

## CANANEA MINING DISTRICT OF SONORA, MEXICO.<sup>1</sup>

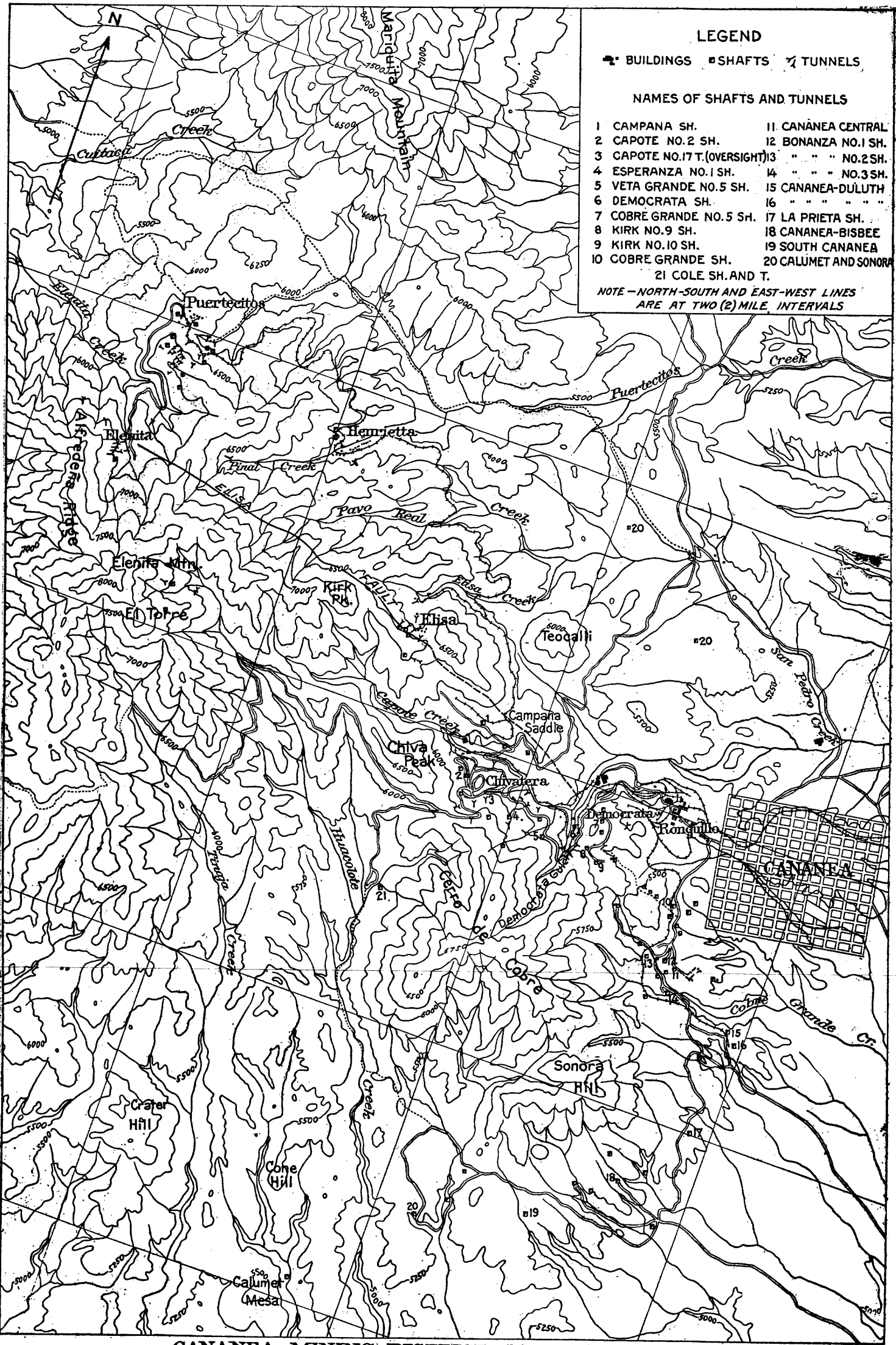
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### INTRODUCTION.

The Cananea Mountains are situated in Sonora, Mexico, directly south of the Huachaca Mountains in Arizona. The town of Cananea at their eastern base lies 25 miles south of the international boundary, approximately in  $31^{\circ}$  north latitude and  $110^{\circ} 30'$  longitude west from Greenwich, and is connected with the boundary town of Naco, near Bisbee, Ariz., by 38 miles of standard gauge railroad.

As seen from the line of this railroad or from the northeast, the Sierra de Cananea presents the general form characteristic of the so-called Basin ranges. That is, it consists of a series of ridges that rise abruptly out of broad, gently sloping valley plains, and represents the upper portions of an older and much wider mountain uplift that projects above the accumulations of Quaternary gravel and silt that have filled the surrounding valley, in places to depths of several thousand feet. As contrasted with the Arizona and Nevada ranges it supports an unusually abundant vegetation, a considerable open growth of coniferous trees having been found on its upper portions, while its lower slopes and the bottoms of the streams that radiate out from its base are well covered by live oak and other deciduous trees. It is, moreover, less symmetrical in shape, being made up of several individual ridges, the most important of which have a northwest-southeast trend, which conforms with the larger features of geological structures, while the average direction of the range as a whole is more nearly north and south.

<sup>1</sup> In the summer and autumn of 1907 a special topographical and geological survey of this district was made under the direction of the writer by R. H. Sargent, topographer, and J. M. Boutwell, L. C. Graton and W. H. Emmons, geologists, during short leaves of absence from their respective official duties in the U. S. Geological Survey. The principal scientific results of this survey are published in the present article by permission of the officers of the Cananea Consolidated Copper Company, at whose expense it was made.



CANANEA MINING DISTRICT, SONORA, MEXICO

0 1 2 3 MILES  
Contour interval 250 feet

It is the central of these ridges, the greater part of which is the property of the Greene-Cananea Copper Company, of which the present article specially treats. To the northwest of this, separated by the valley of Puertecitos Creek, the Mariquita Mountain mass forms the northern extremity of the uplift, while to the south and west the Sierra merges into low broken hills.

The drainage, which is through deeply incised and irregularly winding ravines, flows on the east through Puertecitos, Pinal, Pavo Real, Elisa and Capote gulches into San Pedro Creek, which is a tributary of the Gila River of Arizona, and on the south through Huacolote and Tinaja creeks into the Sonora River, which empties into the Gulf of California.

These streams all have a small flow of water, which is perennial in their upper portion, but more or less intermittent in their lower courses. The region has, however, comparatively abundant precipitation, and during the thunderstorms which are of almost daily occurrence during the rainy season—from June to October—these little streams often become for a short period raging torrents.

Capote Creek, the southernmost of the eastward flowing streams, has a remarkable bend in the lower part of its course within the hills, changing from southeast to due north for about half a mile, then curving eastward around the mesa-like spur upon which the old town of Ronquillo and the present concentrating and smelting works are situated. The new town of Cananea is built upon the wider, more level portion of the mesa eastward and further from the steep mountain slope. The valley of Capote Creek from the bend up to the base of Chiva Peak widens out into an oval valley about a mile in length, known as Capote Basin, in which are situated the most productive mines of the region and the miners' towns of Chivatera and Buena Vista.

The relative position of the mines in the district may be seen on the accompanying map, which is a reduction of that prepared by Mr. Sargent. Commencing at the northwest end they are:

1. The Puertecitos mines, in the limestone ridge that forms the northwestern extremity of the uplift and overlooks the broad

shallow basin of Cuitaca Creek to the west and north, which is entirely carved out of granite or grano-diorite. Other mines have been opened in the same body of limestone along Elenita Creek and around Elenita Mountain, south of Puertecitos, but are not actively worked at present.

2. The next important mine is the Henrietta, with ore bodies at the contact of diorite and quartz porphyries, situated at the point where Pinal Creek emerges from the steeper hills into the more open valley of Puertecitos Creek. At the head of Pinal Creek is a mine in limestone, no longer worked, known as the Union Mexican.

3. Next south is the Elisa mine, at the very head of Elisa gulch, with ore bodies in limestone along the footwall or southwest of the Elisa fault, which is the one great structural fault of the district. Across the ridge to the south, or in the northeast part of Capote Basin, are the Sierra de Cobre properties, with ore bodies in limestone like the Elisa, which formerly belonged to the Phelps Dodge & Company interests, but now are the property of the Cananea Company.

4. The mines of the Capote Basin are, at the base of Chiva Peak and west of the miners' town of Chivatera, the Capote mine, and along the south slope of Capote Basin from west eastwards, the Oversight, the Esperanza, and the Veta Grande mines. In the east part of the basin, beneath the bend of the creek, is the Democrata mine, a small independently owned property, the only one within this large area that is not controlled by the Cananea Company.

5. East of the Democrata mine on the low ridge that separates the steep mountain slopes from the fringing mesa, are the Kirk mines, and south of them the Republic mine, while southeast from the Kirk mines along the major strike of the ore bodies are successively:

6. The Cobre Grande, America, Bonanza and Cananea-Duluth mines, all in the mesa country which forms a fringing border to the steep mountain slopes. The most important of these is the Cananea-Duluth, which has been opened since the merging of the Greene and Cole interests.

All these mines are connected with the reduction works at Ronquillo by the tracks of the company's narrow gauge railroad, over thirty miles in length, which winds in and out, through and over the hills in every direction. A central power plant at Ronquillo distributes compressed air also to the drills in all these widely separated mines.

*History and Development.*—The great amount of iron-stained rock on the surface throughout these mountains must evidently have attracted the attention of prospectors in very early days. The gossans are especially abundant in the Capote Basin, where they form projecting ridges and cover entire mountain slopes. From one glory hole or open cut working in such gossan near Capote Pass, an iron flux that carries upward of 50 per cent. of the metal has been mined since the starting of smelting by the present organization. Moreover, at the heads of most of the various gulches around the mountain mass known as the Cerra de Cobre there are remarkable looking crags of a heavily iron-stained conglomerate, which on closer examination proves to be stream gravels of an earlier period in the physiographic history of the mountain, that were cemented by iron-bearing waters proceeding from the oxidation of the pyrite with which the mountain mass is most abundantly impregnated, and which, owing to the superior resistance of this iron cement, have been left behind as the corrosion has deepened the lower parts of the gulches.

Of the earlier Spanish workings there are rather indefinite traditions. Velasco says that the mines were worked before the eighteenth century by the House of Guco, and that later, after they had long been abandoned by them, José Perez of Avispe, the capital of this department, took out several thousand quintals (hundredweight) of copper ore which were carried overland to Guaymas and shipped from there to Europe. The country has always been in danger of raids by the warlike Indian tribes, the Yaquis and Apaches, by whom more than once the inhabitants have been massacred or driven out, and mining operations consequently suspended.

Finally it is said that in 1865 General Ygnacio Peschirea

(Pesquiera) with an escort of 500 soldiers established a camp at Ronquillo, and erected a small smelting plant, now known as Cananea vieja, two miles below its present furnaces. Mining and smelting operations were carried on in a desultory way for fifteen years. Ore was taken from the Cobre Grande Ronquillo, Campana and San Ygnacio (now Elisa) mines, and smelted to matte, which was transported on mule back to Guaymas and thence shipped to Swansea, England.

About 1881 the Alfredeña, Cananea, Union Mexicana and other mines around the Puertecitos limestone mass were sold to a Cleveland company, whose superintendent, Williams, erected a smelter at Cajoncita, on Cuitaca Creek, at the foot of the mountains about ten miles west of Puertecitos. Ore averaging 20 per cent of Cu and 15 oz. Ag was smelted, and operations carried on for about two years. This smelter was then removed to Puertecitos, to which coke was hauled from Fairbanks on what was then the A. T. & S. F. Railroad, and where it was operated for a year and then abandoned.

The properties around the Cobre Grande at the southeast end of the range were bonded first to Charles Benham, of New York (up to 1886), and later to Major Morton in the interest of F. Aug. Heinze. After taking out about \$110,000 in copper matte this bond was abandoned in consequence of the death of Major Morton.

Col. W. C. Green then obtained from the widow of General Pesquiera and other owners, control of practically all the mining properties in the Cananea Mountains. After fruitless endeavors to permanently interest Daly and Rogers, of Butte, Farrell of Ansonia, Conn., and others in developing the properties, Colonel Green organized the Cananea Consolidated Copper Company (Mexican organization) and later floated the stock of the Greene Consolidated Copper Company (holding company) on the New York stock market, which was subsequently (1906) merged with the Cananea Company.

The first smelting furnace was blown in about May 20, 1899, the first concentrator built in 1900, and the narrow gauge railroad connecting this with the several mines completed in 1902.

The great Capote ore body was encountered in May, 1900, and the Oversight ore body, after adjudication of litigation with the Indiana-Sonora Company, was struck in December of the same year.

Active operations of the modern organization may be considered as having commenced with the completion of the Broad Gauge Railroad connecting Cananea with Naco, about July, 1901.

#### GEOLOGICAL HISTORY.

*Age.*—The Cananea Mountains are made up to so great extent of much altered eruptive rocks that it is very difficult to decipher their geological history. The few sedimentary beds that do occur are quite barren of recognizable remains of ancient life, so that it is only by analogy and lithological resemblance with the nearest known beds, that their age can be determined.

On these grounds the considerable thickness of quartzites and overlying limestones that occur have been with reasonable probability assumed to be of Cambrian age, and to correspond to the Bolsa quartzites and Abrigo limestones of Bisbee, Ariz., as determined by Ransome. The older granite complex on which these beds rest must therefore be of pre-Cambrian age.

The most careful search has failed to discover any trace of Cretaceous sediments in this range, though they are known to occur in the broad valley to the north and in the next range to the eastward. It is assumed, therefore, that it was not submerged during the Cretaceous transgression. On the other hand, as the greater part of the igneous rocks which now cover its surface are intrusive, it is quite possible that at the time of their intrusion the range may have contained some remnants of Paleozoic formations later than the Cambrian, which have since been removed by erosion.

The greater part of the present surface is occupied by igneous rocks, mostly intrusive, of which twelve different varieties have been recognized and designated by specific names. On grounds of analogy and lithologic resemblance it is assumed that these were erupted in early Tertiary times.

The following are the subdivisions of rock formations that

were adopted in making the geological map of the district, with the local names derived from the place of their most typical development. They are given in chronological order, as far as their relative ages could be determined, though, as is apt to be the case with eruptive rocks of the same general type such as occur here, the evidence of relative age of some of the less important varieties, as they are found in different parts, is at times a little conflicting:

- |                                     |   |
|-------------------------------------|---|
| 1. Cananea granite.                 | 9. Elenita syenite-porphry.               |
| 2. Capote quartzite.                | 10. Henrietta diorite-porphry.            |
| 3. Puertecitos limestone.           | 11. Tinaja granite-porphry.               |
| 4. Mariquita diabase.               | 12. Cuitaca granodiorite.                 |
| 5. Huacalote rhyolite.              | 13. Elisa quartz-porphry.                 |
| 6. Mesa tuffs and agglom-<br>erate. | 14. Gabbro.                               |
| 7. San Pedro andesite.              | 15. Later diabase dike.                   |
| 8. El Torre syenite.                | 16. Quaternary gravels and al-<br>luvium. |

The present work has determined that the following ideas which were more or less generally prevalent among those who have previously studied the district are incorrect:

1. That there is one central body of eruptive granite which forms the core of the range, and has metamorphosed the limestones. In point of fact there are two distinct granites; a pre-Cambrian body on which the oldest sedimentaries, the quartzites, were deposited, and a younger, post-Cretaceous granite, the Cuitaca granodiorite, which has produced part of the metamorphism of the limestone body around Puertecitos.

2. That the diabase eruption was later than that of the granite and than the mineralization, whereas it is really older than all the other intrusions, except the pre-Cambrian granite.

3. That the bedded tuffs were among the latest manifestations of igneous activity in the region, and followed the principal mineralization, whereas the present investigation has shown that the explosive eruption which produced these tuffs was one of the early phases of volcanic action, having been preceded only by the intrusion of the Mariquita diabase and the Huacalote rhyolite,

and that they have been mineralized, and contain important ore bodies where they have been intruded by the Henrietta diorite or Elisa quartz porphyry.

#### ROCK FORMATIONS.

*Cananea Granite.*—This is the oldest rock in the district, since it forms the basement complex upon which the oldest sediments, the Capote quartzites, were deposited.

The type rock is a coarse microcline granite with prominent quartzes and occasional indications of mica, now altered to chlorite. The feldspar crystals are large, up to an inch in size. There is a fine-grained phase which is almost porphyritic in texture. Its groundmass, consisting of quartz and orthoclase, is unusually rich in quartz, which occurs in small rounded grains, so that it might easily be mistaken for a conglomerate.

The principal mass of this rock, and practically the only exposure in the district, has been traced northwestward continuously from Chiva Peak, at the western boundary of Capote Basin, to the end of the road leading up Elenita gulch, thus occupying the upper part of Capote gulch and the ridge dividing that from the Huacalote-Tinaja drainage, and part of the northern slopes of Elenita Peak, an area about three miles long by one half to three fourths miles wide. The fine-grained phase is found along the summit of the ridge running back from Chiva Peak. The Capote quartzite rests on it on the east, and on the northeast it is cut off by the Elisa fault, which runs northwestward across the heads of Elisa, Pavo Real, and Pinal gulches.

*Capote Quartzite.*—These quartzites are quite uniformly granular, and rather pure, being brownish on the weathered surface, but almost invariably white underground. In the vicinity of ore bodies they are apt to be rather unctuous, probably by reason of the development of sericite. Where they cross Capote gulch they are arkose at the base, and the conglomeratic phase increases from there to the head of Elisa gulch, where it is a few feet in thickness.

The principal surface exposure of quartzite forms a band about a quarter of a mile wide extending from Capote pass along

the east face of Chiva Peak, to the pass between the head of Elisa gulch and Pavo Real gulch, where it is cut off by the Elisa fault. The beds have a rather steep dip to the northeast, the angle steepening toward the north until they are overturned at Kirk Peak.

They are brought up by faulting in several narrow north-south strips in Capote basin, but they are not known with certainty in any other part of the area.

*Puertecitos Limestone.*—In the few places where the limestone is fresh and unaltered it is a nearly black, dense fine-grained rock, almost like an argillite. It is moderately heavy-bedded, and certain horizons, especially near the base, are so cherty that they stand out on weathering. Most of the limestone is more or less altered, the least profound phase of alteration being marmorization. There are four areas of marble of noteworthy size, the most important extending from Campana shaft in Capote basin to beyond the Elisa workings, in which are the quarries that formerly furnished the smelter flux. This carries five per cent. of magnesia, with four per cent. of silica and other impurities.

Just east of Elenita Creek, on the road from Puertecitos to Elenita it is altered to a dense pink hornstone, which, though hard as flint, carries only 55 to 60 per cent. of silica.

In other places the limestone is mostly altered to massive garnet rock, with epidote, fibrous pyroxene (Hedenbergite) and specularite (the latter along fracture zones) as subordinate occurrences.

Within the marbleized areas are often patches of garnet and epidote, especially where copper minerals have formed.

The garnet rock is of greenish-brown color, and somewhat greasy. When greatly altered it becomes a mixture of finely divided silica and limonite that may be taken for a gossan. Another phase of alteration produces a soft material like decomposed porphyry which is soon obscured by a slide of harder rock, and does not outcrop in ordinary surfaces, though a slight greenish color and mottling of iron oxide may be seen.

There are three principal exposures of limestone, or its alteration products. The northernmost is a north-south band with

rather waving boundaries, about a mile and three eighths long by a quarter wide, that extends from a little north of Puertecitos southward to the head of Elenita gulch. It lies between Cuitaca granodiorite on the west and Henrietta diorite-porphyry on the east. In and around this occur the most distinctly contact-metamorphic ore deposits. At the head of Pinal gulch, around the Union Mexicana mine, is a small patch of garnet rock, in a line with an eastwardly projecting nose of the Puertecitos body, which suggests a possible underground connection between the two.

A body of garnet rock of similar size extends southeastward from Elenita Mountain, along the ridge separating Huacalote from Tinaja Creek. It contains small patches of contact metamorphic ores, which as yet have not proved of economic importance.

The third and most important exposure extends from the east base of Kirk Peak southeastward across the head of Elisa gulch and over the greater part of Capote basin to the Democrata mine, a distance of about two miles. It here rests conformably upon the Capote quartzite, and like it has a general northeasterly dip, with some local variations. In Capote basin it attains an extreme width of nearly a mile, but is much broken by faults, and by the diorite porphyry intrusions. Underground workings show that the original limestone was more extensive than the present exposure, notably in the Veta Grande and Kirk mines. Small patches of garnet rock are found at the surface as far south as the Bonanza No. 1 shaft, which appear to be entirely surrounded by diorite-porphyry.

No trace of organic life has been found in the limestone, and it has not been found possible to make even an approximate measurement of the thickness of either quartzite or limestone series. It is not thought likely, however, that this much exceeds that of Bolsa quartzite and Abrigo limestone of the Bisbee district, which according to Ransome aggregate 1,200 feet in thickness, and have been correlated with the Tonto formation of the Grand Canyon, the Apache of Globe, and the Coronado of Clifton-Morenci.

*Mariquita Diabase*.—This, the earliest intrusion in the district, is a rather basic rock consisting essentially of plagioclase feldspar, pyroxene and magnetite. The typical rock has large white tabular feldspar in a fine-grained, greenish groundmass, which often stands out so prominently on the surface as to have led to its designation by the miners as “bird’s track” or “bird’s foot” porphyry. Away from the central mass the rock is generally finer grained, the phenocrysts being less common, and the feldspars cubical in shape instead of lath-like. Locally scattered grains of primary quartz can be found which sometimes combine in rounded masses that look like amygdules.

The typical rock is very prone to epidotic alteration, the periphery of considerable masses becoming almost solid epidote. When very much altered the rock becomes quite soft, light in weight, and rather chalky in appearance. Near Capote basin, where silicification has also taken place, the surface is pitted by casts of dissolved-out feldspars. It is often strongly impregnated with pyrite, whose decomposition produces much of the abundant gossan observed on the surface.

As its name indicates, this rock forms the principal mass of Mariquita Mountain, where it has a marked bending that dips about 40 degrees northeast, and strikes N. 30° W. It is there flanked on the west by Cuitaca granodiorite, which cuts it, and on the east by the Mesa tuffs which cover it on the lower spurs. From the summit it extends in a long narrow exposure to the northern base of Tascalli, forming both walls of Puertecitos Canyon, and being cut by intrusions of Henrietta diorite and Elisa quartz porphyry. Smaller areas are exposed on the northern slope of Elenita Mountain, at the northern end of Alfredeña Ridge, and southeast of Elenita Mountain, at the head of Tinaja Creek. In the southern half it was not observed, except in a small outcrop within the Huacalote rhyolite area, whose age relations are not quite clear.

*Huacalote Rhyolite*.—This rock is pink, gray or light-green in color, and porphyritic or glassy in texture. Its small phenocrysts are mostly orthoclase, with locally numerous rounded quartz crystals. In the dense glassy phases no phenocrysts are

seen, but the microscope discloses orthoclase, a little altered biotite or hornblende and some magnetite. In places the rock is spherulitic, the spherulites standing out on the surface about pea size.

It is found only along the southern margin of the area mapped where its outcrops occupy either side of the canyon of Huacalote Creek, and extend about two miles north on the ridge marked by Calumet mesa and Cone Hill. It there has the same relation to the mesa tuffs as does the diabase on Mariquita Mountain.

*Mesa-tuff.*—The mesa-tuff in bedded form encircles the range on the north, east, and south, dipping away from it at angles which decrease with the distance from the range, and gradually disappearing beneath the covering of Quaternary gravels. In the town of Ronquillo it dips at about  $15^{\circ}$ , and where it laps up onto the spurs of Mariquita Mountain its angle is as high as  $25^{\circ}$ . Small outcrops occur on the western and southern slopes of Elenita Mountain, where the bedded structure is not so distinct.

The tuff is composed of angular fragments of igneous rocks or of the minerals of which they were composed, mainly feldspar and quartz, among which the fragments of those rocks that form the near surface are apt to predominate. At the base of the tuffs, especially around the flanks of Mariquita Mountain, the material is very coarse—the rock fragments reaching four or five feet in diameter.

In color the finer grained tuffs are purple, pink or olive green, and in the mines they are bleached white. They are locally much altered, with development of epidote and chlorite. The angular shape of the composing material, the repeated alterations in size of grains, together with their generally increasing fineness toward the top, suggest that it is the result of successive explosive eruptions, and that the bedding is due to subaerial rather than subaqueous deposition.

*San Pedro Andesite.*—At various points in the Mesa country along the east flanks of the range are outcrops, often covering a considerable area, of lavas, which are interbedded with the Mesa tuffs. They dip eastward with the tuffs, and evidently represent lava flows which were poured out upon the surface during the

eruption of the tuffs. They are so named because they are abundant along the valley of San Pedro Creek, and are mostly andesites, though they have quite a wide range in composition. To the north and east these lavas become more acid and porphyritic, and some might be classed as latites. In these pink and purple shades predominate, flow lines are common, the groundmass is often glassy, and there are phenocrysts of acid plagioclase, quartz, and biotite, hornblende being rare or absent. Brown mica is quite abundant in these lavas, and this, together with the flow structure, serves to distinguish them from the intrusive rocks.

*El Torre Syenite.*—The main exposure of this rock is on the southeast shoulder of Elenita Mountain, where it forms a castellated crag, from which its name is derived.

It is a granular medium-grained rock, of a pinkish color due to the abundant orthoclase which it contains. As microscopic constituents a little plagioclase and pegmatitic quartz with considerable hornblende are visible. Near the contact with garnet rock it contains much epidote as a secondary alteration product.

It is cut by dikes of Elenita syenite porphyry, and is intruded into the limestone. Other direct evidences as to its age are wanting.

*Elenita Syenite Porphyry.*—This is a fine-grained porphyritic rock, whose predominating feldspar is perthite. It contains also a little acid plagioclase with occasional grains of quartz. When fresh it has a purplish groundmass with small square phenocrysts of feldspar. Except for a local development of biotite no dark silicates have been observed in it. In the sills and portions of the large masses, the rock is very dense, like semi-glassy rhyolite, and has a light color and marked fissility which may represent the direction of flow. In this phase a spherulitic texture is often observed, and the siliceous nodules which stand out on the weathered surface are apt to give the appearance of an oolite or a conglomerate. Evidences of mineralization in it are very scanty. Epidote, pyrite and secondary quartz are very rare. While for the most part a distinctly intrusive rock, the spherulites

and glassy phases indicate the consolidation of some parts near, if not actually at the surface.

There are two principal exposures of this rock. One on the eastern slope of Mariquita Mountain appears to have been intruded as a sill at the base of the Mesa tuffs, and outcrops at several points near the contact with the diabase; the other on the west and south of Elenita Mountain extends for about three miles along the western edge of the area mapped, being separated by a northwest trending outcrop of tuff into two areas, which spread northwest and west from the El Torre syenite body. Here, owing to shattering and brecciation, its line of separation from the tuff is not always distinct. This and the fact that fragments of this rock are frequent in the tuff, make it appear that the two formations are products of the same magma, and belong to the same general period of eruption.

*Henrietta Diorite-porphry.*—This is areally the most extensive and economically the most important rock of the region, for its eruption has produced the greatest contact metamorphism and has been followed by the most extensive mineralization.

As a formation or rock unit it is more variable than any of the others and may include more than one individual species. In texture it varies from a medium-grained granitic type through porphyritic to a dense, dark, almost glassy rock in which no phenocrysts are visible, and which resembles an indurated argillite. The fine-grained rock is very susceptible to epidotization, and when thus altered or when bleached may be mistaken for an altered limestone. When fresh the granular phase of the rock is dark-gray in color and has a spotted appearance from the contrast between white feldspars and dark basic silicates. The dense phases, which show no phenocrysts, are dark green to black. The most prominent recognizable minerals are feldspar, hornblende, and biotite; in some specimens quartz is present in small amount. The feldspars are mainly andesine and labradorite, orthoclase, augite, magnetite and pyrite also occur.

It weathers on the surface very readily to a yellowish white; this outer zone seems to protect the interior, which usually remains dark in the incipient stages of surface weathering. Alter-

ation of this rock has been very intense in the region of maximum mineralization. Sericite has developed from the feldspars, the ferromagnesian minerals have been altered to muscovite, and chlorite and much pyrite have been added, by whose oxidation it becomes iron-stained.

Primary pyrite is more frequent in it than in most of the other rocks, both impregnating the mass and in little flakes along joint planes.

It appears to have been the most important agent of contact metamorphism, for it is almost always found with garnet, and it produces garnetization in limestone wherever both rocks occur together. Its abundant content of pyrite and epidote leads to the belief that its magma was rich in mineralizing solutions.

In the Henrietta mine, from which it derives its name, all varieties of the rock, from the coarse-grained granitoid, to the dense black aphanitic rock, occur. It is typically developed on the north side of the knob opposite Puertecitos store.

It is difficult to give in words a clear idea of the distribution of the rock included under this rubric, the area occupied by its exposures being so irregular in shape. It occupies the whole mountain mass of the Cerro de Cobre, except some intruding patches of quartz-porphyry, and extends westward across the Huacalote Basin to the edge of the map. It is in this basin that the coarsely granular phase is principally developed, which is of minor interest as being less evidently associated with mineralization. The Cerro de Cobre mass, which is intensely altered and impregnated with pyrite and quartz, might be considered a center of eruption. It sends off tongues northward into the limestones and quartzites of the Capote Basin, and its area extends into the Mesa country as far eastward as the line of the Cobre Grande and Bonanza shafts. A tongue also extends northward beyond the Elisa fault from the Democrata ground to a little beyond the east base of Teocalli Peak. There are numerous smaller exposures of diorite-porphyry projecting up through the Mesa tuffs in the Mesa country still farther east, especially around the town site of Cananea.

The northern area has the shape of a right-angled triangle,

whose southern base, formed by the Elisa fault, stretches from Elenita to the Elisa mine, and its western side is formed by the Puertecitos limestone body, while the hypotenuse extends from the Elisa mine to the ridge between Puertecitos and the base of Mariquita Mountain. A smaller body separated from this by Elisa quartz-porphyry lies along the west base of the south spur of Mariquita Mountain, and extends into the head of the broader valley of Puertecitos Creek.

While there is abundant evidence that this rock is intrusive, there are places in the fine-grained rock where there is a decided tendency toward bedding. This is especially definite along the railroad, a half mile east of Puertecitos, where the apparent bedding dips northeast at about the same angle with the sediments, and specimens examined under the microscope look tufaceous, thus suggesting that in part it may have been the result of explosive action.

Underground where the rocks have been much altered, as is especially the case in Capote Basin, it is often difficult, and sometimes impossible to distinguish this from the sedimentary rocks. The rounded grains and peculiar sheen on freshly fractured surfaces may serve to distinguish the quartzite, and the more ready effervescence with acid, or in the case of garnet, crystal faces or greasy luster, are criteria to determine limestone origin.

Along contacts of tuff with intrusive diorite porphyry, when both rocks have been bleached and altered, the distinction is peculiarly difficult. Traces of bedding, the presence of calcite, and the shattered condition of the mineral individuals may serve to distinguish the tuffs.

*Tinaja Granite-porphyry.*—This rock is everywhere quite fresh and shows no evidence of the intense hydro-metamorphism to which other rock formations have been subjected; hence it carries no ore. It is found only in the southwest corner of the area mapped, mostly along the valley of Tinaja Creek, where it cuts both rhyolite and granular diorite. On Crater Hill to the west it is associated with the Cuitaca grano-diorite, dikes of each being found in the other; hence it probably came from the same magma, and is more or less contemporaneous with that rock.

In texture the rock in large masses approaches a granite, and in small dikes is dense and almost glassy, while the color varies from light-gray to pink. The groundmass is microcrystalline or glassy and contains much quartz with orthoclase and some plagioclase feldspar. Phenocrysts of quartz and feldspar are usually present, while the ferromagnesian minerals are biotite and hornblende. Quartz and orthoclase are sometimes seen to be graphically intergrown.

*Cuitaca Grandiorite.*—This rock, which is a typical granite in appearance, covers the semicircular basin-like area at the head of Cuitaca Creek, in the northwest corner of the area mapped. Its actual extent beyond this area is unknown, but it is batholithic in character and size. Its outline on the map runs along the slopes of the hills surrounding the basin, which are composed of rocks for the most part older than the granite; viz., the Mariquita diabase on the east, the Henrietta diorite porphyry and Puertecitos limestone on the southeast, and a little Cananea granite and Elenita syenite porphyry on the south, near the west edge of the map.

Beside this one large area, small patches are found adjoining the Cananea granite on the south around the heads of Elenita Creek, between garnet rock and diorite porphyry on the ridge between Huacalote and Tinaja creeks, in syenite porphyry on the west edge of the map, and in four small bodies more or less completely enclosed in the granite porphyry area that stretches south and east from Crater Hill in the southwest corner of the map.

The granodiorite is of light pink or gray color, and nearly everywhere medium- or coarse-grained, though at a few intrusive contacts it becomes fine-grained, and at certain contacts with limestone tends to pegmatitic structure. Feldspars are the most abundant constituent, orthoclase and plagioclase being in about equal proportions, yet the rock seems hardly as basic as most granodiorites, the specimen tested having 71.4 per cent of silica. Quartz is very abundant, and biotite is the usual ferromagnesian mineral, though never so abundant as in the Henrietta diorite-porphry. Hornblende occurs in some specimens. It weathers

in the large rounded boulder-like masses common in granitic rocks, and is rather barren of vegetation.

It cuts the Cananea granite, the Puertecitos limestone, the Mariquita diabase and the Henrietta porphyry, and is therefore distinctly younger than either. It has altered the limestone to garnet and hornstone between Puertecitos and Elenita, and as it contains some ore bodies near the contact, it must be earlier than some phases of the mineralization. In most places, however, it shows no evidence of hydrothermal metamorphism, and is apparently barren.

*Elisa Quartz-monzonite-porphyry.*—This is the latest rock that has apparently influenced mineralization. It is a distinctly porphyritic rock in which the principal phenocrysts are rounded grains of quartz. When fresh it is greenish-gray in color, and often shows small feldspar phenocrysts, mostly plagioclase, with rare hornblende and altered biotite. The groundmass is microgranular in texture, mostly made up of orthoclase. The quartz crystals are bipyramidal; generally somewhat corroded so that the outline is now nearly spherical. The feldspar crystals are usually small, but in a few instances, notably at the summit of Cerro de Cobre, they are more than an inch long.

When altered, either by weathering or by mineral-bearing solutions, the feldspathic groundmass is bleached, partly by kaolinization, partly by silicification. When the former has gone on without the induration induced by the latter, the rock crumbles and the round quartz grains are exposed without being broken. They may be obscured by a thin coating of kaolin, but the rounded cavities they leave aid in their detection. When silicification has been the predominant process of alteration, the rock is sometimes pitted as a result of the solution of the feldspar phenocrysts. The surface exposures are generally reddish-brown from a stain of limonite.

The main exposure of the rock is a band about three-fourths of a mile wide, extending southeast from the granodiorite body east of Puertecitos to Teocalli, thus including most of the Company's railroad line from Campana saddle nearly to Puertecitos. It here lies between the diabase and diorite-porphyry, and has the

same appearance of a northeast dipping sheet as the latter. The Toscalli mass, however, appears to have forced itself directly through the diabase.

Two smaller, but still considerable masses break through diorite porphyry on Cerro de Cobre, and still smaller ones are found in the northern part of the Huacalote-Tinaja Basin, and as dikes or knobs in various parts of the areas of diorite-porphry, mesa tuffs, and Puertecitos limestone. The rock may be observed in typical development at Elisa station.

A contact breccia is found on the margin of the large body of quartz porphyry which forms the summit of Cerro de Cobre, in which the fragments are diorite porphyry enclosed in a matrix of glassy quartz porphyry. This breccia also occurs on Campana saddle, and in some bands in Capote Basin.

*Gabbro-diabase.*—The latest intrusive rocks are the *gabbro*, which occurs as a narrow band between diorite-porphry and Cananea granite on the ridge east of Huacalote Creek, and in various smaller outcrops in the vicinity, and the *later diabase* dikes and sills which are found cutting almost all the other rocks in the northern half of the area. These two rocks are apparently related, and have no apparent connection with ore deposition. In looking back upon the preceding succession of igneous rocks if we regard this region as part of a petrographic province in which the existing rocks may be considered to have come from one parent magma, it is possible to trace the recurrent sequence which Iddings has formulated as the general rule for such a series of eruptions.

If rocks which have a similar composition and the same general age relation are grouped together as products of a single magma, it is seen that the first eruption of diabase, which may be considered to have proceeded from a magma of mean composition, has been succeeded by recurrent eruptions of more acid and more basic magmas, thus: (1) Diabase, (2) rhyolite, (3) mesa tuffs and andesite, (4) syenite and syenite-porphry, (5) diorite-porphry, (6) granite-porphry, granodiorite, and quartz-porphry, (7) *gabbro-diabase*.

## FAULTS AND FRACTURE SYSTEMS.

While the Cananea district is fractured and crushed to a remarkable extent, there is singularly little evidence of profound faulting accompanied by great displacement such as is seen in mountain uplifts built up by dynamic stresses, where the rock masses consist largely of sedimentary formations. The only great structural fault in the region is the Elisa fault which has been traced continuously for about three miles, and somewhat intermittently for a mile farther. Its general direction is N.  $75^{\circ}$  to  $80^{\circ}$  W., as indicated on the accompanying map, Plate II., but its displacement is not very great, being a downthrow to the north of probably less than a thousand feet. Its movement is apparently of later date than the mineralization of the limestone, but it may represent a recurrent movement along an already determined line of weakness. The general northwestern trend of the principal ore developments and of many of the larger features of geological structure suggest that faulting may have taken place in the sedimentary rocks before the intrusion of the igneous magmas, which has had an influence on subsequent fracturing.

The rock fracturing in this region is such as might be expected to have resulted from the repeated shocks attendant upon successive intrusions of eruptive rock, rather than from the slow mechanical stresses which produce the folding and faulting involved in the uplift of great mountain ranges where the faults can often be traced continuously for miles.

Here the rock masses have been shattered in a most intricate and complicated fashion, and while in the strongly fractured regions like the Capote basin there are abundant well-marked planes of movement, as well as zones of sheeting and brecciation, individual fault planes can rarely be traced continuously over a few hundred feet in a given direction.

The fissure vein in the original conception of the term, that is an open fissure filled by extraneous material, is rarely found. Ore deposition has been largely by metasomatic replacement or by impregnation of the country rock along disturbed zones.

The prevalent observed strikes of fracture systems are:

1. N.  $30^{\circ}$  W., which is most frequent in the closely-spaced

fissures and breccia zones of the great ore bodies in the mines of Capote basin. This is generally parallel with the quartzite-granite contact of the Chiva Peak massive, which may be conceived to have acted as a buttress to the stresses induced in this basin.

2. A N. 60° W. strike is also prominent among the fractures observed underground, and is the average direction of a line drawn through some of the main ore bodies outside of the Capote basin. It is also the direction of the band of quartz porphyry that stretches from Puertecitos to Teocalli.

3. An east-west direction is that of the fracture zone followed by the main ore body of the Democrata mine, and of the best defined portions of the Elisa fault. The main joints in the Puertecitos limestone run east-west and north-south.

4. A north-south direction is that of certain faults of unknown age parallel to the limestone contacts at Puertecitos, and of some cross faults that join the Elisa fault in the Elisa mine and are distinctly posterior to ore deposition.

5. A northeast direction is the main direction of fissuring in the Bonanza mine and a minor direction of fissuring supplementary to the more prominent ones in other mines.

#### MINERALS.

As far as our observation went, there is an unusually narrow range of mineral species in the district, at least among those of common occurrence. It is quite possible, however, that some of the rarer occurrences may have escaped observation, since, the objects of the work being primarily commercial, it was not considered appropriate to make special search for rare species.

Among primary metallic minerals bornite, chalcopyrite and sphalerite predominate in contact deposits in limestones, associated with subordinate pyrite and galena, and a little magnetite and specularite. In the deposits in porphyry, pyrite is the prominent mineral, chalcopyrite being relatively rare, and bornite not observed. Zinblende and galena are also present, the former at times in relatively large amounts rather to the exclu-

sion of copper values. Tetrahedrite is also found, but is only occasionally of economic importance.

Among secondary minerals, chalcocite is the important copper mineral of the sulphide zone. In the limestone deposits at Puertecitos massive chalcocite is known to occur carrying as high as 20 per cent. of zinc, probably a secondary enrichment of zincblende by copper-bearing solutions. As oxidation products chrysocolla, malachite and azurite, cuprite and native copper, once formed large masses near the surface that are now pretty thoroughly mined out. The iron gossans are mostly limonite, but also contain at some points considerable anhydrous oxide.

The most common metamorphic minerals are garnet (probably andradite) and epidote. Both are found as alteration products of limestone, but epidote also results from the alteration of igneous rocks far away from any known limestone body. Other lime-silicate minerals are relatively rare. Some amphibole and pyroxene (hedenbergite) were observed, possibly also vesuvianite and zoisite. Sericite is found as a common alteration product of igneous rocks and of quartzite, chlorite being less frequent. Kaolinization is common as a result of weathering, or the action of meteoric waters. Quartz and calcite are uniformly present in all types of deposit, though nowhere in great quantity and the former rarely in distinct crystals.

#### ORE DEPOSITS.

There has already been considerable discussion with regard to the ore deposits of Cananea, some geologists maintaining a contact metamorphic origin for them, others denying this mode of genesis for the more important deposits. As is apt to be the case in such differences of opinion, actual investigation has shown that there is a modicum of truth in the views put forth by either party to the discussion. Most typical contact-metamorphic deposits are to be found there, as well as those which would generally be classed as of hydrothermal origin, yet it seems evident that they may all be considered as products of the after action of the eruptive intrusions. In some cases two successive periods of mineralization can be distinguished, and it is

susceptible of direct proof that a deposit or a part of a deposit was formed in one period or the other; in others there is still some doubt as to which period the deposit properly belongs.

Again, certain rock types are definitely associated with mineralization through the contact-metamorphic action they have exerted on the rocks into which they have been intruded, and through the fact that they carry ore deposits themselves. These, as has been already stated, are first and foremost the Henrietta diorite-porphyry, and after this, the more acid types, the Cuitaca granodiorite, and the Elisa quartz-porphyry, whose interrelations are, however, not thoroughly known, and which may represent differing phases of the same general eruption. From which of these rock magmas a given deposit has proceeded is likewise not always susceptible of definite proof. The diorite-porphyry, as the more widespread and as more intimately associated with the valuable ore bodies, is regarded as having been the most generally important factor in ore deposition, while each of the other two is known to have exercised a mineralizing action in certain localities, but it is not always possible to determine what special part or phase of a given ore deposit may be ascribed to the influence of either magma.

The study of the eruptive rocks of the district has shown them to possess a certain consanguinity that would lead to the assumption that they proceeded from one common parent magma, and the frequency with which a small percentage of copper has been found in the different varieties of rock occurring there, suggest that this parent magma contained a certain amount of copper. It is easy to conceive that in the successive differentiations of this magma that have produced the different rock types now exposed at the surface, those that produced the three rocks above mentioned may have become unusually rich in this metal.

As regards the method of forming ore deposits from such magmas, it is generally assumed that where an igneous magma is intruded into sedimentary rocks, which are cooler than the magma, the latter commences to consolidate at its contact with the limestone or other intruded rock. In this consolidation certain rock forming minerals crystallize out first, while others more

volatile or fusible, being squeezed out of the cooling mass by the crystallizing process like water out of a sponge, are held back in the still unconsolidated residuum or mother liquor, to be forced in later through the cracks that may have formed in the already consolidated magma, into the adjoining intruded rocks. In this mother liquor will have been concentrated such metals as may have been contained in the magma, in connection with the so-called mineralizers, such as sulphur, boron, fluorine, etc. In this earlier part of the process the magma being under greater pressure and at a temperature above the critical point of water, the solutions still in gaseous form will have more penetrating power and their deposition in the rock masses into which they are forced, being characteristically by metasomatic replacement, will be less dependent upon the existence of large cracks. When deposited in limestone they will be associated with the lime-silicate minerals that are formed only at this elevated temperature. As this so-called pneumatolytic process continues, with the gradually increasing thickness of already consolidated magma the residual solutions that are squeezed out of it will come from deeper and deeper zones and have a continually increasing distance to travel, hence a progressively decreasing temperature. As this temperature gets below the critical point of the substances involved and the solutions have consequently assumed the liquid form, the process becomes a hydrothermal metamorphism, which results in a somewhat differing mineral association, and requires a more extensive fissuring of the rocks to admit a ready passage of the ascending solutions.

At Cananea where it would appear that such a general succession of conditions governing mineral deposition have been repeated with successive eruptions, it is not surprising that the resulting deposits do not always admit of distinct classification.

#### CONTACT-METAMORPHIC DEPOSITS.

The two principal areas of contact-metamorphic deposits are in the limestone belt enclosing and extending southward from Puertecitos, and the irregular mass which stretches southeastward from the Elisa mine, bounded on the north by the Elisa

fault. Small outcrops scattered through the large area of more or less garnetized limestone east and south of Elenita Mountain show some copper, mostly in the form of chrysocalla at the surface, and prospecting has developed small patches of copper carbonates and oxides, which have as yet yielded no bodies of economic importance.

*Puertecitos.*—The Puertecitos limestone body lies between Cuitaca granodiorite on the west and diorite-porphyry on the east, both of which have acted as metamorphosing agents. The limestone is extensively marmorized, silicified and garnetized, and the copper minerals are found associated with the garnet in irregular patches which have no very definite structural relations except that they follow joints and show a tendency to form bodies that dip northeast with the bedding of the limestone. In the primary limestone ore as distinguished from other types of deposit, bornite is more common than chalcopyrite. Some magnetite and specularite are found, and in places zinc-blende is quite abundant, with a little galena. The oxidation products are mainly carbonates with some chrysocolla, which, however, do not generally extend to any great depth, sulphides being found comparatively near the surface. Secondary enrichment has also played a less important part in the formation of these ores than those in the porphyry, yet it has rendered individual deposits quite rich; chalcocite is found which carries as much as twenty per cent. of zinc. Though the primary ore is much richer than that in the porphyry, its irregular mode of occurrence, which increases the relative cost of mining, reduces its economic value.

As at present carried on the ore is mined by quarrying on the steep faces of the limestone ridge back of Puertecitos, which is about a quarter of a mile wide between granodiorite on the west and diorite-porphyry on the east, and its crest about 400 feet above the railroad track. On the east faces are three terraces at about 100 vertical interval, provided with mine trains, and the rock as blasted down, is roughly sorted, the waste being trammed to the waste dump at one end of the terrace, and the ore sent down through chutes to the railroad. The mixture of

rock and oxidized ore thus shipped carries about three per cent. of copper. A similar terrace has been started on the west or granodiorite side of the ridge, but this side had not yet been reached by the railroad.

Ore occurs at Puertecitos also in both granodiorite and diorite-porphry close to the limestone. It follows as a rule fault fissures which are generally parallel to the contact, and have a northeast dip. In these chalcopryite instead of bornite is the prevailing copper-bearing ore.

Considerable mining was done in early days in the southern end of this limestone belt, on the slope of Alfredeña Ridge toward Elenita, but as the mines are now closed it can only be said that the ores are of the contact metamorphic type. The same is true of the Union Mexicana mine at the head of Pinal Gulch, but tetrahedrite, which has not hitherto been recognized as a contact metamorphic mineral, is found in its ore associated with bornite, chalcopryite, hematite, and hedenbergite.

*Elisa Mine.*—The ore at the Elisa mine is of the same general type as the Puertecitos ore, but chalcopryite is the prevailing copper-bearing mineral, and the ore bodies contain more zinc-blende and pyrite. The limestone is in places marmorized, but in connection with the ore it is generally altered to garnet. The ore bodies are irregularly spaced, but as a rule lie near and to the south of the Elisa fault, or, in the short stretch where the fault is double, between the two fault planes; and their long axis is generally parallel with the fault, yet no connection between ore and faulting could be found, and the weight of evidence goes to prove that the faulting is later than the ore. Branch faults run south from the main fault, which contain dragged-in fragments of ore. The ore bodies are sometimes several hundred feet long and forty or more feet wide. They have been developed for over seven hundred feet below the surface, but are oxidized only down to the first level.

The Elisa fault is nearly vertical, in the upper part, but assumes a gradually shallower north dip in depth. In the upper part it is entirely within the limestone, but gradually approaches the contact as it descends. The limestone in the lower levels has

the normal northeast dip, but in the upper part is much disturbed, and in places dips steeply south.

The diorite-porphyry, which adjoins the limestone on the northeast, appears to have been the main cause of the contact-metamorphism, but the quartz-porphyry which immediately adjoins it, at a distance of a few hundred feet from the contact, may also have exerted some action.

Similar deposits in limestone, differing slightly in mineral association, are found across the divide from Elisa Gulch, at the head of the north branch of Capote Gulch. As at present developed they are smaller and more scattered than the Elisa deposits, but are generally associated with some fracture in the limestone which here strikes east and west, and dips to the west of north. They are about an eighth of a mile from the Elisa fault, and from the nearest exposure of the intrusive, which is here Elisa quartz-porphyry.

Secondary enrichment has evidently played a less important rôle in the contact-metamorphic deposits than in the other ores. Though there are concentrations of chalcocite here and there in the richer bodies, it is not universally disseminated as in the pyritous ores, where, were it not present, the bulk of the ores would be too low grade to work. Their content in silver, though always small, is somewhat higher in these ores than the average, being at times as much as 5 to 10 oz. of silver to the ton.

The reason for the lesser secondary enrichment in limestone deposits may be that this rock, especially when altered to garnet, is less susceptible to fracturing and fissuring, and that consequently the downward leaching waters from the surface find less ready access to the ore bodies.

*Other Contact-metamorphic Deposits.*—Among the deposits of present economic value, the above are the only ones to which exclusively contact-metamorphic origin can be assigned. Yet in the other areas of more or less altered limestone which are very considerable at the surface, and as proved by mine workings still more extended underground, frequent small patches of copper ore are found which have the mineralogical characteristics of contact-metamorphic deposits, viz., association with garnet,

and predominance of bornite over chalcopyrite. Where workable ore bodies have developed in connection with such deposits it is at times possible to determine either by direct structural evidence or by the character of the ore that there has been an introduction of copper-bearing material since the primary deposition.

The most definite evidence thus far found has been in the Democrata mine, within a body of limestone that lies beneath the bed of Democrata Creek. The ore body in question lies about three hundred feet north of the Democrata shaft, and has been opened from the 300-foot down to the 700-foot level. It occupies an irregularly shaped fracture zone in limestone 50 feet or more in width, that has a general east-west strike and northerly dip. The ore consists of a breccia of rather large fragments of contact-metamorphosed limestone cemented by quartz and metallic sulphides. In this periphery of the ore body it is easy to distinguish the bornite and zincblende of the first generation from the abundant white quartz with iron and copper pyrite of the second generation, while in the central and richer portions it is difficult to determine in the prevailing quartz pyrite ore that which is distinctly of primary or contact-metamorphic origin; though the latter appears to form but a subordinate proportion of the whole ore mass. The presence of considerable chalcocite in these ores shows that they have been secondarily enriched at a still later period, but to what depth this enrichment may extend was not determined.

The limestone mass in which these ores occur is both cut and covered by diorite porphyry, which constitutes the surface rock of the country eastward from Democrata Gulch, until it in turn is replaced by the mesa tuffs around Ronquillo, while on Democrata Ridge, which forms the east wall of Democrata Gulch, several small patches of garnet rock can be detected in the general covering of diorite-porphry. Good bodies of carbonate ore have been mined from very near the surface downward in two of these patches of garnet rock, the one on the north, the other on the south slope of the little knob (opposite the shaft) that forms the highest point of Democrata Ridge. Both are

in altered limestone cut through or surrounded by diorite porphyry. That on the south slope shows the breccia structure with ore both in breccia fragments and in the matrix. It occupies an E.-W. fracture zone which dips about  $50^{\circ}$  north and is probably the apex of the Democrata ore body already described, though the ore is not absolutely continuous between the upper and lower bodies. In all these cases the ore has evidently formed more readily in the limestone than in the adjoining porphyry.

In the West Cobre Grande and Kirk mines, whose workings have thus far opened only ground within 200 feet of the surface, considerable ore has been developed along fracture planes that cross both diorite porphyry and limestone, the latter rock being in much larger proportion than at the surface. The mineral association in these ores is similar to that in the Democrata mine, and they occur for the most part near the contact of the two rocks, but not always entirely within the limestone or garnet rock. The fractures are very irregular in direction and extent, being mostly N.-W., crossed by north and northeast fractures, and the ore bodies not continuous for over 100 feet in a given direction, hence rather difficult to follow. The ores are generally of good grade but already at the 200-foot level is an apparent falling off in the amount of chalcocite and an increase in the proportion of zinc in the ore, which indicates an increasing importance of secondary enrichment in producing payable ores.

The deposits above described seem to form a transition series in which contact-metamorphic deposition in limestone has played an essential but successively less important rôle, and the present economic value of the ores has been more and more dependent upon the action of solutions of the second generation, or of hydrothermal origin, together with migration produced by surface waters or secondary enrichment.

It seems best to describe next the economically most important deposits of the region which appear to form the extreme type of hydrothermal deposits, as developed in the district, leaving other intermediate or transitional types for later treatment.

*Capote Basin Deposits.*—The economically most important ores of the district, which have been extracted from the great mines of the Capote Basin, present the strongest contrast to the contact metamorphic ores of Puertecitos and Elisa type, both in mineral association and mode of occurrence.

The primary ores consist mainly of pyrite with a small admixture of chalcopyrite, and in places considerable zinc blende. They are very siliceous, and their introduction was accompanied by extensive sericitization and silicification of the adjoining country rocks. Their tenor in copper is so low that it is doubtful if in the early days they could have been mined at a profit, if they had not received additional copper by downward migration or secondary enrichment. They occur in closely spaced fractures or shear zones that traverse both eruptive and sedimentary rock, and disseminated throughout the adjoining country rock. Although the associated limestones show evidence of contact-metamorphic action in their alteration to marble or garnet rock, the little copper ore they may contain apparently forms no essential or important part of the present ore bodies. Still, in the very large amount of rock that must have been removed by erosion from above the present deposits, it is quite possible that there were concentrations of contact metamorphic ore whose leachings formed an important addition to the accumulations of chalcocite that constituted the extraordinary richness of the present ore bodies within 200 or 300 feet of the surface.

*Mine Developments.*—The general disposition of the mines in the Capote Basin may be best understood by reference to the map (Plate II.), and the shafts and tunnels there indicated, the principal shaft of each mine being designated by a number. Thus No. 1 is the Campana shaft, the principal opening of the Indiana-Sonora ground, a tract along the north bank of Capote Gulch that formerly belonged to the Phelps-Dodge interests. No. 2 is Capote No. 2 shaft, which has been sunk to a depth of a thousand feet about 200 to 300 feet east of the main ore body of the Capote mine. No. 3 is the Oversight tunnel (called Capote No. 17), which runs about 20° east of south along the east side of the great Oversight ore body, and at 1,400 feet

reaches the Motor tunnel, No. 4 is the Esperanza No. 1 shaft, to the east of the Esperanza ore body, and No. 5 is the Veta Grande No. 5 shaft, which lies likewise to the east, or in the hanging wall country, of the ore body of the Veta Grande mine.

The main ore extraction of these five mines is through the two connecting motor tunnels, which have an aggregate length of over a mile and a quarter. The Capote No. 9 tunnel starts about 500 feet northwest of Capote No. 2 shaft, running first a little west and then east of south about 3,500 feet to a point under the north spur of Cerro de Cobre. The Veta Grande No. 9 tunnel runs a little south of west, 3,000 feet to the same point, but at a level 170 feet lower, the ore being dropped from one to the other through chutes.

The rocks exposed in the Capote Basin are mainly quartzites and limestones, intruded by large masses of diorite-porphyry and extensively fractured and faulted, with later intrusions of quartz porphyry. The latter rock is in small masses within the basin, but more extensively developed in the bounding ridges; to the north at Campana saddle, and to the south along the upper slopes of the Cerro de Cobre, in each of which localities a contact-breccia phase is developed where diorite-porphyry fragments are cemented by the quartz-porphyry magma.

It is very readily apparent at the surface that the area is one of intense mineralization, where there has been a primary solfataric action or introduction of sulphides of the metals in heated solutions, accompanied by silicification and sericitization of the rocks which has rendered them peculiarly susceptible to subsequent alteration; and that this has been followed by extensive weathering produced by atmospheric agents, in which the feldspathic rocks are kaolinized and softened, and the metallic sulphides oxidized, in each case the original materials being so disintegrated and decomposed as to be readily abraded. That abrasion has been unusually great here is indicated not only by the fact that the basin has been deeply eroded out of a relatively high portion of the range, but by the extraordinary richness, as compared with the original tenor of the ore, of the zone of enrichment. At the surface, furthermore, the great development

of bodies of iron gossan, resulting from the oxidation of pyrite, is most striking, and evidently first attracted the prospector. They have not, however, proved to be a generally reliable guide in searching for ore, for some of the best bodies have no surface gossan with which they can be directly connected, and under some of the largest bodies of gossan, no extensive bodies of pay ore have yet been discovered.

As regards rock distribution, the Capote quartzites are found at the west end of the basin resting on Cananea granite, with a generally northeast dip, and, except for a narrow northwest band faulted up between the Capote mine and Chivatera, have not yet been seen elsewhere in the basin either on the surface or in the extensive mine drifts.

The limestone rests conformably on it, and in the few places where bedding planes can be distinguished, has also a general northeast dip. It is very largely altered to garnet or marble, and under the great gossan at Capote Pass is changed to gypsum over a considerable area. On the north, where it is sharply delimited by the Elisa fault, it forms an almost continuous belt along the north slopes of Capote Gulch, but from there southward is gradually crowded out by the growing intrusions of diorite porphyry until it is entirely lost sight of under the Cerro de Cobre.

The rest of the area, with the exception of the small bodies of quartz-porphyry, is occupied by diorite-porphyry, prevailing of the fine-grained or aphanitic phase, which when highly altered is with difficulty distinguishable from certain alteration phases of quartzite or limestone. The form of the diorite bodies appears to be mainly that of irregular stocks, and of wedge-shaped tongues projecting out into the limestone area from the Cerro de Cobre. In the Veta Grande ground to the southeast, however, the increase in extent of limestone in depth suggests that the diorite is there, in part at any rate, in sheet form.

Although the ore bodies may cross all of these rocks, it is in the diorite-porphyry apparently that ore has most readily formed, actual contact-metamorphic ore in garnet rock being in the pres-

ent workings rather a mineralogical curiosity than an economic product.

Both diorites and sedimentary beds have been extensively shattered and faulted, the major or predominant direction of the fault planes belonging rather to the N. 30° W. than to the N. 60° W. system, the latter of which is the more common strike of such planes in other parts of the district. What relation the faulting bears to the quartz-porphyry intrusions is not definitely known; it may have been contemporaneous with and possibly was in part produced by that intrusion.

The best defined faults in the basin are those in the Capote and Oversight ground at the east base of Chiva Peak. Of these the Capote fault is a zone of shearing or faulting running N. 30° W. from the Glory hole at Capote Pass, which dips more steeply northeast than the bedding and thus cuts through limestone and intruding diorite-porphyry into the underlying quartzite. Its displacement is a downthrow to the east. About a thousand feet east of the Capote fault is a second line of displacement, called the Ricketts fault, which dips steeply southwest, thus converging in depth with the Capote fault. In strike it is nearly parallel with the Capote, but tends to diverge and split up to the south so as to include an ever widening zone toward the Cerro de Cobre. Its movement has been an upthrow to the east, which has brought the quartzite to the surface in narrow parallel bands, while the ground between the two faults is a dropped block or wedge in which occur the great Capote and Oversight ore-bodies. The character and amount of displacement on other fault planes has not been determined.

*Ore Bodies.*—The great productive ore shoots of the Capote basin thus far developed, the Capote, Oversight, Esperanza and Veta Grande bodies, occur in northwest striking zones arranged along the northern flanks of the Cerro de Cobre, with a general parallelism to each other, but each, commencing with the Capote body on the west, set off successively a little more to the west and south, and with a pitch which, when it departs from the vertical, is also to the southeast.

The general relation thus maintained by them to the igneous

mass that forms the Cerro de Cobre is such as might be expected had the solutions from which the ores were precipitated originated at some point beneath that mass.

The *Capote* ore body occurs on the western edge of the down-faulted block between the Capote and Ricketts faults. The central and richest portion has for some years been bulkheaded on account of fire; hence there is some uncertainty about its relation to the limestones which form the greater part of the surface exposures in the interfault block in which it occurs. The gossan above it caps not only the quartzite and porphyry along the Capote fault zone, but also a great width of the hanging wall limestone. The actually stoped area on the motor tunnel level was from 300 to 400 feet in length and up to 165 feet in width, and in this area the ore, as taken from square sets, is said to have never run less than 20 per cent. of copper, and sometimes very much more.

This main ore chimney stood nearly vertical, decreasing in size from a length of 475 feet on the first level to 130 feet on the fourth; a second shoot of somewhat smaller dimensions starts in a little distance to the northwest, and with a general southeast pitch, has been followed down to the 700-foot level, and cut again on the 1,050-foot level. It lies in closely sheeted, altered and somewhat brecciated porphyry at or near the Capote fault, which dips steeply northeast over a footwall of quartzite that is sericitized and impregnated with pyrite. On the east is limestone traversed here and there by porphyry which extends to the Ricketts fault. At about the sixth or seventh level the ore body passes into a breccia made up of fragments of both quartzite and porphyry, and the limestone to the east is succeeded by quartzite. Some of the fracturing is evidently post-mineral, for traces of secondary enrichment are found down to the seventh level.

The whole mass of the country rock for considerable distances from the central chimneys is more or less impregnated with pyrite, which thus constitutes a disseminated ore body that furnishes concentrating ore, when sufficiently enriched.

The *Oversight* ore shoot lies about 2,000 feet southeast of the Capote chimney, and has practically no gossan directly over it,

the surface consisting of fine-grained diorite-porphyry, highly silicified but only slightly iron-stained. With the great gossan body at Capote Pass, which lies about a thousand feet to the west and at only 300 feet higher level, it has no apparent connection. So great has been the mass of ore taken from it, that the whole northeast slope of Cerro de Cobre, at the base of which it lies, is slipping bodily downward, leaving a fresh vertical wall over a hundred feet high, at the summit of the ridge. It occupies a tongue of crushed diorite-porphyry protruding into the limestone on the eastern side of the interfault block, and is bounded on the east by quartzite brought up by the eastern member of the Ricketts fault, and on the west by limestone, which also has a faulted contact.

The ore is, like that of the Capote, an enriched pyritous ore, but the enrichment which is of chalcocite with a little native copper, is less concentrated, the shoot consisting of a series of lenticular bodies of richer ore, with low-grade ore between. The enriched portion commences at about 200 feet below the surface and is over a thousand feet in longitudinal extent. Sericitization has played a greater part in the alteration of the country rock, and the ore is in consequence more greasy and aluminous. But three levels had been opened in the mine, and the limit of secondary enrichment has not yet been determined.

The *Esperanza* ore shoot is a smaller body to the east of the Oversight and separated from it by 200 to 300 feet of quartzite intruded by diorite-porphyry, which forms part of the fault block brought up to the east of the Ricketts fault. It is of similar composition but very much more irregular in outline. To the east of it lies the belt of limestone which separates it from the Veta Grande ground, and which must necessarily have suffered some downward displacement, for as yet no quartzite has been struck beneath the limestone by the deep workings of the Veta Grande mine. No single well-defined fault plane has been found on which this movement could have taken place, and it was very likely distributed over an irregular zone of considerable width, probably that in which the ore body occurs.

The *Veta Grande* shoot lies in an easterly dipping tongue of

diorite that protrudes into the broad limestone area east of the Esperanza mine and is only 250 feet wide where crossed by the motor tunnel. The ore follows a zone of fracturing and brecciation in this diorite, that strikes northwest and dips northeastward at angles of  $40^{\circ}$  to  $80^{\circ}$ . In this zone it pitches to the southeast from its highest point in the ore body at the Massey shaft, above and a short distance west of Veta No. 5 shaft, which was a large mass of exceptionally rich oxidized ore carrying carbonates with cuprite and native copper in a highly silicified and bleached diorite that closely resembles a sugary quartz. From this body downwards in a southeasterly direction the ore has been followed, in practical continuity but with decreasing area and tenor in copper, to the 500-foot level. In the middle levels there is much enrichment by chalcocite, but this enrichment has apparently not extended to the lowest levels.

Limestone is found not far from the ore body both in foot and hanging wall country, but ore is found in similar fracture zones in the porphyry entirely separated from any known body of limestone, notably on the spur to the east of upper Democrata Gulch. Such porphyry ore is generally of lower grade than that associated with the limestone.

#### IGNEOUS CONTACT DEPOSITS.

*Henrietta Type.*—The Henrietta mine presents another type of deposits, which may be called Igneous contact deposits, since they more nearly resemble the contact-metamorphic deposits, except that the limestone and lime-silicates are absent. The ore bodies occur along though not immediately on the contact of quartz-porphyry and diorite-porphyry, sometimes in one, sometimes in the other rock. The surface exposure of this contact follows a rather irregular line in a general N.  $45^{\circ}$  to  $55^{\circ}$  W. direction from the Elisa mine toward Puertecitos. The mine workings, which have only been opened within two or three years, are situated on either bank of Pinal Creek, where it emerges from the steeper hills; the tunnel on the south side is being driven to connect with a similar opening on Pavo Real Creek to the southeast.

The primary ore consists of chalcopyrite and bornite with pyrite and zincblende in a somewhat siliceous gangue. It contains also occasional tetrahedrite and runs higher in silver than the ordinary quartz pyrite ore. One body 10 feet thick was yielding 6 per cent. of copper with 8 to 10 oz. of silver and about 60 cents in gold to the ton.

As shown in the mine workings, the contact is generally a flat, somewhat wavy surface, with a shallow northeast dip, but in places the diorite is crushed, and somewhat mixed with quartz porphyry. The diorite porphyry in this mine presents varied texture from gray and coarsely granular to fine-grained, black and aphanitic. Where impregnated with ore it is bleached, highly siliceous and often porous.

The ore occurs as cement filling in breccia zones and as rock impregnation or replacement along fractures, or filling joints and veinlets. To judge by present developments, whose extent is somewhat limited, the ore bodies have more of the irregular sporadic distribution of the contact-metamorphic deposits, than the linear arrangement along definite zones of fracture of the Capote Basin deposits, yet they have been as much as 150 feet in length and up to 10 feet in thickness. They are found, as already stated, both in diorite-porphyry and quartz-porphyry, hence must be later than either, and are presumed to be an after-effect of the quartz-porphyry intrusion. Chalcocite and even native copper are found in them, but developments have not been carried to sufficient depth to prove whether they will become of low grade when out of the reach of secondary enrichment.

*Cananea-Duluth Mine.*—This is the most important among the newly developed ore bodies. It lies in the mesa country about a mile and a quarter south of Cananea, and a half mile east of the steeper slopes of the range that are made up of diorite-porphyry. It is far away from any known body of limestone and entirely surrounded by mesa tuff, but the ore occurs in a protrusion of diorite-porphyry that has thrust itself up through the tuff. This is much shattered and all more or less mineralized, especially along its contact with the surrounding tuff, so that it is in one sense a contact deposit. Yet the contact is not

well defined, it being often difficult to distinguish in the upper levels where the rocks are generally kaolinized, and the contacts observed are mostly slip-planes rather than eruptive contacts as in the Henrietta mine.

The body is of a rather elliptical form, the longer axis having a direction of about N. 60° W., is over 1,200 feet long, up to 150 feet wide, and has thus far been opened to a depth of 400 feet. On the surface the only favorable signs are the brecciated, slightly stained and silicified character of the country rock, which is practically barren for some distance down. The first considerable values commence with the zone of secondary enrichment where primary sulphides are coated with sooty chalcocite. In depth the character of the primary deposition is best seen along the periphery of the body where slip planes and breccia structure are most distinct. Here it is seen to be a mixture of chalcopyrite and pyrite, with some bornite and occasional tetrahedrite, in a quartz gangue replacing the cement of the breccia, which itself consists of the same material as the large fragments but more finely ground-up. The large fragments are themselves silicified and shot through with fine-grained pyrite, and are often made up of clastic material, thus suggesting two periods of mineralization.

Through the middle of the mass ore occurs in small joints or veinlets and as impregnations of the rock, thus resembling "disseminated deposits" in porphyry. The whole is very generally silicified, while the development of sericite is less than in the Capote Basin ores; thus the lower grade material is "dry" rather than "greasy," and hence concentrates better, so that it constitutes a very valuable ore in that a very large proportion of the whole mass can be profitably extracted. The downward limit of secondary enrichment is not yet well defined in this mine, but the grade of the ore does not seem to have fallen off at depths thus far reached.

There are many planes of movements, which, however, are not continuous over great distances, but they rather form zones along the boundaries of the body, those on the north side tending to dip to the northeast, and those on the southwest are nearly verti-

cal or have a steep southwest dip. Where these are wanting, the distinction between ore material and country is the absence of brecciation in the latter. A clastic structure is common to tuff and altered porphyry, and in the latter this sometimes suggests a flow-breccia.

These ores carry more silver than the Capote Basin ores, the tenor being higher where tetrahedrite is more frequent.

*Other Deposits in the Mesa Country.*—Intermediate in position as well as in character, between the Duluth and the Kirk deposits, are those of the *America* or *Bonanza* and the *Cobre Grande* mines. The latter was one of the early producers of the district, and had so valuable a body of oxidized ore within a hundred feet or so of the surface, that, as shown by the remaining slag heaps, it was smelted on the spot. These old workings being now inaccessible, only a few drifts in the sulphide zone could be visited; but there appears to be a general resemblance in geological relations between these and the more recently opened Bonanza deposits to the south.

In a general way these deposits may be said to have been formed by solutions which rose along a line or zone of fracturing, partially replacing and impregnating the adjoining country rock with pyritous ores, that have been subsequently enriched by downward leaching. This line of fracturing which has a steep dip westward, runs northeast in the Bonanza ground and northwest in the Cobre Grande ground, there being a more or less complete curving connection between the two in the intermediate America ground, and a northwestern continuation of the Cobre Grande fracture being traceable under Watertank Hill in the direction of the Democrata mine. Both in Bonanza and Cobre Grande ground an irregular mass of garnetized limestone lies immediately west of the ore, though not necessarily in immediate contact with it, and the fracture zone is at or near the contact between diorite porphyry and Mesa tuffs. Furthermore in each case there is a so-called flat body, the solutions having branched off and deposited for a limited distance on a plane that dips  $15^{\circ}$  to  $20^{\circ}$  eastward and connects with the main vertical fractures, the suggestion that presents itself being that this plane is con-

formable with the bedding of the tuff, which generally forms the country rock of the flat body. The vertical fractures are often double or triple, thus enclosing a considerable area of more or less impregnated country. In the kaolinized and bleached condition of the country rock, it is at times impossible to determine whether a given specimen is diorite or tuff, especially as the former often has a finely brecciated or clastic structure. Yet both rocks are undoubtedly present.

The surface rock for 30 or 40 feet down, in the Bonanza ground, is barren or slightly impregnated with oxides and carbonates of copper. The enriched zone of pyritous ores covered by a coating of chalcocite, and carrying veinlets of fairly pure chalcocite, runs up to 10 per cent. of copper, but the values rapidly fall off with depth, and at 200 feet it is already of quite low grade. The relatively slight extent of secondary enrichment can not be assigned to any want of permeability of the overlying rock material, hence it is assumed to be due in part to a relatively slight amount of erosion, and in part possibly to the fact that the original depositing solutions did not reach a very much higher horizon than the present.

At various points in the mesa country to the south of the Duluth mine shafts have been sunk through the Mesa tuffs, which have developed diorite-porphyry intrusions that are slightly impregnated with disseminated ore, enriched by sooty chalcocite, none of which have as yet found actually productive ore bodies.

To the north of the town of Cananea the *Calumet & Sonora* Company has opened some interesting deposits of a type that differs from any yet described. They occur in a belt of brecciated diorite-porphyry that is cutting through the Mesa tuffs. Not being accessible at time of visit data as to underground relations were obtained from the mine manager. The fractures, which are nearly vertical, have a general  $70^{\circ}$  Northwest direction and the two shafts are on a N.  $60^{\circ}$  W. line, but it does not necessarily follow that they are on the same line of fracture. The ores in the southernmost shaft are very varied in mineralogical composition.

The southernmost, or Norton shaft, was sunk 240 feet and developed a vein carrying galena, antimonite, zincblende and chalcopyrite and a little dolomite with 80 oz. of silver to the ton in a diorite-porphry breccia.

At the northernmost or Topo Chico shaft a so-called dike of breccia about 30 feet in width cuts the purple and greenish tuffs, in the middle of which is a vein of coarsely crystalline galena, zincblende and chalcopyrite practically without gangue. The galena is said to carry 30 ounces and the chalcopyrite 4 to 6 ounces of silver to the ton. The zincblende is of the rosin type and yields over 60 per cent. zinc in carload lots. The vein is a solid mass of metallic sulphides between clean walls 8 to 10 feet wide. A branch makes off at right angles to the main vein which has 5 feet of breccia. The ore first appeared at 20 feet from the surface and was partially oxidized down to 100 feet. The vein itself yields abundant water, highly charged with mineral salts, but the Mesa country rock on either side is quite dry.

Developments in this type of deposit are as yet too limited to determine whether they are merely sporadic local concentrations of ore, or whether they are likely to lead to large and permanent bodies. The fact that they have practically no outcrops, and very little surface indications, render the search for them very uncertain and expensive.

#### CONCLUSIONS.

In the previous pages the Cananea Mountains are shown to have been an original uplift of Paleozoic quartzites and limestones resting on an older granite, that had been intruded, broken up and partly buried by no less than twelve successive eruptions of igneous rocks, of which most were intrusive, but one at least took the form of an explosive outbreak and spread its materials out upon the surface.

Of these successive eruptions only three have exercised contact-metamorphism upon the intruded limestones, the most marked and wide-spread effect having been that caused by the diorite-porphry, and to a less degree by the granodiorite and

quartz-porphyry intrusions which followed it. The gabbros and later diabases, which were the final phases of eruptive action, had apparently little or no metamorphic effect, and no connection with the ore deposits.

The ore deposits of the region that have thus far proved of economic value are all included in a belt of country lying along the northeast flanks of the range, from one to two miles wide and six miles long, in a general northwest-southeast direction. Although contact-metamorphism and ore deposition have not been strictly confined to this belt, it is here that the dynamic disturbance of the rocks has been greatest, and their action appears to have been most energetic.

Ore deposition has evidently taken place from highly heated solutions emanating from the cooling magmas and in the deposits themselves it has been possible to distinguish two periods of deposition, one in which they were above the critical point of water and hence in gaseous form, the other in which, though still highly heated and endowed with great penetrative force, the temperature of the solutions had so fallen that they were in liquid form.

In the first period were formed the typical contact-metamorphic deposits in garnetized limestone, such as are being worked at Puertecitos and in the Elisa and adjoining mines. The great ore bodies of the Capote Basin, following fracture zones that cross both sedimentary and igneous rocks, represent the second class. In the Democrata mine both types are combined. In all these cases the ores are characteristically metasomatic deposits, for though some follow certain lines of fractures, the fractures had produced only sufficient open space to admit the circulation of the uprising water, which had penetrated and replaced the adjoining rock from the various movement planes outward. In mineralogical composition the hydrothermal deposits of Capote Basin are essentially quartz-pyrite ores with a little chalcopyrite and zincblende, in original condition probably not averaging more than one or two per cent. of copper. The contact-metamorphic ores in limestone consist of original bornite and chalcopyrite with zinc blende and pyrite, and have a much

higher original content of copper and silver. The variety of mineral species present, both in ore minerals and lime silicate or gangue minerals, is unusually restricted.

Other types represented by the deposits of the Henrietta and Duluth mines, which occur at or near the contact of two varieties of eruptive rock, and away from any known sedimentary rocks, have been provisorily designated igneous contact deposits.

The deposits of the Henrietta mine occur near the rather flat-lying contact between diorite and quartz-porphyry, mostly in the former, but at times also in the latter rock. Although they contain little or no limesilicate minerals, the mineralogical composition of the deposits resembles that of the Puertecitos and Elisa contact-metamorphic ores. The Cananea-Duluth deposits, of similar mineralogical composition with the Henrietta ores, occur in an intrusion of diorite-porphyry cutting through bedded Mesa tuffs, the richer ore being found along brecciated fracture zones on the periphery of the intrusion, which is of elliptical shape, 1,200 feet by 150 feet in its longer dimensions, while in the interior of the mass the porphyry is more or less impregnated with disseminated quartz-pyrite ore. A certain amount of tetrahedrite is found in both types of deposits, and each is rather richer in silver than the average ore of the district.

The Bonanza and Cobre Grande ores are impregnations of diorite porphyry and tuff by quartz-pyrite ore near the contact of the two rocks.

*Secondary enrichment* has played a rôle of varying importance in the different types of deposits, a difference which has been dependent on physical, rather than on chemical causes. It has been of the greatest importance in the Capote Basin deposits, where out of low grade quartz-pyrite ore, probably too poor to work under ordinary conditions, it has produced the richest ores of the district and those which on account of their great volume and ready accessibility have thus far yielded the greatest amount of copper. The reasons for the great enrichment have been, first, the greater permeability of the enclosing rocks through fracturing and brecciation; second the amount of clay resulting from their alteration, which would have retained the copper

from descending solutions by absorption, and third, the greater amount of overburden removed by denudation from which the enriching material was derived, which was due to their position near the axis of uplift, and further to the probability that this overburden carried rich deposits of copper ore, possibly of contact-metamorphic origin.

To the deposits in porphyry in the mesa region secondary enrichment has also been an important factor, but it has been less in amount and has not extended so deep as in the Capote Basin deposits. This difference may be accounted for by a lesser overburden removed, and the improbability of any contact-metamorphic deposits having existed in that overburden.

In the contact-metamorphic deposits in limestone, secondary enrichment below the zone of oxidation has been comparatively inconsiderable, probably because the garnet rock is tough and does not fracture readily. Chalcocite is found locally, generally in massive form, rather than as the silty sulphide-coating of pyrite which characterizes the porphyry deposits. It seems more abundant in the igneous contact deposits, but at the depths now reached it is not yet possible to determine its amount or extent.

As a whole the Cananea district presents a most interesting field for the study of deposits from mineral-bearing magmatic waters at high temperatures, a field which is constantly being enlarged under the well planned and vigorous system of underground exploration carried on by the present management. In a general way one can trace a change in the character of the deposits as distance from the probable central line increases and the depositing waters may be assumed to have come from lower levels.

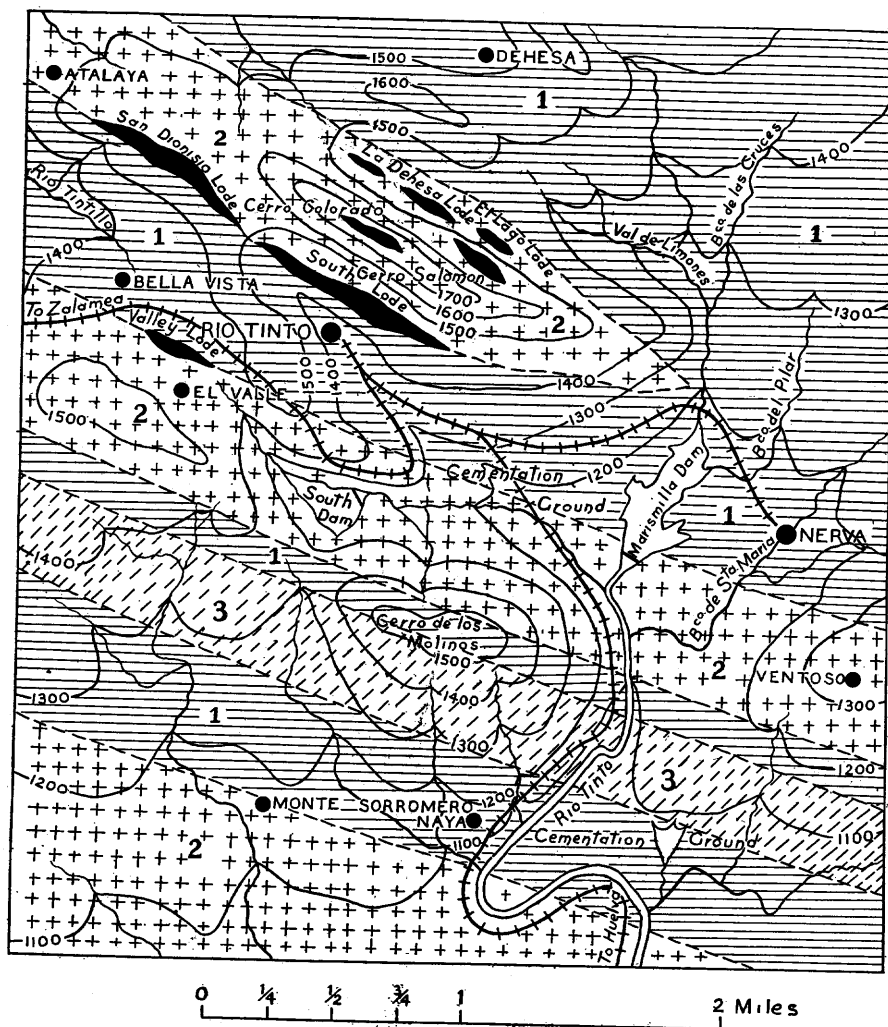
As contrasted with other districts where contact-metamorphic processes have been active, many of the differences are probably due to structural causes. Thus in the Clifton-Morenci district, as described by Lindgren, a second period of ore deposition by hydrothermal waters has likewise followed that of contact-metamorphic ores in limestone, but the veins in which the later deposits have formed are described as fissure veins having at

least one well-defined wall. At Cananea the character of the dynamic disturbance was not such as to form well defined fissures.

In both districts, however, deposition has been exclusively a metasomatic process, and in the porphyries adjoining the veins are aureoles of disseminated pyrites which are only payable when they have been enriched by a deposit of secondary chalcocite. On the other hand, the disseminated ores in porphyry, like those of Bingham and Ely, or in schists, like the Miami and Ray deposits, differ from the Capote Basin or Bonanza deposits mainly in that the fracturing has been so slight as only to admit of a general impregnation of wide areas of the country rock, and not of its concentration into considerable masses of ore. They were probably deposited from highly heated waters with great penetrative power, and at Cananea there still remain large areas of porphyry impregnated with pyrite that would probably pay to work, if they had been sufficiently enriched by chalcocite and the conditions were such as to admit of mining and concentrating on a large scale and at very low cost.

The following list includes all the articles on the geology of the Cananea district known to the writer. While these writings were consulted in preparing the present report, no specific reference to them has been made, as it seemed unnecessary where they agree with present determinations, and the differences may be readily explained by the inferior facilities possessed by the earlier observers.

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Geological Map of Rio Tinto. Contour interval 100 ft. 1 = Slates (Culm).  
2 = Porphyry. 3 = Diabase.