MINERALOGY AND GEOLOGY OF CERRO MERCADO, DURANGO, MEXICO

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INTRODUCTION

Cerro Mercado, near Durango, contains Mexico's chief domestic supply of iron ore. The existence of these deposits has been known since 1552, and there have sprung up many fanciful estimates of their importance. The "Cerro" is still often referred to as "a mountain of iron," an exaggeration that rests upon old and superficial examinations. It is, however, a deposit of considerable magnitude, and this, together with its long history, invites attention and a number of descriptions of it have appeared. Most of these are brief and inaccurate. Bulletin No. 44 of the Instituto Geológico de Mexico "El Cerro de Mercado, Durango," however, is a detailed and important contribution upon which the present writer has freely drawn.

The present paper is based largely upon information collected during a summer of field work in 1926, during which time six days were spent on Cerro Mercado and a few days in the surrounding areas. The investigation was undertaken under the joint auspices of the United States National Museum and the Mineralogical Museum of Harvard University and was made possible by a grant from the Holden fund of the latter institution. The writer is deeply indebted to Prof. Charles Palache, of Harvard University, for his very kind interest in this work. Grateful acknowledgment must also be made to Señors Manuel Rangel, manager, and Garcia, mine superintendent, for the Compañía Fundidora de Fierro y Acero de Monterrey, S.A., at Durango, for the privilege of visiting the deposit and for furnishing much assistance and information relative to the ore occurrence; and to David J. D. Myers, American consul at Durango, for his interest in the investigation. Some questions of interest and importance have been left without adequate solution since the press of urgent business necessitated the immediate return of the writer to Washington after a week spent in Durango.

LOCATION

The city of Durango, capital of the State of Durango, is in the southern part of the State. Four railroad lines enter the city; one from the east joining the main line of the Mexican Central Railroad at Torreon; one in the west from Salta, a lumbering station in the Sierra Madre Mountains; another in the north from a mining district in the Sierras, Tepehuanes; and the last one in the southeast again connecting with the Mexican Central line at Canitas. The Salta line is planned to eventually extend to Mazatlan, a seaport on the Pacific coast; while the Tepehuanes branch will be advanced through the rich mining district of northern Durango and southern Chihuahua to Parral.

The city of Durango is located at the western edge of the valley of Guadiana, through which, about 8 kilometers from the city, flows the Rio Tunal. To the east and south lie rich meadows and ranches, while to the north and west the mountains rise step on step to the crest of the Sierra Madre Range. Looking from the town the two most important eminences are Cerro de los Remedios to the west and Cerro de Mercado to the north. One can also see, away to the south, the tilted pine-clad slope of Sierra Colorado. From the summit of Cerro de los Remedios the surrounding country can be scanned in all directions. To the east lie the city and the valley of Guadiana, to the west a series of smooth sloping benches—faulted volcanic flows rising step upon step. To the north are the farms of the valley, the low-lying lava flows of Cerro Sanctuario, and the abrupt slopes and ore cliffs of Cerro Mercado.

Cerro Mercado from the south appears as a long ridge with a steep and turreted mass of iron ore, Picacho de la Cruz at its eastern end and a gentler peak, Picacho Socavon 4, at its western end. Between these are two gentle domes of iron ore, Cordon Rangel to the west and Picacho Sur to the east. (Pl. 1.) The western slope is also steep, with Picacho Socavon 4 at the southern end and Picacho Socavon 2 at the northern end. The northern slopes are gentler and more irregular and melt away to the northward into a long ridge called El Pedrigoso. Cerro Mercado has a length of 1,500 meters and rises 175 meters above the valley floor.

At the time of the writer's visit (September) the hill was clothed in vegetation. On the southern slope, especially near the summit, grows an open grove of nopales (*Opuntia*), at that time in abundant fruit. These fruits, *tunas*, form an important article of food for many of the native inhabitants. At the base of the hill are a few scattered mesquite trees. The northern slope is bare of larger plant forms, although it is covered with small shrubs and especially with a mat of long grass, so thick as to almost completely mask the rocks and to make progress and geological study difficult. About the foot of the Cerro are cultivated fields of beans or pasture lands.

HISTORY OF THE DEPOSIT

Shortly after Cortez had conquered Mexico and its environs he dispersed his captains to the outlying provinces of Mexico. One expedition leaving Acapulco invaded California, while others founded towns in Sonora, Sinaloa, and penetrated Zacatecas and New Mexico. All these expeditions brought back tales of the marvelous richness of the country, among which was a report of a mountain carrying abundant silver and gold. In 1552 the Governor of New Galicia (Jalisco) sent Genes Vasquez de Mercado to conquer the valley of Guadiana and investigate the reports of this mountain of silver and gold. Mercado procured the services of an Indian who assured him that he knew the place and after some days spent on the way arrived at the indicated hill, found no gold or silver, but a huge mass of iron ore; the search proving futile, Mercado began his return, but the band was attacked by hostile Indians, at which time Mercado was mortally wounded. In 1563 the town of Durango was established by Francisco de Ibarra.[1]

The presence of so much iron ore led many, under the belief that it constituted a gossan, to prospect the hill for gold and silver, while its possibilities as a source of iron remained untouched until 1828, when an English company under the patronage of the Governor of Durango, constructed iron works on the banks of the Tunal River at a spot known as Piedras Azules. Prior to this, planters from the neighboring farms succeeded in smelting the ore from Cerro Mercado in simple Catalonian furnaces for the iron that they needed to cultivate their fields.[2]

In 1881 the Iron Mountain Co. was organized and established reduction works at the foot of the hill. In 1885 this company sold its holdings to the Mexican Iron Mountain Manufacturing Co. of Des Moines, and in 1888 it was again sold to the Durango Iron & Steel Co. During this period some iron was smelted with charcoal, but the high costs, especially of transportation, for the nearest railroad point was Torreon 150 miles to the east, made operations unprofitable.[3]

With the advent of the railroad to Durango and the acquisition of the iron deposits by the Compañía Fundidora de Fierro y Acero de Monterrey, the deposits were actively developed and under the direc-

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[1] Fr. Francisco Frejes, Historia breve de la Conquista de los Estados independientes del Imperio Mexicano. Quoted by Frederico Weidner. Annales del Ministerio de Fomento, Mexico, vol. 3, p. 164, 1877.

[2] John Birkenbine, Amer. Inst. Min. Engrs., vol. 13, pp. 196-7, 1884.

[3] Private communication to the writer by John S. McCaughan, of Durango.

tion of Señor Manuel Rangel, became the chief iron ore producer of Mexico.

GENERAL GEOLOGY

The geology of the northern plateau region of Mexico falls into two main divisions: (1) Mesozoic sedimentary rocks with rare and scattered intrusions of granodiorite, diorite, and other injected forms, and (2) Tertiary volcanic flows and tuffs with minor areas of later sediments. Along the line of the Mexican Central Railroad both types are encountered, this being in a rough way the line of demarcation of those areas predominantly of Mesozoic rocks and those of Tertiary rocks. To the east Cretaceous sediments abound almost to the entire exclusion of the eruptive rocks of later age, while to the west the sedimentary formations rapidly give way to flows and tuffs of Tertiary age.

Along the railroad from Torreon to Durango limestone is prominently exposed and can be found at Torreon and for some distance to the west. At Velardena, limestone with intrusions of granodiorite, diorite, alaskaite, and other rocks are abundant and Tertiary eruptive rocks cap many of the hills and ranges. Farther west the sediments become less and less prominent until at Durango they have given way entirely to rhyolite, latite, and tuff. From Durango west, across the Sierra Madre Range, the rocks are all eruptive and are largely rhyolitic in character. The Sierra Madre Mountains are built up of successive flows of eruptive lavas. On the east they lie directly upon folded slates; upon the west they overlie older andesite and more rarely granite. These eruptive rocks are capped in many places throughout the Sierra Madre by later basalts. The order of succession as given by Weed [4] is (1) andesite, (2) trachyte, (3) granite, (4) dacite, (5) rhyolite, and (6) basalt.

The rocks in the immediate vicinity of Cerro Mercado are entirely volcanic and include, according to A. R. Martinez-Quintero,[5] crystal tuff (Cerro Santuario and Cerros de los Presos), rhyolite tuff (Cerro de los Remedios, Cerro Frey Diego), lithoidal rhyolite (Cerro de los Remedios), lithophysal rhyolite (Cerro del Calvario) and latite (Cerro de San Antonio).

SPECIAL GEOLOGY

The rocks of Cerro Mercado can be divided into three types: (1) latite, (2) rhyolite tuff, and (3) rhyolite. (See fig. 1.) Of these latite is the lowest in the sequence, tuff intermediate, and rhyolite the topmost member. The latite is well exposed on the western and southern slopes to the crest of the hill but is absent from the northern

[4] Amer. Inst. Min. Eng. Trans., vol. 32, p. 458, 1902.

[5] El Cerro de Mercado, Durango, Bol. 44, Inst. Geol. Mexico, pp. 21–39, 1923.

slopes. It is uncovered by the excavation of the *tolva* on the western slope and can be conveniently studied there. About the ore bodies it is often altered to a pyroxenitic rock or strongly hydrated to a soft clayey mass that still retains its original structure.

Above the latite lies rhyolite tuff, fine grained or made up of fragments that do not greatly exceed 1 inch in size. This borders the hill

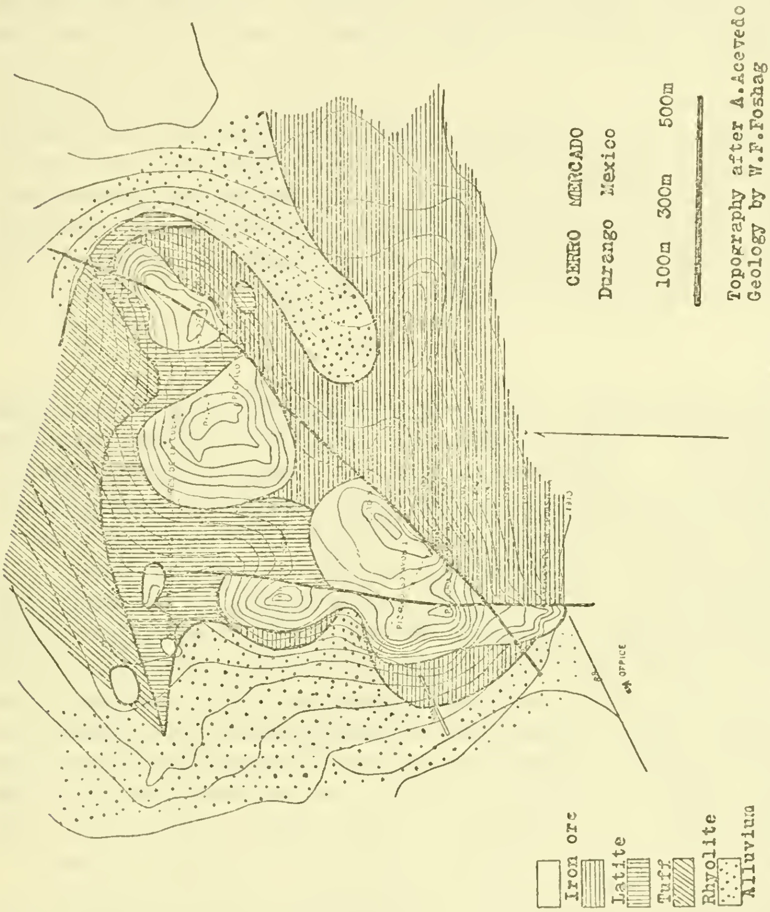

Fig. 1.—Map of Cerro Mercado

on the north and east with a small patch or two on the south slope below Picacho de la Cruz. This is well exposed by workings at the Socavon de la Cueva.

The rhyolite is confined to the lower northern slopes extending to an unknown distance to the north, where it follows the ridge of El Pedrigoso. Rhyolite also occurs in a small hill a short distance east of Cerro Mercado, known as Cerro del Almagre, and in another small hill a short distance south of the main mass.

Two main faults have been noted, although it is probable that there are more that are less evident. The more prominent fault strikes northeasterly, bordering the ore bodies of Cordon Rangel. Picacho Sur, and Picacho de la Cruz on the south and is responsible for the steep southern slope of the hill. This fault is postulated in large part upon physiographic evidence and upon the fact that the small patches of tuff at the foot of Picacho de la Cruz may be best explained as small down-faulted portions of the tuff of the northern slope.

A second fault strikes in an almost exactly northerly direction, bounding the iron-ore bodies of Picacho Socavons 4, 1, and 2 on the east and separating the ore body of Picacho Socavon 1 from that of Cordon Rangel. This fault has been encountered in Socavon 1 at a distance of 150 meters from its portal, where it abruptly terminates the ore body. The fault plane is sharp, without much slickensiding but with a considerable brecciation of the ore.

PETROLOGY

Latite.—The latite forms a fine-grained rock of a vinaceous gray color (92142).[6] The groundmass is aphanitic, often with numerous irregular gas cavities that contain minute corroded quartz crystals or small plates of specular hematite. The phenocrysts, seldom exceeding 5 millimeters in length, are in part glassy feldspar and in part a feldspar partially or completely altered to sericite or kaolin. Another mineral that may be detected with a hand lens is iron ore, presumably magnetite, the result of the magmatic alteration of the pyroxene of the rock. No phenocrysts of quartz were observed. In thin sections of the rock the groundmass, while indistinctly birefracting in places, appears to be largely glass. Throughout this groundmass there are the usual numerous microlites, the larger ones being chiefly the magnetite residues of resorbed pyroxene. The phenocrysts are orthoclase with a small optical axial angle or feldspars now completely or partially altered to a birefracting mass. In the specimens studied most of the feldspar phenocrysts have the optical properties of orthoclase but smaller amounts are andesine. No twinning was noted in the plagioclase. Martinez-Quintero[7] describes the latite as being somewhat variable in the proportion of its feldspars, some specimens having the orthoclase predominant, in others plagioclase is the chief feldspar. Besides the small altered pyroxene crystals in the groundmass there are numerous larger ones in the form of phenocrysts but the original mineral is now entirely destroyed leaving only magnetite. Near Pozo de Aguacera is a glassy

[6] The numbers refer to the catalogue number of the specimens.

[7] Inst. Geol. Mexico, Bol. 44, p. 23, 1923.

latite (92143) colored mottled brown and black, with prominent brownish feldspar phenocrysts up to 8 millimeters in size. The groundmass is a brown perlitic glass with very minute microlites. Throughout the groundmass are scattered phenocrysts of both orthoclase and plagioclase. The orthoclase is variable in its optical axial angle, in a few grains it is small but many have a large angle. The plagioclase is andesine. Twinning is not very prominent in the plagioclase but does occur in some grains as very fine striae. Augite is present in irregular to subhedral grains with a pleochroism of c= brownish green and a=brown.

Tuff.—The tuff ranges from buff-colored fine-grained rocks with a harsh feel to brick-red forms with fragments over 1 centimeter in size (92146). The original fragments are all strongly altered. Under the microscope the groundmass is amorphous except where it carries abundant secondary chalcedony as radiating globules or masses. The rock fragments are made up of a very fine birefracting substance thought to be montmorillonite or a similar clay mineral.

The finer grained tuff from the base of Picacho de la Cruz (92145) shows under the microscope a complete crystalline structure of interlocking grains of quartz, some bright-green grains of augite, a few flakes of muscovite, and rarely some feldspar. This tuff has undoubtedly been recrystallized and largely silicified.

Rhyolite.—The rhyolite (92144) forms a vinaceous to cinnamon-red rock with numerous glassy phenocrysts of quartz and smaller ones of feldspar in an aphanitic groundmass. Small grass-green augites occur in some of the more chalky streaks and are often arranged in small circular masses. The groundmass, as seen under the microscope, is made up of interlocking grains and apparently has been somewhat recrystallized and silicified. The chief constituents are quartz and orthoclase. In some parts the grass-green augite is abundant in thin veinlets. About these veinlets the rock is somewhat recrystallized. Hematite in thin hexagonal scales occurs rarely.

ROCK ALTERATIONS

The common type of wall-rock alteration is a "kaolinitization" and is often accompanied by the introduction of much diopside. This hydration is strongly developed in Socavon 4, after this adit has passed through the iron-ore body. The remainder of the adit is entirely in a completely altered latite. The texture of the original rock is well retained, the small feldspar phenocrysts are easily observable, but the entire mass is now hydrated to a soft claylike mineral. Under the microscope this mineral appears as matted small shreds with a strong birefringence and with a mean index of 1.49. A partial analysis of a sample of the pure mineral gave: Water

19.22, silica 51.20, alumina 16.15, giving an approximate alumina-silica ratio of 1:5. The mineral is therefore montmorillonite.[8] Small patches of diopside are scattered through much of this material, or the diopside may be in such abundance that the resulting rock is largely this mineral. In much of this pyroxenized material the diopside is arranged in radiating groups. Small octahedrons of magnetite are scattered through the groundmass and some streaks carry abundant honey-yellow crystals of titanite. The groundmass often carries later gypsum in small clear cleavage plates and some dispersed calcite. Bluish-colored chalcedony is sometimes observed and there are also occasional masses and veins of quartz visible.

All gradations can be found from the slightly altered latite to almost pure diopside rock so that there can be little doubt concerning the nature and origin of this "pyroxenite." Plate 3 shows a breccia of latite partially replaced by the dark-colored diopside. The residual latite fragments are now largely altered to montmorillonite.

At the point called Labores de la Cueva a similar type of alteration is encountered. The brecciated character of the rock is well shown there. The dark-gray matrix of the fragments consists largely of calcite and magnetite. (Pl. 4.) Occasional crystals of diopside are observed and rarely crystals of zircon. There are small veins of calcite or vugs lined with the same mineral. The alteration of this type is similar to that of the latite described above, but pyroxenization is very much less pronounced and calcification much further advanced.

On the west slope of El Pedrigosa, immediately north of the main ridge of Cerro Mercado, the rhyolite is extensively silicified, usually with a complete obliteration of all structure of the original rock, though rarely containing some of the original quartz phenocrysts of the rhyolite. The material so silicified may be either compact and porcelainlike or it may be soft and friable or again hard and vuggy. Under the microscope the rock is fine grained and made up largely of small radiating spherulites of chalcedony, with the interstices filled with opal. Some quartz seems to be present, although the fine grain of the aggregate precludes its definite determination. Many of the individual grains are sharp cornered, suggesting that they may be pseudomorphous after some other mineral, perhaps calcite or adularia, but no unaltered mineral could be detected. This material is mined and used for siliceous furnace linings. It consists of 97.7 per cent silica and over 2 per cent water, with other constituents in very minor amounts.

[8] The Minerals of Bentonite and Related Clays and Their Physical Properties. Clarence S. Ross and Earl V. Shannon. Journ. Amer. Ceramic Soc., vol. 9, No. 2, pp. 77–96, 1926.

MINERALOGY

The mineralogy of the iron deposits of Cerro Mercado is comparatively simple. The iron minerals are in very large excess over the other minerals and consist almost entirely of the pseudomorphous variety of hematite known as martite. Other iron minerals are inconspicuous in the deposit; they may actually be said to be rare. Associated minerals are not abundant. The iron ore forms a mass of considerable purity and the accessory minerals are found only in the vugs and cracks of this ore.

In addition to the chief ore mineral, martite, there are also goethite and limonite; and the accessory minerals include apatite, dahllite, an unknown phosphate mineral, hedenbergite, sepiolite, quartz, chalcedony, opal (variety hyalite), titanite, calcite, and barite. Other minerals have been listed from this locality but some of them have certainly been erroneous determinations, while others, such as topaz, have come from neighboring localities but not from Cerro Mercado itself.

Martite.—All of the ore that is found in well-defined crystalline form belongs to the pseudomorphous variety of hematite called martite. This leads to the reasonable assumption that the massive material is of the same nature. At Penascos de la Industria it is hard and firm with numerous cavities lined with well-formed or flattened octahedral crystals (92151). Martite crystals up to 2 and 3 inches across have been found here. The octahedrons are frequently flattened and then resemble stout rhombohedral crystals of hematite. Twins among the flattened crystals are common; sometimes larger crystals show several smaller individuals in twinned position along the edges. In the finer grained ore of Picacho Socavon[9] 1 (92160) one can readily distinguish the small constituent octahedrons of martite under the binocular microscope. A section of this under the petrographic microscope reveals the martite crystals arranged in delicate fernlike groups, suggestive in their arrangement but lacking the delicacy of the magnetite crystals that are found between lamellae of mica. Some of the harder lenses of this material (92161) have the same structure but owe their superior hardness to an impregnation of quartz and chalcedonic silica. The compact ore of Picacho Socavon 2 (92162) is also martite. It is firm and compact with a semimetallic luster. In some of the cavities, now lined with crystals of quartz, are to be found small brilliant modified octahedrons. Since they show no magnetism and have a red streak they, too, are martite. This ore on polished section appears to be homogeneous

[9] The word *socavon* is the Spanish term for adit. The various adits of Cerro Mercado have lent their names to some of the individual hills.

except for small areas within the ore and for thin bands lining the cavities that have a yellow streak and are geothite.

All the martite is in part magnetic, although visible magnetite is absent. Analyses of the ore, however, show a content of ferrous iron sufficient to account for its magnetism. Whether this magnetic portion is finely dispersed throughout the martite grains or whether it represents residual masses of unaltered magnetite within the octahedrons is unknown. An analysis of the magnetic portion of a sample from the Penascos de la Industria made in the laboratory of the United States National Museum yielded the following results:

Magnetic portion of ore, Penascos de la Industria

Forest A. Gonyer, analyst

Insoluble	10.84
Fe_2O_3	80.72
FeO	2.58
H_2O	1.36
Undetermined	4.50
	100.00

The ferrous-iron content of the above sample corresponds to 2.77 per cent of magnetite in the ore. Other analyses of the ores examined with reference to their ferrous-iron content show the amount of ferrous iron to vary from 0.5 to 5 per cent.

Goethite.—The hydrous oxide of iron goethite is widespread although not abundant in the deposits. It forms thin velvety blooms of a light chocolate-brown color on martite crystals in the vugs of the more massive ore (92155), especially at Penascos de la Industria. The lens reveals these velvety blooms to be made up of thin needle-like crystals. Rarely larger crystals of a thin barrel shape and brilliant black color and up to 1 inch in length are found in the vugs. In other places the goethite occurs as crusts, with drusy surface and made up of radiating laths (92152).

Limonite.—The amorphous hydrated oxide of iron, limonite, is only sparingly present as thin secondary films due to hydration, the result of ordinary surface weathering.

Hematite and magnetite.—These minerals, other than in the form of martite, are essentially unimportant. Martinez-Quintero[10] describes specular hematite in the form of beautiful rhombohedral crystals tabular to *c* and often twinned on the base. This description fits the characters of the flattened twinned octahedrons of martite so well as to appear likely that the two occurrences are the same mineral.[11]

[10] Inst. Geol. Mexico, Bol. 44, p. 35, 1923.

[11] The flattened form in twin crystals is very common especially in the spinel twins of magnetite and related minerals. (Note the flattening of quartz twins as well.)

Range[12] describes several different forms of hematite, including the compact, specular, and earthy hematite. He says[13] that, while it was at one time believed that magnetite was present in considerable quantities in the deposits, careful search has demonstrated its essential absence. He believes that a certain amount does occur at Picacho Socavon 2 but in minor amounts. An analysis of the ore from this point shows 4.88 per cent of ferrous iron equivalent to 5.24 per cent of magnetite, and this is the largest amount thus far reported from the deposit. In general appearance and in magnetic effects this ore comes nearest to magnetite of any mineral yet reported. Small octahedrons and masses that are strongly magnetic are scattered through the altered wall rock and can be properly classified as magnetite.

Apatite.—Clear, glassy apatite crystals (92153) are not uncommon in many parts of the hill, where they are called "*amarillas*" (yellows) by the miners. They may be found in small numbers at Penascos de la Industria, in greater numbers and finer crystals at Cueva de la Marmaja, at various places in Socavons Nos. 1 and 2, and on the northern slope of the hill. Their color is a clear lemon yellow. In form they are hexagonal prism modified by narrow faces of the second-order prism and terminated by the six faces of the unit hexagonal pyramid. (Fig. 2.) The largest crystals observed by the writer are two presented by Señor Rangel to the collections of the United States National Museum and to the Holden collection of the Harvard Mineralogical Museum and which measured 4 centimeters in diameter and 5 centimeters long. Many of the crystals are sufficiently clear and flawless to be cut into semiprecious gem stones.

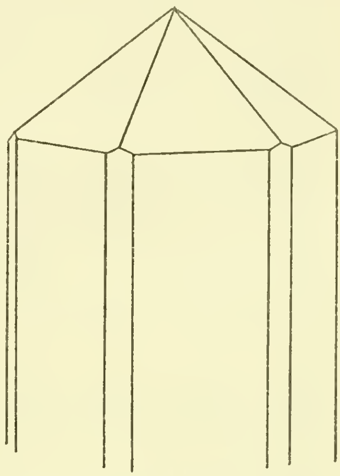

Fig. 2.—Crystal Habit of Apatite

The apatite crystals are found in several different modes of occurrence; most commonly in small crystals in the cavities of compact martite ore at Penascos de la Industria where it is associated with martite crystals or more rarely imbedded in the massive ore. At Cueva de la Marmaja they are found in small veinlets in the soft ore and it is from here that the better grade of "*amarillas*" come. In Socavon 1, they are associated with quartz and chalcedony and are always broken and imbedded in light masses of sepiolite. In the older workings on the north slope of the hill the apatite crystals are

[12] Inst. Geol. de Mexico, vol. 16, p. 6, 1902.
[13] Oral communication to the author.

found with augite in the cracks of the brecciated rock where it coats the pebbles of the breccia. Very often they are broken off and lie in a cement of silica.

Phenacite and topaz have been reported from Cerro Mercado by Wiedner and his reference to these minerals has been passed down to the present time. The phenacite crystals have been reported as numerous on the north side of the hill and are described as yellow in color, consisting of hexagonal prisms terminated by a six-sided pyramid. Wiedner described the crystals as being somewhat altered because they did not have the superior hardness of phenacite although they still retained their natural luster and brightness. Later Wiedner calls these crystals apatite. The topaz is described as occuring in prismatic crystals of a straw-yellow color. All these associations are common for the yellow apatites and search by a number of observers have failed to reveal any true phenacite or topaz.

A second type of apatite is frequently found in the vugs of the martite ore at Penascos de la Industria (92151). This apatite is colorless or white and is characteristically in radiated groups of small crystals. They are of a later generation than the yellow apatite for in many cases the latter are coated with goethite and this in turn supports the colorless apatite. These later crystals differ in habit from the yellow ones and occur in three forms. The commonest is long needlelike crystals with a steeply curving pyramidal zone so that they are barrel shaped. Others are long needles terminated by steep but rounded faces of a pyramid similar to the "berylloid" of beryl. A third form are short prisms terminated by the unit pyramid or by the base.

The clear yellow crystals of apatite are normal fluorapatite in their properties. They are uniaxial, optically negative with $\epsilon=1.630$, $\varpi=1.633$. The acicular needles are likewise apatite although their indices of refraction are somewhat lower than those of the yellow ones. They give a weak reaction for carbon dioxide and carry only a trace of chlorine. Their indices of refraction $\epsilon=1.626$, $\varpi=1.629$, are somewhat low for normal apatite, due to the small carbon dioxide content.

Dahllite.—At Penascos de la Industria there occurs sparingly in the vugs of martite small hexagonal plates or prismatic crystals, usually not more than 1 millimeter in length, consisting of the simple prism and unit pyramid (92150). These tabular crystals effervesce with hydrochloric acid and are always divided into six weakly birefracting segments which in turn are again divided into a variable number of concentric zones. Their indices of refraction are $\epsilon=1.609$, $\varpi=1.626$. The sectors are biaxial and negative, with a small but variable axial angle and they show inclined extinction with the outer hexagonal edge under crossed nicols. This extinction is very variable, the same zone extinguishing heterogeneously and varying from 8° to over 30°. The prismatic crystals are likewise zoned, the outer shell peeling off easily leaving a firm glassy center. Their indices of refraction are higher than normal apatite $\epsilon=1.648$, $\varpi=1.653$. They effervesce slowly with acid and give a microchemical test for chlorine and hence may be considered as an isomorphous mixture of chlorapatite and dahllite.

The platy dahllite has been found as a very fine grained mass with a somewhat silvery luster coating martite crystals. The prismatic type occurs as isolated crystals seldom over 1 millimeter in size scattered over goethite that in turn coats the martite crystals.

Unknown phosphate.—Associated with the colorless apatite in the vugs of martite is a mineral occurring in rose red to lavender botryoidal masses with a finely drusy surface (92156). This mineral gives strong microchemical reactions for lime and phosphorus and weak reactions for iron. Its amount, however, is insufficient for a complete chemical investigation. The mineral has the following optical properties: Biaxial, optically negative with a large axial angle. Dispersion strong, ρ greater than v. $\alpha=1.568$, $\beta=1.578$, $\gamma=1.582$. Color pale to bright rose, the tint being more intense at the center of the radiated groups. It is pleochroic in shades of rose in thick grains only.

Augite.—Augite is a common constituent of the altered wall rock about the iron ores, where it forms reticulated to radiated masses in the clayey altered latite (92147) or forms a pure augite rock (92148). The color varies from bright grass green to a dark greenish black. In some of the old workings on the north slope of the hill crystals of augite were found in abundance associated with clear yellow apatite, coating the fragment of breccia. These crystals are prismatic (92159) and the larger ones exceed 1 centimeter in length. Measurement on the two circle goniometer shows the following faces to be present *c* (001), *m* (110), *g* (210), *f* (310), *a* (100), *b* (010), and sometimes *e* (011). The crystals are nearly all twinned, and Figure 3 shows their general habit.

In color these crystals are dark greenish black but in thin sections or in small grains under the microscope they have a clear grass to emerald green color. Their pleochroism is weak. The optic axial angle is about 60° and the extinction angle about 40°. The indices of refraction are $\alpha=1.700$, $\beta=1.708$, $\gamma=1.727$. An analysis made in the laboratory of the United States National Museum upon selected crystals that had first been washed with hydrochloric acid to remove some slight stains of limonite gave the following results:

Analysis of augite (92159) from Cerro Mercado

Forest A. Gonyer, analyst

SiO_2	50.97	MnO	None.
TiO_2	.20	K^2O	0.05
FeO	6.96	Na_2O	1.86
Fe_2O_3	7.08	H_2O	.19
Al_2O_3	.95		
CaO	20.96		100.77
MgO	11.55		

The mineral is therefore essentially diopside with minor amounts of the hedenbergite and acmite molecules. The mineral composition, calculated from the above analysis, is:

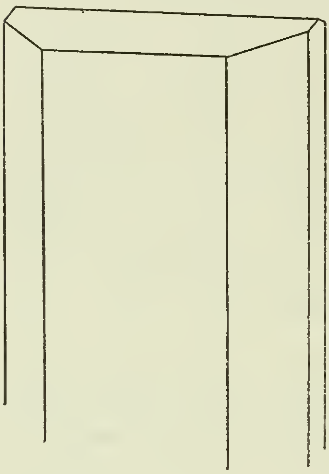

Fig. 3.—Crystal Habit of Augite

Diopside	65.0
Hedenbergite	22.8
Acmite	11.0
Magnetite	1.2
	100.00

Sepiolite.—In Socavon No. 2 occurs a white mineral made up of very fine fibers matted into light masses (92157, 92158). The writer has been told by some of the workmen that masses of this mineral several feet in diameter have been encountered. This mineral proves to be sepiolite. An analysis of this material, essentially pure as determined under the petrographic microscope, yielded the following results:

Analysis of sepiolite (92158), from Cerro Mercado

W. F. Foshag, analyst

H_2O (—)	8.60	CaO	0.24
H_2O (+)	10.20	MgO	22.95
SiO_2	55.34		
Al_2O_3	1.81		99.57
Fe^2O^3	.43		

Under the microscope the sepiolite is so finely fibrous that the precise optical properties can not be determined. The mean index, however, was found to be 1.52, which corresponds well with that of ordinary sepiolite.

Sepiolite is later than the martite and, since it incloses broken crystals of apatite, is later than this mineral as well. Associated with it is quartz that is obviously later than the sepiolite.

Quartz.—Quartz is not abundant and is one of the later minerals to form. It is commonly observed as nests of small crystals of the orindary prismatic habit in the open spaces of the sepiolite or as crystal coatings in the brecciated ore, cementing broken martite and apatite, sometimes associated with barite.

In the soft ore of Cueva de Marmaja harder lenses occur in which the ore owes its superior resistance to a cement of quartz. In this ore the delicate branching forms of the martite are inclosed in a quartz matrix. Some small quartz crystals are also found in the cavities of the compact ore of Socavon No. 2.

Chalcedony.—This mineral is encountered as a constituent of the augite rock found at the contact of the latite and the ore. In other places typical chalcedony coats some of the earlier minerals, but it is not common. It forms an important constituent of the tuffs where it is secondary and impregnates the rock to a large extent. Massive cherty silica is abundant to the north of the hill where it completely replaces the rhyolite porphyry in such abundance that it is quarried and used as furnace linings.

Opal.—Some hyalite was noted as clear glassy botyroidal crusts on some of the earlier minerals, especially on the colorless apatite crystals in the vugs of the martite ore of Penascos de la Industria.

Calcite.—Carbonate of lime is sparingly present as a cement of crushed martite and apatite associated with abundant quartz at Socavon No. 2 and as a replacement of crushed porphyry at Labores de la Cueva.

Barite.—Tabular crystals of barite, white to pink in color and aggregated into platy masses were identified associated with quartz and calcite cementing broken martite and apatite at Socavon No. 2. It is of the same generation as quartz and calcite.

Unknown pseudomorphs.—There was noted in the cavities of the ore from the Penascos de la Industria associated with delicate needles of goethite, a mineral now completely altered to red hematite. These crystals do not exceed a millimeter or two in size and are tetragonal in crystal form. The forms noted are the prism and a steep pyramid, and their habit is much like that of octahedrite, but the original nature of the mineral is unknown.

Other minerals have been described from Cerro Mercado but have not been confirmed. Rangel mentions a phosphate of iron from Cueva de la Marmaja and showed the writer some such material. Similar specimens collected from this spot had the rusty appearance of the specimens shown to him but carried no determinable phosphate of iron. Chrustschoff reported, in addition to those already described, amethyst, fluorite, and garnet. Probably these three species come from some near-by point, but it is doubtful that they came from Cerro Mercado itself.

PARAGENESIS

The first definite step in the formation of the ores of Cerro Mercado was a brecciation of the country rock. This brecciation can be best seen in the old workings on the north side of Picacho Norte at the point called Labores de la Cueva and from which the specimen illustrated on Plate 4 was obtained. The groundmass is now completely altered, or nearly so, to a mixture of calcite and magnetite with minor amounts of diopside. One may also find here partially altered fragments of wall rock coated over with a thin crust of martite crystals. This brecciation may also be observed in a number of places along the western contact of the ore. The effects here are illustrated in the figure on Plate 3 illustrating the alteration of the fragments of brecciated latite to a pyroxene (diopside) rock.

Following this brecciation came the introduction of magnetite and minor amounts of calcite. Apatite and diopside began to form later in this same stage, and continued after the complete crystallization of the hematite. This was followed again by brecciation leaving much of the ore in a badly broken condition and with numerous broken apatite crystals which were cemented by later quartz, calcite, and sepiolite.

A still further stage was hydrothermal in character, its chief effects being an introduction of silica and the alteration of some of the minerals already formed. In this stage magnetite (or martite) was hydrated to goethite; colorless apatite and dahllite were formed; small amounts of quartz, calcite, and barite were introduced and in places a considerable development of sepiolite took place.

Later changes were of minor importance and only feebly developed. Chalcedony was introduced in small amounts, to be followed later by opal, and finally, as a secondary effect due to surface weathering, a small amount of limonite formed.

The various steps in the paragenesis of these ore bodies may be tabulated as follows:

- Brecciation of the country rock.
  - Introduction of magnetite.
    - Introduction of apatite and diopside.
- Brecciation of the ore.
  - Formation of goethite.
    - Formation of (1) sepiolite, (2) colorless apatite, dahllite, quartz, calcite, and barite.
      - Formation of chalcedony.
        - Formation of opal.
          - Formation of limonite.

Concerning one of the most important steps of the sequence—the conversion of magnetite to hematite—we have as yet no data. It is the writers' opinion that this took place after the brecciation of the ore and during the hydrothermal stage that resulted in the formation of the sepiolite, quartz, calcite, and barite. It is possible that the brecciation of the ore was due to this conversion of magnetite to hematite, since there is a small diminution of volume involved in this change. Many of the broken surfaces seem quite fresh, others are somewhat altered. Few, if any, show a development of goethite upon them.

ORES

The ores of Cerro Mercado are as already stated essentially all martite, although other minerals of iron are encountered in minor amounts. The ores as mined contain 65 to 68 per cent of iron and while they are quite high in phosphorus, they are practically wanting in sulphur and titanium. Manganese is present in essentially negligible amounts. Its exceptionally high content of iron means that there is practically no gangue mineral in the ore and indeed an inspection shows nothing more than a very small amount of silica and apatite.

The chief workings are at the southwestern corner of the hill where a cliff of iron ore rises from the valley. At this place, called Penascos de la Industria, the iron ore is hard, has numerous cavities lined with octahedrons of martite, but carries no other minerals except very minor amounts of goethite, and apatite. The goethite lines the cavities and coats the martite while the apatite is found as small white needles. The ore is dark steel gray in color and of the highest grade.

Martite ore, Penascos de la Industria

Forest A. Gonyer, analyst

SiO_2	0.32	MgO	0.72
TiO_2	None.	MnO	Trace.
Fe_2O_3	93.64	P_2O_5	None.
Al_2O_3	4.04	H_2O	.31
FeO	1.15		
CaO	None.		100.18

The locality on the west flank of the Picacho Socavon 4, called Cueva de la Marmaja, is also being actively worked and produces high-grade ore. Here the mineral is a friable sandy mass made up almost entirely of small black octahedrons of martite. The softer material is a black sand that can easily be picked down, while the somewhat more compact ore is spongy and friable. Occasional hard lenses owe their superior resistance to a siliceous cement. In color the ore is dark bluish to greenish black which sometimes show numerous small brilliant yellow crystals of apatite, apparently contemporaneous with the martite. An analysis of this ore yielded the following results:

Iron Ore, Picacho Socavon 4

Forest A. Gonyer, analyst

SiO_2	0.52	MgO	0.20
TiO_2	.48	MnO	None.
Fe_2O_3	86.60	P_2O_5	None.
Al_2O_3	1.76	H_2O	.19
FeO	4.88		
CaO	2.56		100.01

Later examination of the specimen analyzed showed it to be abnormally rich in apatite and accounts for the high phosphate value. The iron content calculated to metallic iron is 64.41 per cent.

From Picacho Socavon 2, the ore is less crystalline and more compact. Here it is massive, with only a few small vugs, is dark steel gray to brilliant iron black in color and is hard and tough. Except for small druses and thin seams of quartz no other mineral was noted except that on polished surface the small vugs are seen to be lined with a thin coating or goethite and a few small patches, apparently former cavities, are now completely filled with that mineral. An analysis of this ore gave the following:

Iron Ore, Picacho Socavon 2

Forest A. Gonyer, analyst

SiO_2	9.44	MgO	0.20
TiO_2	None.	MnO	None.
Fe_2O_3	85.40	P_2O_5	None.
Al_2O_3	4.12	H_2O	.19
FeO	.58		
CaO	.08		100.01

Besides the ores now being mined the so-called *boleo* ore flanking the hill on several sides was of importance in the early days of smelting. This ore consists of pebbles and bowlders of detrital ore, in some places loosely cemented, in others loose and gravelly. It consists largely of hematite in the form of pebbles or as loose martite crystals, often superficially converted to limonite or coated and cemented by the latter mineral. Because of its lower phosphorus content, this ore is said to be very high grade and is therefore particularly desirable.

ORE BODIES

There are four main masses of iron ore at Cerro Mercado. The one now being actively worked flanks the hill on the west, forming a prominent ridge and has a length of 800 meters and a maximum width of 150 meters, with a thickness as near as can now be judged not exceeding 60 meters. Its outcrops form prominent clifflike exposures 30 to 40 meters high. Viewed from the south this ore body appears to be a tabular mass with a general dip to the west. Its contact with the country rock on the east is sharp, due to the well defined fault that borders it. On the west the ore body passes abruptly into numerous anastamosing veins so that its border has the general appearance of a breccia with a cement of ore. This ore body is probably made up of two segments; the main one including Picachos Socavon 1, 2, and 4; and a down faulted segment that forms the ore of the Penascos de la Industria.

Socavon 1 which penetrates this ore body begins at its contact with the latite at an elevation of 1,950 meters above sea level and passes through 150 meters of solid iron ore and then enters a wide zone of highly altered latite for the rest of its length (225 meters). Another adit, Socavon 2 begins at the contact of the ore at an elevation 1,975 and is driven east and north for a considerable distance and is entirely in solid ore.

The other ore bodies have not been explored but their size can easily be judged from their prominent outcrops. Immediately east of the ore body now being worked is a broad tilted tabular mass of ore that caps Cordon Rangel. This body, roughly circular in outline has a diameter of about 250 meters. Socavon 1 passes directly under this ore capping but after leaving the western ore body is in altered latite for the rest of its length. It can reasonably be concluded that this ore body is tabular in form and probably does not exceed 40 meters in thickness.

Further east and capping the central portion of the hill is the ore body of Picachos Sur and Norte. Its southern outcrop is bold; to the north it merges into the smoother slopes. Some old workings on the north side of this body show that the rock has been considerably brecciated and later cemented by the calcite, magnetite, and augite. The southern part, however, is of firm iron ore of high grade. This body is probably tabular in form with a slight dip to the north.

The easternmost ore body is that of Picacho de la Cruz and Relices Prieto where the iron ore forms bold castellated outcrops of pure mineral. It is apparently faulted into several segments but lack of any work on it precludes determination of its true form.

Several minor bodies occur at the northern foot of Picacho Socavon 2 of which the most interesting is that of Socavon de la Cueva. This ore body has been opened by several adits and shows fine flaky hematite as bedlike schliers in a soft tuff. These schliers are continuous for considerable distances.

Farther north, at the small knoll of iron ore called Picacho Rangel the ore is similar to the ore of the main deposits but the country rock is rhyolite instead of latite.

SIMILAR DEPOSITS

In some respects the iron ores of Cerro Mercado are unique in that they are deposits of the first importance connected with extrusive volcanic rocks of Tertiary age. There are, however, a few minor iron-ore occurrences of this type, and some of the features of the famous Kiirunavaara deposits of Sweden as described by Per Geijer, Stutzer, and others are similar. Minor developments of hematite in some of the rhyolites of Tertiary age, especially when associated with tin, are common in Durango and other parts of Mexico but are of only mineralogical interest and are perhaps of somewhat different origin. In this case the iron mineral is always specular hematite and never martite.

The iron-ore deposits of Barth, Nev., described by J. Claude Jones [14] are remarkably similar to the Cerro Mercado. Like them the ores are found in Tertiary eruptive rocks of andesitic character. The iron mineral is hematite. Apatite is present and there is a development of biotite along the walls. The boundary of the ore and the andesite wall is sharp; that is, without gradation of ore to wall rock, but the ore extends into the footwall as anastamosing veins, cementing the included fragments of the andesite into a breccialike mass. Where the veins are particularly abundant the fragments are changed in color to a deep green and contain much biotite in an indefinite matrix. Clusters of apatite radiate from the angles of the andesite fragments and phlogopite is particularly abundant in their vicinity. The ore is massive and compact hematite, through which are disseminated euhedral crystals of apatite. It is somewhat magnetic but little or no magnetite can be detected.

This is an almost exact description of Cerro Mercado ores with the augite of Cerro Mercado in place of the biotite of Barth. Such close similarity argues for a close relationship.

The martite deposits of Twin Peaks, Millard County, Utah, described by Horace Patton [15] are also closely related to those of Cerro Mercado. The country rock is a light colored rhyolite with abundant phenocrysts of quartz and some biotite and hornblende. It is a very massive rock but only exceptionally is it fresh. It is cut in different directions by sharply defined veins of martite which vary in width from 1 inch to 7 or 8 feet. Associated with this martite are two other minerals—apatite and augite. The apatite crystals, originally white and quite transparent, are small, rarely over an inch or more. The pyroxene occurs in slender crystals of a black color. Specimens of these augite crystals now in the National Museum are exactly

[14] Economic geology, vol. 8 pp. 247–263, 1913.

[15] Martite Crystals from Twin Peaks, Millard County, Utah. Colorado School of Mines, Quart., vol. 2, pp. 7–13, 1907.

similar in habit and twinning to those of Cerro Mercado. The martite veins are sometimes open fissures with the two walls lined with crystals. In other cases the veins are brecciated, the fissure partially filled with rhyolite fragments now coated with martite crystals. In the occurrence of the martite with rhyolitic rocks, the presence of apatite and augite, and in the brecciated nature of some of the veins with the breccia fragments coated with martite crystals, this deposit is similar to those of Cerro Mercado.

The resemblance between Cerro Mercado and Kiirunavaara, Finland, has been suggested by Per Geijer [16] but since definite data at that time were lacking no real conclusions could be drawn. Like Cerro Mercado the ore deposits of Kiirunavaara are sheetlike bodies in acid volcanic rocks, here largely syenites and quartz porphyries; whether extrusive or intrusive is still a mooted question. Lundbohm, Backstrom, and Geijer regard them as flows, while Stutzer and Daly believe them to be intrusive rocks. The ore mineral is magnetite, and only to a small extent is it mixed with hematite. In the exposures on "Professorn," however, hematite is abundant and the ore is unusually porous and is believed by both Stutzer and Geijer to be secondary.

Minerals other than magnetite are quite rare in the entire field; the most abundant of these extraneous minerals being apatite. The amounts vary from masses of pure magnetite to others of pure apatite but the main mass of ore does not average over 1 to 2 per cent. Pyroxene and hornblende are present in much smaller amounts. Sulphur seldom exceeds 0.05, titanium varies between 0.04 and 0.80 but may reach 1.36 in Luossavaara. Other minerals noted are calcite, quartz, biotite, tourmaline, asbestos, and siderite. The tenor of the ore is very high, varying from 65 to 70 per cent.

As a rule the contacts between the ore and the country rock are sharp and often without noticeable alteration of the inclosing rock. Often, however, the country is penetrated for a distance of several meters by a complex system of anastamosing veinlets of ore to such an extent that the rock appears brecciated. About the borders of the ore in many places the wall rock is altered to a *skarn* of amphibole or to a diopsidic pyroxene. The hornblende is, without doubt, the result of the uralitization of preexisting pyroxene.[17]

The analogies between the ore deposits of the Cerro Mercado and Kiiruna district may be listed as follows:

1. The association of the ore bodies with acid volcanic rock.
2. The high iron content and purity of the ores.
3. The abundance of apatite in the ores.

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[16] Igneous Rocks and Iron Ores of Kiirunavaara, Luossavaara, and Tuolluvaara. Per Geijer. Stockholm, 1910.

[17] Per Geijer. Inst. Geol. Mex., Bol. 44, 1923, p. 246.

4. The anastamosing veinlets that cut and brecciate the country rock.
5. The alteration of the wall rock to a pyroxenic skarn.
6. The tabular form of the ore bodies.

The resemblances are much greater in those portions of the Kiiruna district where the original magnetite has been secondarily changed to hematite corresponding to the martite ore bodies of Cerro Mercado. One may reasonably conclude that the hematite ores of Cerro Mercado are formed by the secondary oxidation of magnetite, such as those Geijer describes at "Professorn," the oxidation having been carried to the almost complete alteration of the magnetite.

ORIGIN

A number of writers have expressed views on the origin of the great ore bodies of Cerro Mercado but only two are the result of a sufficiently detailed examination to merit serious attention. These are the works of Manuel Rangel [18] and Leopoldo Salazar-Salinas and his coworkers.[19] We may, however, mention very briefly some of the earlier views.

Frederico Weidner [20] one of the first to visit the locality and to report upon its iron resources held that the ores were the result of volcanic activity:

> One finds rounded ore masses from Cerro Mercado of the shape and figure of projectiles scattered on all the immediate terrain, not only on the lower portions, as is natural, but also on some of the higher hillocks which seems explainable only that the volcanic force of the hill to have flung and transported them to these points.
>
> In the porphyry hills which encircle Cerro Mercado one finds the most apparent vestiges of volcanic action of the mass of Cerro Mercado, because there one finds that the porphyries are altered in color, luster, and texture as if they were smelted and fragments of the porphyry rock are found inclosed in the crystallized magnetic iron; on the south side of the Cerro the porphyry incloses particles of micaceous iron, which could have penetrated it only through sublimation; to the southeast side the porphyries are wrapped in oxide of iron to the extent of being partially converted to *almagre;* in the central part of Cerro Mercado and its folds lies pieces and banks of destroyed porphyry evidently lifted by the iron; all of which proves that the Cerro Mercado is of an origin later than the porphyry in which it rests, that the porphyry previously occupied the place now of metal. This last, impelled by volcanic force has burst the floor of the valley, breaking through the porphyry, dislocating, lifting, and breaking some of it in its path and involving in its mass many fragments of the same rock which it has just destroyed.

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[18] Los criadoros de fierro del Cerro de Mercado, Durango. Bol. 16. Inst. Geol. Mexico, 1902.

[19] El Cerro de Mercado, Durango. Bol. 44, Inst. Geol. Mex.

[20] Anales del Ministerio de Fomento. Mexico. Vol. 3, pp. 169-170, 1877.

While Chrustschoff[21] does not accept this idea entirely, still he believes that the deposits were due to some form of eruption, probably a fluid aqueous mass, that rose through channels to spread out about their openings.

Birkenbine[22] in his description of the occurrence has little to say regarding its genesis. His ideas are embodied in the following citation:

I incline to the belief that the Cerro de Mercado is formed of one or more immense veins or lenses of specular iron ore, standing nearly vertical, the fragments of which have, by the action of the elements for ages been thrown down to form the slopes of the mountain as a talus.

Manuel Rangel[23] describes the ore body as follows:

The mineral part presents the form of a very strong dike, ramifying in the western part, with two small branches to the north and includes admixture of rhyolite. Erosion operating primarily on the inclosing rock, has disintegrated it into blocks of diverse shapes that have been deposited on the talus slopes of the hill; the part of the mineral so uncovered has suffered on its part, the slow and continued action of the weather and has been disintegrated into fragments of variable size which have formed as talus deposit, an apron of mineral which gives to Cerro Mercado the appearance of a mountain made up only of ferruginous minerals. The illusion disappears through a close examination of the structure of the mountain. In effect, in the base one sees enormous banks of rhyolite; higher, the fragments of rhyolite, covered on some of their faces with crystallized minerals of iron in small octahedrons, are mixed with pieces of mineral, whose proportion increases with height until it constitutes the entire deposit forming the crest of the hill.

Since Señor Rangel wrote this he has continued exploratory work on the deposits and has demonstrated that the ores do not continue downward but that the form is that of dipping tabular bodies; hence the inference that the ore bodies are of the nature of a dikelike intrusion, I believe, Señor Rangel is now willing to modify.

In the report of Cerro Mercado by Leopoldo Salazar-Salinas and his coworkers,[24] there are two somewhat distinct conceptions advanced. According to the interpretation of A. R. Martinez-Quintero[25] the pyroxenitic rocks that surrounded the iron-ore bodies are intrusive pyroxenites, and he refers the source of the iron to a batholith of which this rock is a basic border phase.

According to Martinez-Quintero:

The intrusive is probably a batholith with a basic border phase forming the contact; the visible portion of the intrusion being a pyroxenite whose principal constituent is the hedenbergite-diopside, which in narrow crystals is encountered, among other places, in the differentiated dikes of the Cerro de Fray Diego.

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[21] Eineges ueber den Cerro del Mercado bei Durango in Mexico, Würzburg, 1878, Abs. in Zeit. Krys., vol. 3, pp. 632–634, 1879.

[22] Amer. Inst. Min. Engrs. Trans., vol. 13, pp. 189–209, 1885.

[23] Criadero de fierro del Cerro de Mercado. Inst. Geol. Mex. Bol. 16. pp. 3–14, 1902.

[24] El Cerro de Mercado. Inst. Geol. Mex., Bol. 44, 1923.

[25] Salazar-Salinas. Inst. Geol. Mex., Bol. 44, 1923, p. 41.

Forming an ultrabasic phase at the contact, a part of the iron must have accompanied it and upon solidification the globules of oxide of iron which were first suspended became imprisoned in the pyroxenite, as one sees in the samples that have been studied.

Later, when the magma had solidified, the gaseous emanations of water vapor, P_2O_5, CO_2 Cl, and some others, as well as the magnetic solutions, contributed to the enrichment of the mass of iron already formed, transporting iron from the lower to the higher portions and being deposited in the same oxides through simple crystallization or through substitution of the adjacent igneous rocks. At the Cueva de la Marmaja one encounters vestiges of the rock which was not completely substituted but altered and which appears to belong to the porphyritic rock in which the K_2O predominates over Na_2O.

Salazar-Salinas's[26] own views are expressed in the following citation:

There was formed, at a profound depth, a magmatic chamber of basic nature, which moved through a fold of sedimentary formation, this same fold accentuating its effect upon the pressure was able to bring about the fusion of the deeper siliceous sediments, giving a new magmatic chamber which, through the lesser density of its constituents penetrated the basic chamber and terminating in superposition, staying in part intermixed, one with the other; or admitting the existence of the acid effusive rock, this was penetrated by the magmatic products leaving traces of this passage in the phenomena of metamorphism and in the mixture of the elements.

To properly explain the origin of the ores of Cerro Mercado account must be taken of the following features:

1. The occurrence of iron ore in Tertiary acid volcanic rocks, including rhyolites, latites, and tuffs.

2. The occurrence of iron ore in broad tabular bodies.

3. The occurrence of iron ore as martite, the pseudomorphous form of hematite.

4. The association of the minor mineral constituents, especially the apatite, with the ore.

5. The alteration of the wall rock to pyroxene, chert, and montmorillonite.

6. The numerous anastamosing veinlets of ore in the wall rock.

The objections to the ores of Cerro Mercado having originated as a flow of magnetite are quite evident. The ore bodies are without doubt a later introduction and not contemporaneous with the inclosing rocks. Alteration of the wall rock has taken place to a perceptible degree and the ore bodies are not concordant with the position of the flows of volcanic rock but are inclosed in all the types of rock exposed.

The explanation that the ore deposits are dikes seems at first a logical one but continued exploration under Señor Rangel's direction has demonstrated that they are not in the form of dikes, but that their mass has no great downward extension and that they are more in the nature of flat lying tabular bodies of ore. With this

[26] Salzar-Salinas. Inst. Geol. Mex., Bol. 44, 1923, p. 44.

new evidence in hand one can readily determine that such ore bodies as that of the west side of the hill of Cordon Rangel and of Picachos Sur and Norte are also not dikelike as they appear to be, but portions of a larger tabular form broken up into segments by faulting. One may point also to the occurrence of ore as schlieren in the tuffs of the Socavon de la Cueva as further evidence contrary to the formation of the ore in dikes. Soler[27] has attempted to explain this tabular form of the ore as a faulted body of segregated ore; that is, the magnetite is a magmatic segregation in tabular form that has been faulted into segments. The difficulties of accepting such a mode of origin are, of course, obvious, chief of which is the occurrence of ore in the tuffs and it does not explain the occurrence of pure hematite in siliceous rocks such as rhyolite.

There are but three genetic processes that merit serious consideration: Firstly, an origin through intrusion of a magnetite magma, invading the rhyolite, latite, and tuff; secondly, a replacement of these rocks by iron-bearing solutions; and thirdly, fumarolic activity. All these ideas are open to criticism and objection but it is believed that the final choice must lie between them.

The association of magnetite and apatite immediately suggests that the ores are the result of magmatic segregation of some sort. That they can not have segregated from such rocks as rhyolites and tuffs in which they are now found is quite evident. They must have had their origin in some deeper source. The numerous anastamosing veinlets are also suggestive of intrustion, as is also the further fact that, while the wall rocks are altered, the alteration is not as great as one would ordinarily expect from aqueous solutions, but might be accounted for by the smaller amounts of solution accompanying a dikelike intrusion. So far the evidence points satisfactorily to intrusion but when we come to consider the manner in which a magma of such composition may form we are confronted with difficulties. If our present ideas on magmatic differentiation are correct a magnetite-apatite body could form by the separation and segregation of the crystals of these minerals into definite bodies. But the difficulty arises in that this body of magnetite and apatite must be brought again to a state of fusion in order to traverse and inject rocks as readily fusible as itself without contamination.

The suggestion that the iron ores of Cerro Mercado may be the result of fumarolic action rests upon the observations of E. G. Ziess[28] of the formation of magnetite at the Katmai region of Alaska. About some of the hotter fumaroles there formed great

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[27] Report to the Cia. Fundidora de Fierro y Acero de Monterrey, S. A., pp. 30-35, 1925.

[28] The Fumarolic Incrustations in the Valley of Ten Thousand Smokes. Nat. Geol. Soc. Tech. Papers. Katmai Series vol. 1, No. 3.

quantities of magnetite, measurable by the thousands of pounds. The iron chloride vapors were continually swept out by the continuous passage of steam, reacting at the mouth of the fumarole with this steam to form magnetite and hydrochloric acid. As the fumarole decreased in temperature the magnetite thus formed was reattacked by the acid and the deposit of iron ore eventually disappeared. While there seems little evidence to support such a hypothesis for Cerro Mercado, yet the occurrence of the iron minerals there in tuffs, as at Katmai, and the physical resemblance of the Katmai magnetite with much of the martite ore of Mercado is striking and such a hypothesis may well be borne in mind.

An origin by the replacement of the inclosing rocks by iron bearing solutions is suggested by a number of features of the iron deposits of Cerro Mercado and is the hypothesis most favored by the writer. The impression that one first receives upon examining the ore bodies is that they are deposited by replacement but close consideration of the matter shows that all points are not entirely clear. This, however, resolves itself down largely to lack of definite knowledge concerning the chemical and physical behavior of iron bearing solutions.

The direct replacement of the brecciated country rock by iron ore has not been observed by the writer but the replacement of the fragments by pyroxene is common and the close relationship of the pyroxene to the iron ores makes it probable that the ore minerals are a result of this same process. There has been observed in specimens from the locality called Labores de la Cueva a replacement of the breccia fragments by calcite which is in turn replaced by magnetite. Further the *schlierenlike* masses of ore in the tuffs at Socavon de la Cueva can only be explained as a replacement of the tuffs by ore and not by any means of injection. The puzzling feature of this occurrence, however, is that in a mass as susceptible to chemical change as a tuff, there is no appreciable effect accompanying the introduction of the iron ores.

The alteration of the wall rock to pyroxene must certainly have been brought about by aqueous solutions but whether these solutions were the iron-bearing solutions or solutions given off by a magnetite magma there is no way of determining. The amount is less than one would expect if a large volume of solution had passed, yet a large amount of porphyry has been completely altered to montmorillonite although not pyroxenized. What the relation to the extensive silicification of the rhyolites at the north side of the hill has to the ore-bearing processes is still to be determined.

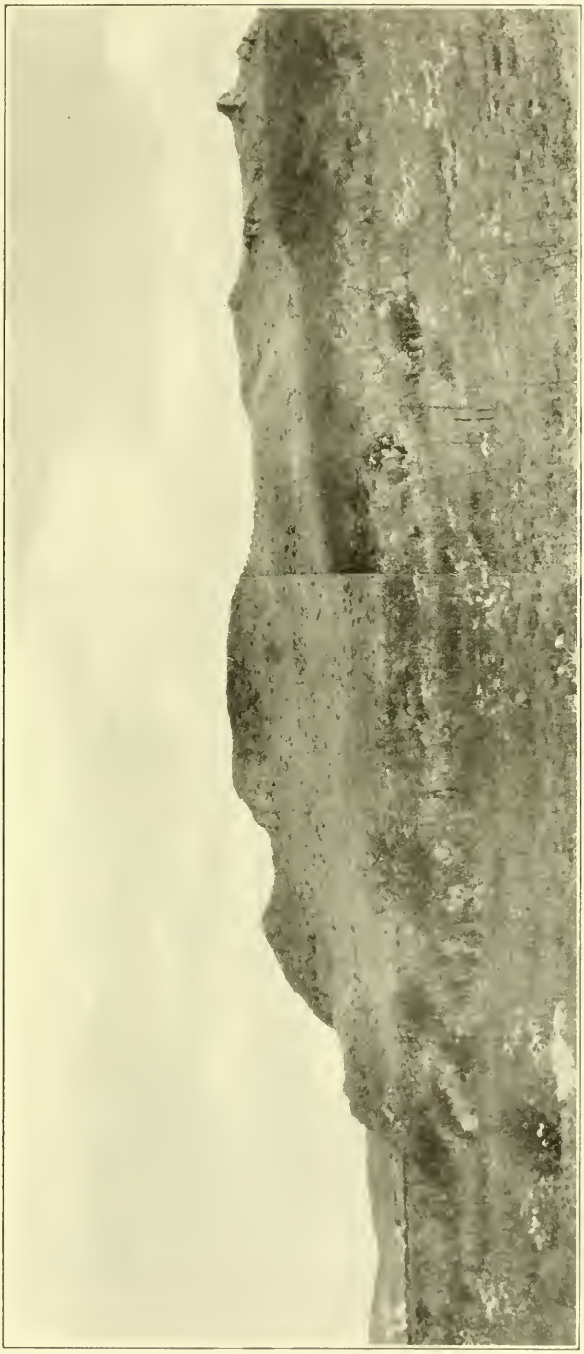
The nature of the solutions that may have carried the iron and replaced the wall rock is a matter of speculation and will not be discussed. Our knowledge of such solutions is still too incomplete to draw any reasonable deductions from the data yielded by this occurrence.

MINING METHODS AND PRODUCTION

The occurrence of the iron ore as cliffs of hard ore or as banks of soft ore make mining both easy and cheap. (Pl. 2, left.) The hard ores of Penascos de la Industria are blasted down upon the quarry floor where the bowlders of ore are broken up either by sledge hammers or by further blasting, the broken ore transported by wheelbarrows and loaded directly onto the cars. The soft ore of Cueva de la Marmaja needs no blasting, but is readily picked down upon the quarry floor, loaded into barrows, dumped into a bin from which it is drawn into cars, and trammed to the loading bins. The grade of the ore is high, averaging from 65 to 67 per cent; it is practically free of manganese, titanium, and sulphur, but carries some phosphorus. The cost of mining and loading is 64 centavos a ton. The total production of ore from this deposit in 1926 was 81,000 tons, but this amount can easily be increased several fold should it become desirable. According to the estimates of the Compañía Fundidora de Fierro y Acero de Monterrey, the ore reserved of Cerro Mercado was approximately 100,000,000 tons.

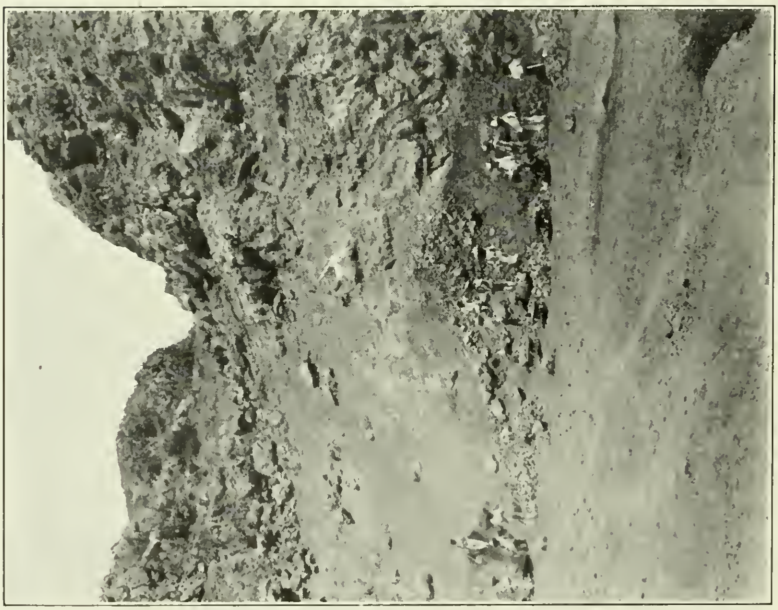
Much of the early production of the Cerro Mercado came from the detrital or *boleo* ore that flanks the hill on the east, south, and western sides. (Pl. 2, right.) This ore was high grade and comparatively free of phosphorus, but the richest areas have been extensively worked out and the reserves of this type of ore are small. A large amount of this ore was mined and used as flux at the smelters of northern Mexico.

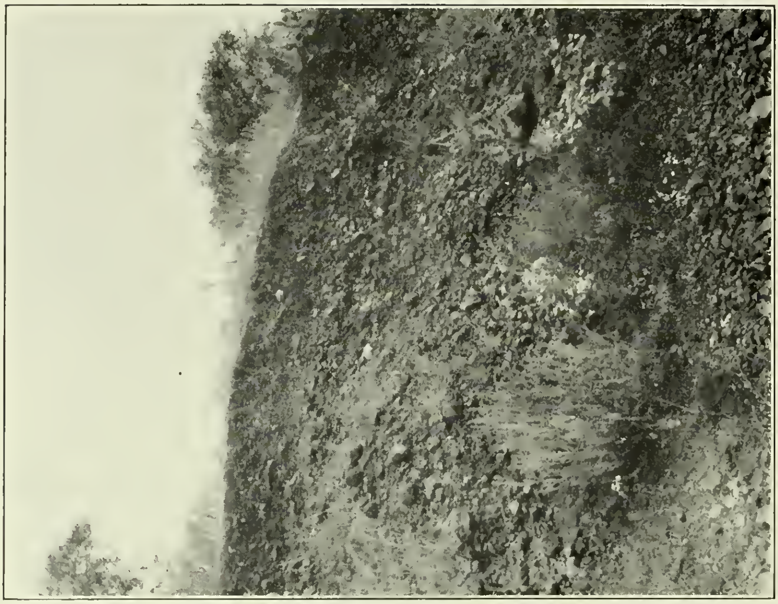
O



CERRO MERCADO FROM THE SOUTH. THE BOLD OUTCROPS ARE IRON ORE

FOR EXPLANATION OF PLATE SEE PAGE 2





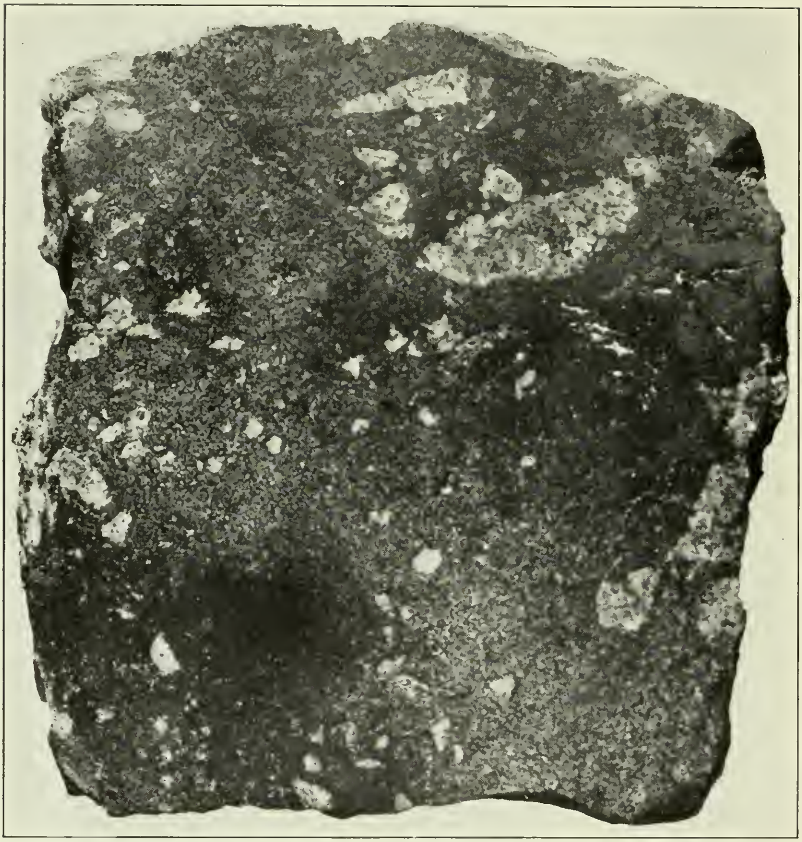
VIEWS OF CERRO MERCADO

Left: Quarry in iron ore (Penascos de la Industria). Right: Cut in "boleo" ore (east slope)

FOR EXPLANATION OF PLATE SEE PAGE 27

BRECCIA PARTIALLY REPLACED BY DIOPSIDE

FOR EXPLANATION OF PLATE SEE PAGE 8



Breccia Partially Replaced by Calcite and Magnetite

For explanation of plate see page 8