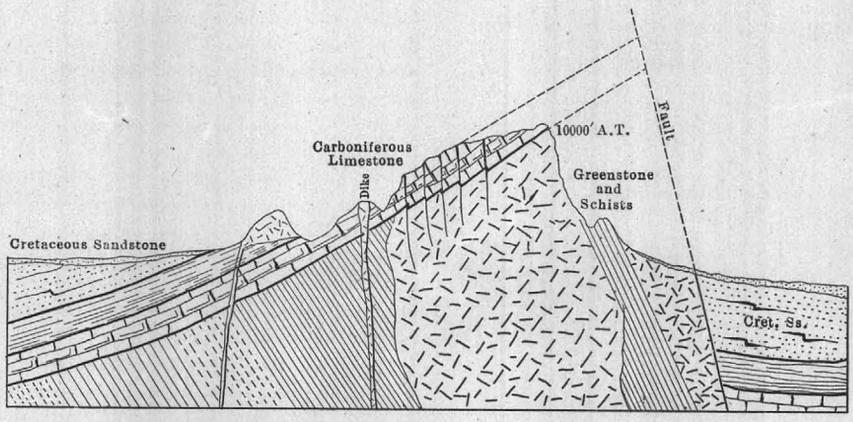

FIG. 2. GEOLOGICAL CROSS-SECTION OF THE MAGDALENA MOUNTAINS, NEW MEXICO

*Consulting mining engineer and metallurgist, Denver, Colo.

showing as nearly as possible the position of the adjoining mineral claims, and the shape and size (expressed in meters) of the claim or fraction desired to be recorded. The "holder" is not entitled to more than one mineral claim on the same vein or lode. A claim may be abandoned by filing written notice thereof with the recorder.

Work or improvements worth 1000 pesos is a condition precedent to patent and the Government must be paid 25 pesos per hectare for the land embraced in the claim. Placer claims cannot exceed eight hectares for an individual claimant and 64 hectares for an association of persons, irrespective of the number of persons composing such association. Millsites are limited to two hectares. Tunnel claims, as such, are not recognized.

Coal lands may be entered by a competent person more than 21 years old to the extent of 64 hectares, or 128 hectares by an association. The Government price for the land ranges from 50 to 100 pesos, according to the situation of the land. Saline lands are subject to auction or private sale for not less than six pesos per hectare.

This act seems to foreshadow the temper of Congress in relation to ultimate changes in the United States Mining Act, which was originally passed (1866) after an opposition so determined that it bore the singular title of "An act granting the right of way to ditch and canal owners, and for other purposes," the better to conceal its purpose and insure its enactment.

Back-stoping vs. Underhand Stoping in Large Bodies of Iron Pyrites

By J. J. Rutledge*

Theoretically, in mining large bodies as uniform in nature as iron pyrites it would seem that the overhand or back-stoping method would be most economical, and yet in several large iron-pyrites mines, it has been found by experience that the best method is that of underhand stoping. A consideration of the conditions which have led to the adoption of the underhand method may not be out of place.

Ordinarily, when back-stoping has been the method of mining employed, it has been necessary to drive the drift above the stope in order to open it up and this has added to the cost of the stoping as well as delaying the rapid opening out of the stope. The usual practice is to use stulls in mines in which the walls require support and the deposit dips at a high angle, and to allow the ore and rock to fall on the stulls at the bottom of the stope, chutes being used to load the ore into the cars in the level below. By this method gravity assists in the work of mining and less powder is necessary to break the ground than in underhand stoping. The ore is separated from the rock on the stulls and the rock left to support the walls, instead of being sent to the surface.

Little labor is required to load the cars, since the chutes are always kept full of ore and the cars can be loaded almost instantly. The miners usually are close to their work and can examine the ground overhead at all times and pull down any loose pieces of ore or rock.

Disadvantages of Back-stoping

The method of back-stoping, however, usually has the following drawbacks: When a top drift and pillar are left at the top of the stope, it is necessary to hoist the stulls into place instead of lowering them, as in underhand stoping. Again the back-stope occasionally requires the shooting of rock from the walls in order to fill the stope and give the miners access to the breast. While this work is being done no ore is being produced and consequently there is no output from this particular stope. Back-stoping gives an uncertain output. There may be a stope full of ore on one day and it may require several days' labor before the chutes can be again filled.

If drills are placed on staging made usually of lagging poles, instead of being set upon the loose rock and ore in the stope, there is always vexatious delay in cutting hitches for the lagging poles, before the staging can be erected. The spring of the lagging, if long, bothers the driller and the staging often falls, endangering the lives of the driller and helper; there are often loose scales of pyrite, sometimes of considerable thickness, which must be dislodged before the staging is set up, or before any work whatever can be done in the stope, and this delay of necessity retards all other work; loose pieces of ore are found over the back of the drifts, as well as over the stopes, and become very dangerous, for they cannot easily be detected, as the ground may be solid one moment and the next a dangerous piece of ore or rock may become loosened from the backs.

All holes drilled are necessarily dry holes and must be carefully tamped and fired or there will be great danger from sulphur fumes. In addition to the foregoing the drillings fall down upon the drill and tend to shorten its life. Drillers and timbermen, especially those inexperienced, generally dislike to trim the breasts and walls of back-stopes, or to prepare for and erect the stagings, for the work is dangerous. If the stope is wet the men cannot as easily avoid the droppers as they can in underhand work.

Underhand Stoping

With this method properly employed it is only necessary to drive one drift to open up the ground, i.e., the drift on the uppermost level. All the levels below can be opened without the necessity of driving drifts, unless it is decided to leave pillars over the stopes. Under careful management the drillers, timbermen and muckers always work in safety under well-lagged stulls and, if the walls are carefully trimmed of all loose pieces and closely and constantly watched, there can be no danger from falls of ore or rock. The drillers, muckers and timbermen have all their work underfoot instead of overhead as is the case in overhand stoping and consequently the ground is constantly under inspection.

Stulls can be lowered into the hitches instead of being raised as is the case in overhand stoping. All the holes are down holes, and wet, hence the danger from sulphur fumes is nearly negligible. There is no fine ore falling upon the drill as when all holes are dry. If floor or jointing planes occur in the orebody, advantage can be taken of this fact more readily in this method than in the other one. Water falling over the underhand stope can be caught by canvas sheets or light planks and led off to the footwall.

It is true that all waste in the orebody worked is more easily handled and disposed of in overhand work than in underhand, but, by keeping well-lagged stulls close to be breast of the stope, the muckers can easily pass all waste rock up to the lagging on the bottom stulls and stow the rock at that point. There may be cases, however, in which it will be cheaper to load and hoist the rock to the surface than to pass it through the handling necessary to stow it on the bottom stulls.

Of course, mucking and tramming are usually easier and cheaper in overhand than in underhand stoping but, by placing boiler-iron plates, or a floor of heavy 3x12-in. planks at the bottom of the stope, before the shots are fired, all muck can be dropped on this flooring and thence easily shoveled into the cars. By such means, and the use of low, open-ended cars, the mucking in underhand stoping can be done nearly as easily and cheaply as in overhand stoping. By making stopes of sufficient hight and working three or more benches simultaneously, there will always be working places for the drillers and at all times a good quantity of muck at the bottom of the stope.

The underhand method gives greater safety in mining, yields a much more uniform daily output, and usually mining can be done cheaper by this system than by overhand stoping.

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Tom Johnson (*Journ.* Chem., Met. and Min. Soc. of South Africa for March, 1908) states that in waste-filled stopes, when the hanging-wall of the stope gives way, the subsidence amounts to about 50 per cent. of the hight of the excavated area, and on the Rand he thinks this subsidence will travel to surface with little diminution.