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THE VEINS OF CHAÑARCILLO,

CHILE.

by

Thesis

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Institute of Technology in partial fulfilment
of the requirements for the degree of Doctor
of Philosophy.

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C O N T E N T S

	Page
<u>INTRODUCTION</u>	1
The Silver Districts of Chile	
History of Chañarcillo	
Location	
Production	
Literature	
Scope of the present investigation	
Acknowledgements	
<u>THE REGION OF NORTH CHILE</u>	7
Introductory Statement	
Climate and Vegetation	
Topography	
General Geology	
Lower Jurassic Series	
Peñon Formation	
Middle Jurassic Series	
Loreto Formation	
Upper Jurassic Series	
Lower Cretaceous Series	
Chañarcillo Formation	
Tierra Amarilla Formation	

Copiapó Intrusives	
Structural Geology	
Physiography	
<u>THE CHAÑARCILLO DISTRICT.</u>	22
Introductory Statement	22
Stratigraphic Geology.	24
Chañarcillo Formation	
Descubridora Limestone	
Verde Tuff	
Negro Limestone	
Ahuesado Tuff	
Delirio Limestone	
Constancia Tuff	
Azul Limestone	
Segundo Tuff	
Igneous Geology.	31
Dike Rocks	
Los Carros Intrusive	
Structural Geology	34
Folds	
Veins Fractures	

	Page
Mineralization.	35
First Deposition	
Faulting	
Erosion	
Enrichment	
<u>THE VEINS.</u>	37
Direction and Loci of Veins	37
Introduction of history	
Direction and attitude	
Connection with folds	
The Fissures.	39
Origin	
Character	
Primary Mineralization.	45
Depth	
Stratigraphic position	
Character	
Factors affecting ore shoots	
Mineralogy	
Faulting.	58
First period	
Second period	

	Page
Erosion	59
Enrichment.	61
Depth	
Stratigraphic position	
Character	
Mineralogy	
Factors affecting ore shoots	
Oxidation	65
Stratigraphic position	
Depth	
Character	
Factors affecting ore shoots	
Mineralogy	
Chemistry of the Vein Processes	76
Economic Importance of Supergene Processes.	80
<u>THE FUTURE OF MINING IN THE DISTRICT</u>	83
<u>BIBLIOGRAPHY</u>	86

THE VEINS OF CHAÑARCILLO, CHILE.

INTRODUCTION

The barren deserts of the north, first seen by the early Spanish conquistadores of Chile, presented to them little of attraction. These adventurers, coming in the Sixteenth Century from the mountains of Peru and Bolivia in the search for gold, were greatly disappointed in the region of Atacama; but, upon finding gold in the rich veins of Malga-Malga at Quillota, of Madre de Dios at Valdivia and of Culacoya near Concepcion (I, pp. 21-26)⁽¹⁾, they settled in the fertile country of the south. Many years thus elapsed before careful prospectors, combing the northern deserts, were successful. Early in the Nineteenth Century, however, came the discovery there of deposits rich in the precious metals. Gold was found at Guanaco, at Cerro Blanco and in many other localities; silver was encountered at Huantajaya, Caracoles, Ladrillos, Tres Puntas, Arqueros and at Chañarcillo. The silver veins of these celebrated districts

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Numbers refer to the publications listed in the bibliography.

proved exceedingly rich in bonanza, and during their maximum exploitation, from about 1860 to 1880, Chile enjoyed a period of mining prosperity long to be remembered.

Of these districts that of Chañarcillo, situated 50 kilometers south of Copiapó at a position approximately of latitude S. $27^{\circ} 49'$ and of longitude W. $70^{\circ} 20'$, was richest and perhaps best known. After the discovery of its Veta Descubridora by the prospector Juan Godoy, during the period of the gold finds in California, the great richness of the superficial portions of the veins caused rapid development. Over one hundred claims varying in size from 1000 to about 50,000 square meters, were staked. The town of the district, Juan Godoy, crept up the lower slopes from the valley towards the mines, attained a population of ten thousand or more and was embellished by a plaza with substantial buildings of church, school and theatre. Good fortune continued through the Sixties and early Seventies. Mining, somewhat slow by the old methods of steep zigzag inclines, caminos, was improved by the driving of vertical shafts through which ore was hoisted in leathern buckets by horse whims, the familiar malacates. Hand methods of mining and drilling were used, and the ore was shipped out of the district without concentration; but the continuance of bonanza at depths of 300 to 400 meters assured the miner

of rich returns. With deeper exploration, however, results were disappointing. Lower grade ore was found at depths of 500 to 600 meters in the southern part of the district; but the methods of mining in use were not adapted to the extraction of such ore. Furthermore in lateral exploration in the southern mines faults carrying heavy flows of water were encountered. After ineffectual attempts at control by the introduction of pumping machinery, work ceased about 1885 and the deep connected mines of the district were flooded. A few tentative efforts have since been made to resume mining. Some ten years ago, the pumping equipment at the Constancia Mine again proved inadequate for the lowering of the water and more recent projects have been unsuccessful through a want of mining intelligence by their operators. Several mines not in the flooded area are now being worked and one find of high grade ore in the Bolaco Viejo Mine has of late attracted some attention in Chile; but at present the district on the whole is in a state of decay.

The visitor today after leaving the fertile valley of the Rio Copiapó at Pabellon and traversing the steep, tortuous wagon road or the more circuitous route of the railroad, finds at Chañarcillo a village almost deserted. Here at Juan Godoy, but 79 kilometers by excellent railroad

from the old city of Copiapó and 160 kilometers from the port of Caldera, is a town of ruins. A few only of the more optimistic remain awaiting the reopening of the great mines on the scarred mountain above the town.

The present production as might be expected under these conditions is almost nothing. In 1903 from 160 metric tons of fairly high grade ore were produced about 800,000 grams of silver (II, p. 109). Years during the decadence of the district after 1885 have probably witnessed little greater production than that of 1903. In 1885 one mine, the Manto de Ossa, produced silver valued at 1,000,000 pesos of 18 pence. In 1880 the Constancia Mine gave like returns. From 1869 - 1875 during the best days of Chañarcillo, 178,625 kilograms of fine silver was sold from the district, and the opinion is held by Chilean authorities that this amount was substantially greater due to "high grading" (III, p. 426-427). At this period, therefore, Chañarcillo was mining more than one-fifth of the silver production of Chile. The total production of the district is difficult of estimation; but some figures are available on the total production of certain mines. The Descubridora Mine produced the value of 40,000,000 pesos of 18 pence; the Manto de Peralta, 15,000,000; the Candelaria about 15,000,000 and the mines of the Corrida vein between 180,000,000 and 200,000,000

of pesos (III, p. 426). The total value of silver recovered from the mines of the district is thus about of the magnitude of 260,000,000 of pesos of 18 pence or of approximately \$100,000,000 United States. This sum at the price of silver for 1874, 112 pesos per kilogram (II, p. 24), would represent about 2,300,000 kilograms of fine silver. The fact that from 1860 to 1885 Chile produced a little less than 3,000,000 kilograms of fine silver and that her total production of silver for 210 years to 1902 was 7,988,186 kilograms (II, p. 22-23), makes vivid the preeminent part played by Chañarcillo in Chilean silver mining.

The fame of her rich mines during their prime spread far from the desert valley of Juan Godoy. Travellers from Sweden, from Germany, from England and from the United States paused to see the richness of her veins. Their published descriptions are manifold (See Bibliography) and their specimens of her ores are distributed widespread in the museums of the world.

Upon a collection of the ores of Chañarcillo in the laboratories of the Massachusetts Institute of Technology the present investigation was begun. The mineralogy was carefully studied in polished and thin section and conclusions regarding the origin of the ores were postulated. The opportunity, however, was presented during the summer

of 1917 to visit the district and at this time the earlier work was enlarged in scope and the field work was performed. The mines accessible were entered, the geology of the district and the surrounding region was studied and tentatively correlated with the results of other work done farther north and valuable maps and sections were copied.

During the progress of the investigation criticism, information and assistance were obtained from many sources. It is, indeed, a pleasure to acknowledge the kindly advice and supervision of Dr. Waldemar Lindgren and Dr. C. H. Warren of the Massachusetts Institute of Technology, and the invaluable information received from Señores Jerman Brain and Nicomedes Echegaray of Chañarcillo. Especial indebtedness is also felt for the many kind personal favors of Mr. Josias Rogers, of Copiapó, and for the able assistance in the field of Mr. L. C. Baena. The excellent publications upon the district by Señor Echegaray (IV, V) and by Dr. Fr. A. Moesta (VI) have proved at all times helpful.

THE REGION OF NORTH CHILE.

The important silver districts of Chile are distributed over a length of the narrow coastal strip of the country greater than 1000 kilometers in elongation. Huantajaya, 10 kilometers east of Iquique, and Caracoles, 150 kilometers northeast of Antofagasta, lie respectively about 800 and 450 kilometers north of Copiapó and are representative with such minor deposits, as Challacollo, of a northern silver belt. South of Caracoles is encountered a stretch of about 400 kilometers barren of rich silver veins. At Tres Puntas, 65 kilometers north of Copiapó, however, a southern silver belt begins, and continues through Ladrillos, 10 kilometers east of Copiapó, and Chañarcillo, to Arqueros and Condoriaco near Coquimbo and some 200 kilometers to the south. This region of North Chile, included between Coquimbo and Iquique, is that of primary importance in connection with the silver mining of the country.

The climate of the region varies little from north to south. From Iquique to a line between Chañaral and Taltal extends the barren desert of Atacama with its deposits of salt and nitrate. Precipitation here is slight, occurring perhaps annually in gentle showers, more often in deposition of dew from the fogs near the coast, but in heavy rainfall

only once in six to ten years. Vegetation is entirely absent and the surface is clothed in a mantle of sand and rock debris. South of this area and north of Copiapó lies a zone characterized by a climate much like that of the north but with a slightly greater rainfall. Vegetation though sparse is found in many of the quebradas or dry valleys. The valley of the Rio Copiapó is green and fertile due in great part to efficient irrigation; but to the south of the river the evidences of increasing precipitation abound. The steep valleys are dotted with shrubs, bushes and a few trees, while a sparse growth of shrubs and coarse grass is to be observed often upon the hillsides. Flowing streams other than the branches of the Copiapó in the mountains and that river itself are, however, absent, until, proceeding south, the Rio Huasco is reached and the rainfall towards Coquimbo becomes progressively greater. The region on the whole, however, is today essentially arid.

Due perhaps in great part to these climatic variations, topographically the region is divisible into three units. In the north the Coast Range rising precipitately from the sea to an altitude of 1200 to 2000 meters extends inland some 40 kilometers in a series of rough ranges. At the eastern flank of these mountains and a few hundred meters below the peaks lies at an elevation of 1000 to 1200 meters

the Interior or Central Valley. The valley, flat and rolling, descends to an enclosed centre of drainage and then to the east, through low hills east of Antofagasta and precipitously in the Iquique district, rises to the peaks of the Cordillera which attain a height of 3500 meters. Beyond a plateau east of these ranges, extends the chain of the high Andes from 5000 to 6750 meters in altitude. In the second topographic province extending from just south of Taltal to the Rio Copiapó, from the persistent range at the coast the slopes descend to a poorly defined continuation of the Interior Valley and then rise to broken ranges which mark the eastern boundary of Chile. These mountains drain not into an enclosed basin as in the north but by deep, well developed quebradas or dry rivers into the sea. In the third province the valley of the Rio Copiapó near the sea cuts through the continued Coast Range and turns abruptly through a right angle for a few kilometers into the prolongation, ill-defined, of the Central Valley. On the east of this north-south course of the river sharp ranges dissected by flowing streams rise abruptly to the Cordillera. About 50 kilometers south of the city of Copiapó, the river has swung to the east, branching into the mountains, and the Central Valley, relieved by a few low ranges of which Montana Chañarcillo is one, lies between high cuervas sloping gradu-

ally east and west. In this province the valleys, both dry and containing streams, are often steep walled cañons, the streams are swift and filled with rapids, and the relief is great.

The surface in this southern topographic province, though deeply dissected, does not, however, intersect the lowest rocks exposed in the region. This earliest horizon outcrops first to the north in the Taltal area. It is considered tentatively to be of Lower Jurassic age and from its excellent exposure on the Pampa Peñon has been named the Peñon formation. The Lower Peñon volcanics, ranging in composition from rhyolite to andesite, are made up of stratified tuffs, flows and breccias. They are separated from a similar series of the Upper Peñon by a thin stratum of limestone.

Conformably upon the Peñon formation lie a series of flows and clastic volcanic rocks principally of andesitic and basaltic composition. They have been provisionally placed in the Lower Jurassic and have been named in the Peñon district the Aeroplano formation.

These formations represent enormous volcanic activity of Jurassic time. They attain in the Province of Antofagasta a thickness of more than 1000 meters and their reds, browns and yellows lend color to the debris covering

the Central Valley and its lower slopes toward the Coast Range and the Cordillera from Taltal to Iquique.

On the Aeroplano effusive rocks lie without marked discordance limestones with intercalated tuffs. This, the Loreto formation, so-called from its observation upon the Pampa Loreto, carries abundant marine fossils. *Gryphaea* cf. *arcuata* and an ammonite somewhat allied to *Parkinsonia parkinsoni* have been thus far identified from these beds. The formation is correlated with the Dogger beds of Copiapó and is probably of Middle Jurassic age. In the north this unit is of less thickness than in the Cordillera near Copiapó; but it is distinctly developed throughout the region.

In Iquique the Loreto limestones outcrop at Huantajaya and in the eastern Coast Range. Farther south they continue on the eastern slope of this range and from Caracoles and Calama follow in a similar manner the west flank of the Cordillera. From Taltal to Chañaral they probably underlie much of the Central Valley.

South of Chañaral and continuing into the Province of Copiapó a series of volcanic beds are found; but at Chulo, east of Copiapó, another elongated area of limestones begins, passes through Chañarcillo and extends onward to the south. This limestone, the Chañarcillo formation, of Lower Cretaceous age, in the district of its more detailed study

has a proven thickness of 700 meters. Pure, shaly and tuffaceous limestones are interstratified with andesitic tuffs. This formation and that of the Loreto limestone, outcropping in the silver districts from Iquique to Coquimbo, seem to have been exceptionally favorable loci for the deposition of rich silver veins.

Cretaceous sandstones, conglomerates and shales with interbedded lavas succeed the limestones of the Chañarcillo formation; but in unknown relation to them regarding conformity. At Tierra Amarilla, these beds tentatively given the name Tierra Amarilla formation, are well shown in the cliffs above the Rio Copiapó. They form the cuestas east and west of Chañarcillo, the top of Cerro Blanco and some of the western part the mountainous country east of the Rio Copiapó. To the north, they make up the basement of a great part of the Coast Range. At Antofagasta conglomerate overlain by red shales and sandstone with intercalated green beds of lava compose a strikingly colored series. The Cretaceous sandstones and lavas are also found in the Cordillera.

Few of the beds of the Jura-Cretaceous series probably are free from volcanic debris. The lower section of the series is almost entirely composed of tuffs, breccias and flows. The middle sections, principally of limestones,

contain abundant interstratified effusives and the limestones themselves are often tuffaceous. The upper section again is of lavas and clastic sediments. Although the later deposition was characterized by sedimentation, volcanic activity has been greatly preponderant during this period.

Following the Cretaceous and affecting many parts of the region, came a period of deep-seated igneous activity. Great masses of magma were injected into the earth's crust. They tore and pushed their way upward until cooling they solidified as granites, granodiorites and diorites. Large areas of these intrusive rocks in the form of stocks and batholiths occur in the Cordillera and in the Coast Range near Copiapó and to the north. Smaller bodies cut the volcanics and limestones of the north and south Central Valley. These intrusive rocks have not been differentiated; they are grouped together as the Copiapó intrusives and are believed to be of essentially the same age.

Subsequent to the post-Cretaceous intrusions the region was affected by great compressive forces. The beds of the Jura-Cretaceous series in the Coast Range were tightly folded; in the Central Valley and in the foothills of the Cordillera they were more gently flexed; and in Cordillera they were plicated in steep folds and the granites and granodiorites were strongly jointed. At this time,

though later slight modifications have no doubt taken place, the main structural features of the region were developed.

At Iquique the folds are complex near the coast; but the dips appear generally to the west at the sea. The eastern part of the Coast Range here is made up of folded limestones and the Peñon volcanics below. The structure of this range, therefore, would seem to indicate that the range lies upon a fluted homocline with north-south trend and western dip. The section ⁽¹⁾ east of Antofagasta has been studied in somewhat greater detail than that of the Iquique Coast Range. At Antofagasta the dips of Cretaceous rocks are steep into the sea. Some 40 kilometers to the east, the folds of the Coast Range have died out and the strata are nearly horizontal. East of the Central Valley the gently folded rocks of the Peñon formation dip westerly, until, upon entering the Cordillera, steeply folded limestones and Cretaceous beds and strongly jointed intrusive rocks are encountered. The structure of this section is most clearly that of an anticlinal or great arch fluted with minor folds. In Taltal the Antofagasta anticlinal seems somewhat more poorly developed; but it is perhaps probable that this

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Observations on the geology of the northern region were made by the author during the examination of nitrate deposits.

structure, though flat, extends through Chañaral into the Department of Copiapó. The Central Valley south of the Rio Copiapó is situated along the axis of an anticline. This fold, narrow and steep at Chulo, broadens and flattens to the south. At Chañarcillo, it is about 30 to 50 kilometers in width. To the west the structure is obscure due to intrusive rocks; to the east in the Cordillera steep folds which expose the whole Jura-Cretaceous section probably obliterate the eastern dips of the arch to the north.

After the relief of the east-west compressive forces causing this folding, the great arches of the anticlines and anticlinals were unsupported. In many places they yielded, subsided and broke into a mass of blocks bounded by normal faults. Certain reverse faults of lesser importance are not to be assigned to this cause; but rather to the diastrophic forces. A greater number of the minor faults and all of the known faults of large displacement are, however, normal. In Antofagasta and Iquique great north-south faults bound the Central Valley which is a graben. Faults occur also at angles near 45° to the strike of folds. In Taltal and Chañaral, the Central Valley and thus perhaps its determinant faults are less well developed. In Copiapó, however, faulting is marked, as in the Chañarcillo district, and the faults of the Central Valley no doubt are

to be found. The age of this period of faulting is obscure; but is believed to be distinctly earlier than the recent formation of the great fault, the scarp of which determines the high cliffs on the coast from Arica to Coquimbo.

Mineralization occurred during the period of faulting. Solutions, no doubt derived from deep-lying igneous rocks, obtained access through fractures to the rocks now exposed at the surface. Veins were formed in the fissures; gold and copper being often deposited in volcanic rocks and silver in limestone. Alteration of rock took place near these fissures and in porous volcanic rocks, as tuffs and breccias, wide areas were strongly altered by the process of silicification. Though some mineralization doubtless took place by contact metamorphism during the intrusion of the igneous rocks, the important ore deposits as well as the economically worthless evidences of ore forming activity are due to this metallogenetic period.

The history of the region subsequent to the time of ore formation and faulting has been on the whole free from the cataclasmic geologic processes. Volcanoes have poured out their lavas in the range of the Andes; uplift has probably taken place; the great coastal fault has been formed; and earthquakes even yet give frequent evidence of the present slight movement upon fault planes, particularly upon

that of the coast; but the region has been subject mainly to the process of erosion. At this time, therefore, after that faulting which persisted later than the deposition of veins, the physiographic history of the region begins.

The chronology of erosion, however, can not be given in precise detail. Unfortunately time was not available for the widely conducted exploration necessary for exact physiographic research. In consequence the earlier history of erosion is somewhat obscure and the dates of the various events must remain at present indefinite.

In the northern part of the region, at present subjected to extremely arid erosion, evidence is to be found of a former cycle probably wet. The concordance of summit levels in the foothills of the Cordillera and in the Cordillera itself, benches observed high on the flanks of the Andes range and well rounded, water-worn boulders of numerous gravel deposits of the high benches of Taltal offer indication of an early topography probably developed by normal processes of erosion. This topography, perhaps that of a peneplain, it would seem must have been developed during Tertiary time.

Uplift having warped the inferred peneplain to an elevation to the east of from 4000 meters in the Andes and Cordillera to 2500 meters in the foothills, a dry climate,

possibly during late Tertiary or early Pleistocene time, was imposed upon the region. During the consequent arid erosion, the land throughout the region was dissected to an early mature stage. Though positive topographic results no doubt were persisting in the building up of the volcanoes of the Andes, erosion, principally by the agents of the intermittent streams, was predominant. Basins consequent upon the faulted graben of the Central Valley were formed. Subsequent quebradas or dry rivers became well adjusted to the geology of the region and are found following the axes of anticlines, the faults and the soft beds. The lower land was reduced to a rolling plane upon which rounded hills often were due to hard strata and intermediate valleys and enclosed basins were filled with debris. The higher land of the Cordillera has been dissected to a more accentuated relief, but one nevertheless distinctly mature. Everywhere great fans of polished, subangular fragments were spread out from the hills and mountains into the valleys.

On the north, from Iquique to Taltal the desert cycle still persists. Its peculiar topography is but slightly modified by a few recent faults cutting alluvial fans and by the great coastal fault intersecting it at the sea. From Taltal to the Rio Copiapó, however, dry channels intersect the arid topography and in the south of the region

it is preserved only on the upper slopes of the mountains.

Here, south of the Rio Copiapó, steep cañons tributary to broad alluvium-filled valleys cut these remnants of the older desert stage. Relief is great and stream capture of west draining valleys often takes place by the branches of the Rio Copiapó. The greater valleys, to some extent adjusted, have attained an early maturity and have been aggraded perhaps by a slight depression. The tributaries are typically young.

In the region, therefore, the physiographic history has probably included an early stage of normal wet erosion which proceeded nearly to peneplanation. Arid erosion, succeeding this stage, had reached the beginning of maturity throughout the region when in the south elevation and the imposition of a wetter climate caused the arid topography to be dissected to renewed youth. At present in the north the desert cycle persists; in the south slight depression has partly filled the main valleys.

THE REGION OF NORTH CHILEGEOLOGIC COLUMN

<u>RECENT</u>	Desert deposits, alluvium of greater valleys in Copiapó.
<u>TERTIARY</u>	Water worn bench gravels.
<u>POST CRETACEOUS</u>	<u>Copiapó intrusive rocks.</u> Granites, granodiorites and diorites.
<u>CRETACEOUS</u>	<u>Tierra Amarilla Formation.</u> Sandstones, conglomerates and shales (with gypsum). Interbedded lavas.
	<u>Chañarcillo Formation.</u> Limestones with interstratified tuffs and lavas.
<u>UPPER JURASSIC</u>	<u>Chañaral Formation.</u> Volcanic rocks.
<u>MIDDLE JURASSIC</u>	<u>Loreto Formation.</u> Limestones, interbedded volcanic rocks. Gryphaea cf. arcuata and Parkinsonia parkinsoni (?) at Pampa Loreto.
<u>LOWER JURASSIC</u>	<u>Aeroplano Formation.</u> Volcanic rocks of andesitic and basaltic composition, sediments.
	<u>Pefion Formation.</u> Tuffs, breccias and flows of rhyolitic and andesitic composition. A few beds of metamorphosed limestone.

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SECTION FROM COPIAPO INTO THE CORDILLERA

AGE	CHARACTER	CORRELATION; FORMATION	FOSSILS
Cretaceous	Gypsum beds (near Copiapó) Porphyries and tuffs	Tierra Amarilla	
Urgonian Middle Neocomian	Limestones at Chañarcillo	Chañarcillo	Crioceras emeric Acanthoceras angulicostatum Sphaerulites blumenbachi Trigonia transitoria
Lowermost Cretaceous Malm Upper Dogger	Porphyry and tuff	Chañaral	
Lower Dogger	Red and gray sandy limestone	Loreto	Harpoceras striatulum H. murchisonae H. sowerbyi Stephanoceras sauzei S. multiforme
Upper Lias	Porphyry and sandstone Limestone and sandstone (near Manflos) Red bed at top contains fossils	Aeroplano (?)	Hammatoceras insigne Cerithium armatum Trigonia pulchella Astarte volzii Brachiopods Gryphaeas Janira alata
Middle Lias	Limestone and sandstone		Gryphaea arcuata Spiriferina walcotti Turritella andium Janira alata Lingula metensis
Lower Lias (Perhaps Rhaetic)	Porphyries Conglomerate, sandstone, clays Thin beds of coal		Plant remains Baiera Dictyophyllum Zamites Silicified wood
Lias	Thick porphyries and tuffs Altered limestone Porphyries and tuffs Crystalline rocks (perhaps intrusive granites)	Peñon	Aricula substriata

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Section by G. Steinmann VII; VIII, p. 694.

THE CHAÑARCILLO DISTRICT

Introductory Statement

The Chañarcillo district is included in a portion, some 8000 square kilometers in area, of the southern part of the region of North Chile. This quadrangle (Plate VII), the Copiapó area, extending from about 30 kilometers south of Chañarcillo to a few kilometers north of Copiapó and from Chañarcillo 40 kilometers east and west, covers that section of the region of primary importance in connection with the broader geologic relations of the Chañarcillo veins. In it, as far as is known, are exposed at the surface rocks only of the Chañarcillo and Tierra Amarilla formations and of the post-Cretaceous intrusions.

These last occur in great bodies composing an igneous complex which invades the western Copiapó area. In this field, principally underlain by intrusive rocks, may be found in the future volcanic rocks of the pre-Chañarcillo beds. For the present, however, limited observation requires its characterization as an area of undifferentiated igneous rocks. In the eastern part of the area and certain central portions of indefinite extent, west of Tierra Amarilla and Juan Godoy are exposed the Tierra Amarilla sandstones cut by

a few intrusive bodies. From Chulo, Juan Godoy and to the south outcrop the Chañarcillo limestones. Another small area of these beds is to be found at a point represented in the southeast corner of the map of Plate VII. The Copiapó intrusions also intersect the limestones in masses of relatively small size ⁽¹⁾.

The intersection of the sedimentary beds with the surface is in accord with definite structural causes. The axis of a syncline in the Tierra Amarilla beds passes through Cerro Blanco and onward to the northeast. The area of the Chañarcillo limestone last described is upon the eastern limb of this syncline. From Chulo southeastward extends the axis of an anticline. At Chulo the limestones outcrop in almost vertical beds on this fold. At Tierra Amarillo the dips are flatter; the limestone and its cover of the beautifully exposed Tierra Amarilla sandstone lie at an inclination of some 30°. To the south of Pabellon the anticline is invaded by plutonic rocks and the structure is obscure; but about Chañarcillo it distinctly broadens and

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The geologic data of the area are obtained from personal observations by the writer and from the sections by Lorenzo Sundt, *Estudios Jeolojicos i Topograficos del Desierto i Puna de Atacama*, Vol. 1, Santiago de Chile, 1909.

the dips upon its limbs are perhaps 20°. The fold thus, in spite of its narrowing to the north, probably pitches to the southward throughout its length.

Stratigraphic Geology

The Chanarcillo district, a rectangular area of about 2.5 kilometers north-south elongation and of 1.6 kilometers width upon the hills above the town of Juan Godoy, is intersected by the axis of this anticline. The beds thus have gentle dips and in the section of some 800 meters to be observed at the surface and in the mines are all of the Chanarcillo formations. Igneous rocks occur in the form of numerous dikes and of a small stock; but are of distinctly subsidiary importance. A consideration of the geology of the district is, therefore, principally concerned with the Chañarcillo formation.

The formation is made up of alternating beds of pure or impure limestone and of volcanic rocks. The limestones vary somewhat in appearance; but they are usually well bedded in strata a few centimeters to half a meter in thickness and when weathered to a buff or light brown color at the surface form a striking contrast to the volcanic rocks.

The latter at the surface are medium grained with a distinctly tuffaceous texture. Their color is green to black, and the cliffs composed of them are dark and irregularly rough. In the mines certain of the lower horizons of volcanic beds are fine grained and of a gray color difficult of distinction from the limestones. The variations in the physical characteristics of the beds have been, however, quite apparent to the keen perception of the Chilean miner and his subdivisions, the panizos or beds, have often coincided with those of the geologist. Indeed the names of the eight members into which the formation has been divided⁽¹⁾ have in several cases been taken from the names of these beds customary to the miners in the district.

The uppermost of these members has been named, from its outcrop in the prominent cliffs above the Descubridora Mine, the Descubridora limestone. This member subdivided by the miners into many "mantos" is a distinct unit. At the top of brecciated texture, it grades below into chalky limestone and penetrated farther becomes dark colored and carbonaceous. At the bottom of its 190 meters of thickness it is a pure gray limestone.

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The excellent descriptive sections of Dr. Fr. A. Moesta and Señor N. Echegaray have been of great value as a basis for the subdivision of the formation.

The tops of the higher peaks of the district are composed of this limestone. It persists upon the slopes of the hills downward to an elevation of 1000 to 1030 meters to the northeast and of about 950 meters to the southwest. Its well bedded strata of some 50 centimeters thickness, its buff, white or gray color, and its rounded outcrops lend a characteristic appearance to the summits of the mountain of Chañarcillo.

Microscopically the typical Descubridora limestone is seen to be composed predominantly of fine crystals of pure calcite. A few coarse crystals of this mineral are sparsely disseminated throughout, and narrow veinlets of calcite penetrate the rock. Interstitially to the calcite grains of quartz with ragged outline are of usual occurrence. They contain empty inclusions and a few shreds of calcite. More rarely laths of altered feldspar are to be observed. The rock is distinctly a pure, fine-grained limestone which has been subjected to no, or very slight, alteration.

Below the Descubridora limestone lies a tuff, known as the "Panizo Verde" by the miners, and for this reason called the Verde tuff. This member outcrops on the lower slopes of the mountain and determines the dark, rugged cliffs of the lower slopes. It is coarse grained, of

distinctly tuffaceous appearance and is dark green in color. The thickness is variable, ranging from 30 to a rare 140 meters; but averages perhaps 50 meters. This rock with the Descubridora limestone underlies the greater part of the surface of the district.

The Verde tuff, under the microscope, is found to be composed of rounded and subangular grains of altered volcanic rock. The greater part of these grains are of such fine texture that their component minerals can not be resolved by the microscope. In others chlorite and actinolite have replaced former minute phenocrysts of ferromagnesian minerals imbedded in a fine groundmass. A few grains have a coarse texture and in these plagioclase feldspar in many laths is strongly altered to chloritic material. The feldspar probably is albite. Many areas of a ferromagnesian mineral are replaced by actinolite. Indeed the rounded fragments are almost completely altered and are cemented by calcite and actinolite. In spite of the altered character of this tuff, it is believed its original composition was andesitic.

The Negro limestone, "Panizo Negro y Cenizo" of the Chileans, is found below the Verde tuff. This bed, composed of black shaly appearing limestone with intercalated strata of chalk and of fine breccia, varies in thickness

from 25 to 65 meters. It is intersected by the surface in the southeastern and southwestern corners of the district only; but is found in all of the mines.

The chalky strata of this rock are composed of pure CaCO_3 . Under the microscope the black beds characteristic of the member are resolved into a fine-grained mass of interlocking feldspar and calcite crystals with a few small disseminated areas of pyrite. The feldspar evidently as in the Verde tuff originally albite is seemingly replaced in part by calcite. Calcite surrounds and penetrates the laths of plagioclase and is the predominant mineral of the rock. Actinolite of a nearly colorless variety is a common constituent. The breccia is of fine texture similar to that of the Verde tuff. Rounded and subangular grains of fine volcanic rock are cemented by coarsely crystalline calcite. The grains themselves are also filled with crystals of calcite and more rarely of actinolite. Alteration of the feldspar of the volcanic fragments to these minerals has no doubt taken place. This rock, while typically an impure limestone, is thus not shaly but tuffaceous and has certainly been at least in part of volcanic origin.

The Negro limestone is underlain by a thick bed of a fine textured, gray-green rock, the Panizo Ahuesado.

This member is recognized in nearly all of the mines and varies in thickness from 120 to 165 meters. At a distance of some 40 to 50 meters below its top it is interrupted by the thin stratum of the Bocano limestone. It is of such fine-grained texture, and of such obscure color that except for its tough break its recognition underground would be of extreme difficulty. The massive beds of the Ahuesado are easily separated from the black limestones above; but are indefinite in their contact with the succession below.

The Ahuesado may be recognized, under the microscope, as a tuff. Coarser beds near the bottom of the member in the Santa Rita Mine appear much like the Verde tuff. Rounded grains of an almost submicroscopically textured volcanic rock are cemented by calcite and shreds of actinolite. The typical rock, however, is composed of rounded, evidently abraded, crystals of feldspar, of a large amount of calcite accompanied by actinolite, and of a few laths of epidote (Pistacite). The Ahuesado tuff, as is the case with the other volcanic rocks of the district, has been severely altered.

The downward succession is continued by a thin bedded limestone containing alternating pure and impure strata. It attains a thickness of 120 to 150 meters in the

Delirio and Constancia mines. This, the Delirio limestone, resembles in all respects the limestones of the upper sequence. The purer layers are of calcite; the shaly-appearing strata are tuffaceous.

A second bed of fine tuff about 30 meters thick occurs next in the series. The Constancia tuff, as it has been called, is of a character similar to that of the Ahuesado.

Persisting for some 70 meters below this tuff, is a blue-gray limestone, the Panizo Azul of the Delirio Mine. This member is a massive and impure limestone.

The sequence clearly exposed in the mines is closed below by a bed of character nearly identical with the Verde tuff. It has been named by the miners the Segundo Panizo Verde. The Segundo tuff, as it will be called, is at least 70 meters in thickness. It is believed that this member has not been passed in deep exploration; although an indefinite report states (III, p. 426) that on the lowest level of the Delirio shaft a limestone carrying ore had been found below the Segundo tuff.

The Chañarcillo formation is thus made up of beds, varying in thickness from 25 to 190 meters, and composed of alternating tuff and limestone. The tuffs are altered, range from exceedingly fine texture to coarsely fragmentary

character, and were probably of original andesitic composition. The limestones contain impure, tuffaceous and altered strata at the bottom of the formation; but the uppermost member, the Descubridora limestone, is on the whole of unimpaired purity. The formation attains a maximum thickness of 880 meters.

Igneous Geology

At a time indefinitely later than the deposition of the Descubridora limestone, intrusive igneous activity began in the district. Many dikes were injected into the rocks of the Chañarcillo formation and are at present found in the mines and outcropping on the surface. Their strike is prevailingly southeast, their thickness varies from one to three or four meters, and their attitude is near the vertical.

The dike rocks are highly altered. Calcite occurs abundantly throughout the groundmass and the phenocrysts, originally no doubt of plagioclase feldspar. Unaltered feldspar has not been seen in these rocks. Aggregates of interlocking quartz grains and a few crystals ^{of} holohedral outline are imbedded in the groundmass. Chlorite, sericite, and actinolite are of rare occurrence. Calcite and some

quartz have certainly been introduced during the alteration and their presence renders the classification of the rock difficult. The dikes can, therefore, only be called altered porphyries possibly of original dioritic or tonalitic composition.

Igneous activity in the district was closed, at a time probably considerably later than the injection of the dikes, by the intrusion of a small stock just east of the town of Juan Godoy. This rock outcrops in a small area, perhaps 200 meters across, on Cerro de los Carros. The rock has been so severely altered that little of its original texture is to be seen. The specimens have a dull gray vitreous appearance, and little of composition or mineral characteristics can be determined megascopically. Under the microscope, however, it is seen to be of fairly coarse texture, the crystals varying in size to a maximum diameter of several millimeters. Of its original constituent minerals, andesine feldspar alone remains in large, typically twinned crystals. Diopside in coarse grained crystals, showing the characteristic twinning, occurs in ill-defined veinlets and irregular areas and no doubt replaces both the feldspar and some ferromagnesian mineral now quite altered. Associated with diopside are wollastonite, a few grains of epidote and

a fibrous mineral, perhaps a serpentine, but of indeterminate character. A later stage of the alteration has introduced a mineral in elongated, interlocking, colorless crystals with bent forms and undulatory extinction. It has positive optical character, negative elongation, an index of refraction about 1.60 to 1.62, low birefringence (0.012 - 0.015) and parallel extinction. It is biaxial with an optic angle ($2E$) about 50° , the axial plane appears to be perpendicular to the cleavage; but the optic axis emerges in sections showing no cleavage. The identity of this mineral is uncertain, for its characteristics do not seem to agree with any known species. It replaces both the earlier pyroxene and the feldspar.

The composition of this igneous rock is peculiar. Its alteration, however, seems certainly of a contact metamorphic nature and, in all probability, after its consolidation near the upper contact of the stock, hot solutions of igneous origin penetrated it under high pressure from below. Lime may have been introduced; the rock appears to be abnormally high in this component. Iron was most certainly removed. Many of the minerals were entirely replaced by those stable under contact metamorphic conditions and the rock was changed to its present character.

Structural Geology

During and probably persisting after this period of igneous activity, the rocks of the district were subjected to compression. The anticline whose limbs dip east and west of Chañarcillo was formed. In the district itself which lies upon the axis of this fold the rocks have but gentle inclination. Their folding, though slight, is, however, believed to be of great structural importance.

The flat apex of the anticline is represented in the Chañarcillo district by a bifurcating fold with a maximum dip at the eastern and western extremities of the district (Plate I) of about 5°. At the northern end of the area the fold is single, its apex falls upon the claim of the Manto de Ossa Mine and continues to the northeast. From the Manto de Ossa southward this anticline parts. One slight flexure, an anticline, passes through the claims of the Colorado, Desempeno, San Francisco, Delirio and Constancia Mines. Another similar fold extends due south from the Descubridora Mine. A shallow syncline separates these anticlines. East and west of these flat folds the dips increase gradually to their maximum. The folding, therefore, has been gentle but complex upon the apex of the great anticline; but upon the limbs has been steep and essentially simple.

Probably in genetic connection with this folding, the vein fractures were formed. They strike predominantly parallel to the major axis of folding and dip steeply near the axial plane. A few are to be found, however, at an angle near 45° to the strike of the axis. The fractures were manifold, at least 20 in number, they were imbricating and discontinuous often locally; but they no doubt extended to great depths and were open.

Mineralization

Next penetrating them came vein forming solutions of indefinite but probably igneous origin. Veins were deposited varying in width from 25 centimeters to one meter, and containing calcite, barite, quartz, siderite, arsenopyrite, zincblende, pyrite and many arsenides, sulpharsenides and sulphantimonides of silver. Ore shoots in places rich in silver were formed and, before the end of this single, and perhaps short, metallogenetic epoch, the primary or hypogene veins of the district had been produced.

After a period of faulting, during which the strata and the veins were dislocated by one normal fault of marked displacement and by several small faults of essentially

lateral displacement, the rocks of the district have been affected principally by the process of erosion. During this wearing down of the surface from its former inferred position to that of the present day many constituents of the veins have been dissolved, have been carried downward into the veins, reopened in part by the movements of faulting, and have been precipitated. This process, repeated again and again, has produced rich bodies of ore. In the upper portion of the veins, in the oxidized zone, chlorides, iodides and bromides of silver, native silver and dyscrasite have been deposited. Below in the enriched zone native silver, dyscrasite, argentite, stephanite and other sulphides have been precipitated. The veins in both zones have been widened in places to a rare 10 meters. This process, that of oxidation and enrichment by supergene solutions of atmospheric origin, has been the cause of the great bodies of bonanza ore of Chañarcillo.

THE VEINS

Direction and Loci of Veins

The history of the veins of Chañarcillo is to be read only during the late geologic events inferred for the district. The deposition of sediments, the effusion of lavas, the injection of dikes into the strata and the intrusion of plutonic bodies of igneous rocks have all preceded the formation of the veins. The results of these pre-vein processes have in many cases exerted marked influence upon deposition of the veins; but their effects have been mainly those always produced by the environment into which vein-forming solutions are brought. The vein history itself is introduced after the close of igneous activity at the horizon of the present surface of the district and was also preceded by the period of folding.

The connection between the direction of the veins and the axes of folding is striking. Of these axes, that of the more persistent anticline strikes N. 25° E., and that of a minor divergent anticline branches from the main fold on the Descubridora claim and strikes directly south. Ten of the twenty-four veins recognized in the district have a direction parallel to these axes. Six lie parallel to the

major fold; four strike with the minor flexure. These ten veins include all but one of the great continuous veins of the district and have no doubt produced considerably more than 70 per cent of the silver mined at Chañarcillo. The other veins, nine in number, have a strike at about 40° to the major axis of folding. Three, at $N. 65^\circ E.$, of which the Veta Candelaria is one, are veins of some importance; six, at $N. 15^\circ W.$, are poor. Two curved branches of the Corrida Colorada seem each to be composed of joined veins of these 40° systems at about 90° one to the other. A third curved vein, the Guias del Descubridora, branches from the Veta Descubridora at the north, follows it for several hundred meters, tends toward the $N. 65^\circ E.$ strike, and finally to the south dies out in the trough of the shallow syncline between the greater and less anticline. Two barren veins, at $N. 50^\circ W.$ and $N. 55^\circ W.$ in the northern part of the district, are of obscure directional relations. The greater number of veins, about 90 per cent indeed, however, may be said to have a direction parallel to an axis of folding or at about 40° to such an axis.

Moreover, the character of the vein seems to vary with its position with regard to the folding axis. The richest vein of Chañarcillo, and the one also continuous

over a distance of more than two kilometers lies directly upon the crest of the greater anticline. This, the Corrida Colorada, has been the great vein of Chañarcillo. The Veta Descubridora, a rich producer, is upon the axis of the minor, divergent anticline. Away from the axes of the folds the veins parallel to them grow less continuous and poorer. Among the veins at 40° to the anticlinal axes but one, the Veta Candelaria, is rich, and it attains its best development upon the crest of the two folds at their junction. The dips of all veins are steep to the west or northwest. The stronger, more continuous veins thus lie near the axial planes of the folds, those weaker and of short extension are upon the limbs.

The Fissures

From such considerations a genetic relation of the vein fractures to folding is to be inferred. The mechanics of the formation of mineralized fissures, however, has always proved to be a difficult and obscure subject. In many cases the rocks are of a nature or the alteration is so severe to give the geologist no precise index of folding, and the literature is thus deficient in the treatment of

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fracture origin in mining districts. Willis , however, while not discussing the feature, has illustrated fractures, or small faults, near the axial plane of anticline in competent strata. The unpublished results of A. R. Whitman and of the author in the Cobalt District, Ontario, also give excellent proof of the genetic connection of folds and vein fractures. The veins of Chañarcillo seem to offer further indication of this mode of origin of vein fissures.

An origin of the fractures during folding postulates the upbending of the anticlinal arches and the subjection of the competent strata of limestone and tuff to tensional forces near the axes of the folds. Fractures of great continuity would form under these conditions upon the axes; parallel to them minor fractures would occur. Furthermore, the forces of compression, which produced the folds, are in a direction of about 90° to the axes of folding. Such forces are often known to cause fractures or joints in rocks at an angle near 45° to their direction as diagonals of an

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Willis, Bailey Mechanics of Appalachian Structure:
U. S. Geological Survey, Thirteenth
Annual Report, Pt. II, p. 217, Plate
LXXVI and following.

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ellipsoid of strain . As the stress and the consequent strain upon the rock increases, the ellipsoid becomes flatter, the diagonal planes are changed and the angles between the planes of fracturing and the directions of force become greater. Thus the systems of vein fractures at 40° to the axes of the folds are easily explicable and indicate an ellipsoid of strain but slightly changed from the undeformed sphere.

The facts of the field seem to agree with such an hypothesis of fracture origin. Few of the veins lie in a direction in disagreement to this explanation. The veins of the Dolores Tercera and the Loreto Fifth have a north-south strike, but are far removed from the fold of this direction. The two barren veins of the northern part of the district, those crossing the claims of the Bolaco Nuevo, Manto de Ossa and the Manto Peralta, and of the Bolaco Nuevo, Esperanza and Descubridora respectively, are also of direction obscure in its connection with folding. Such exceptions are, however, rare and include only four minor veins out of the total of twenty-four. The others, constituting more than 80 per cent of the number and all of the more continuous

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Becker, G.F. Finite Homogeneous Strain, Flow and Rupture of Rocks: Bull. Geol.Soc.America, Vol. 4, pp. 13-90, 1893.

rich veins, fill fractures of which it may be stated with some confidence that their origin is due to the forces producing folding.

VEINS APPROXIMATELY N. 25° E.

- 1 Corrida Colorada
- 2 Guias de Carvallo
- 3 Veta Esperanza
- 4 Veta Mercedes
- 5 Veta Loreto 1a
- 6 Veta Loreto 2a

VEINS APPROXIMATELY N. - S.

- 7 Veta Descubridora
- 8 Guias del Manto de Ossa
- 9 Veta Dolores Tercera
- 10 Veta Loreto 5a

VEINS APPROXIMATELY N. 65° E.

- 11 Veta Candelaria
- 12 Veta Bolsa
- 13 Veta Nuevo Bolaco

VEINS APPROXIMATELY N. 15° W.

- 14 Veta Loreto 3a
- 15 Veta Loreto 4a
- 16 Veta Atravieso
- 17 Veta Chacabuco
- 18 Veta Desempeno
- 19 Veta Yungai

VEINS CURVED (BOTH N. 65° E. AND N. 15° W.)

- 20 Veta Forastera (branch)
- 21 Guias de Colorada (branch)
- 22 Guias del Descubridora

VEINS APPROXIMATELY N. 55° W.

23-24 Two barren veins of the northern district

These may be of later formation and
connected with faults at N. 55° W. (see p.58)

The vein fissures thus fall in two groups, that of the axial fissures and that of the fissures at 40° to the axes of folds or the shear fissures. The axial fractures probably produced by tensional stress were doubtless open certainly in places to a width of 25 centimeters and perhaps locally to a width of one meter. Movement occurred upon them as evidenced by the gouge usually upon the footwall; but this movement slight in extent does not indicate their classification as faults. The shear fractures, also loci of small displacements, similarly were open fissures; but the character of their origin suggests that the openings upon them were generally narrower than upon fissures of the former class. The Candelaria fracture, however, must have been a wide fissure and here the factor of bending may have been operative. Upon all fractures the hanging wall appears to have been broken by innumerable imbricating cracks and fissures. Indeed upon the Corrida Colorada a fracture parallel to the main fissure in its hanging wall was continuous over a great distance. The footwall has been usually unbroken, however, and is in many places polished, slickensided and covered by gouge.

The Primary Mineralization

The primary mineralization was produced by solutions which penetrated this network, perhaps immediately upon its opening. They no doubt came from below, were hot possibly of a temperature of 150° C. to 300° C., and were under high pressure. Their origin, as is often the case with vein-forming solutions, is obscure; but the contact metamorphism of Los Carros diorite is significant in this connection. This type of alteration of the intrusive strongly indicates in the light of the present knowledge of contact metamorphic processes that the igneous rocks injected below the present surface of the district gave off emanations charged with soda, lime, silica, water and other volatile substances. These emanations at high temperature and under great pressure altered the contacts of the intrusion from the deeper core of which they were derived and undoubtedly continued onward to impose similar metamorphism upon the surrounding limestone. A few crystals of albite feldspar replacing limestone near bedding planes is the only evidence of this latter process obtained in the field. Los Carros intrusion is not, however, believed to be the immediate origin of the vein solutions of Chafarcillo; but from the nature of plutonic igneous activity in the region strong

probability exists that similar intrusions lie at greater or less depths below the zone penetrated by the mines. Los Carros stock is merely a cupola of a deeper intrusion which undoubtedly had other excrescences. From these points, loci of concentration perhaps of the igneous emanations of the cooling magma below them, solutions perhaps rose and, after producing in all probability contact metamorphism of a nature comparable to that noted at the present surface, penetrated under great pressure all openings offered them. Fissures presented an excellent mode of egress and, as the mineral-laden waters progressed upward along the fractures in the cooler rocks deposition took place. The Chañarcillo fissures were of a nature to become such channels, the presence below of the magma parent to the solutions is strongly indicated and it is believed the vein-forming solutions of the district had such an igneous origin.

The solutions, whatever their source, introduced the mineralization of the Chañarcillo veins. During the period of their access to the fractures the fissures were filled and the wall rocks were replaced in part by the minerals of the primary or hypogene mineralization.

Veins representative of this stage alone are rare in the district. Almost invariably the primary ore has been subjected to some supergene alteration; but many important

ore shoots are predominantly composed of hypogene ore. Such ore bodies lie at an appreciable depth below the surface. In the northern district extending southward to the Bocona property on the Corrida Colorada the depth of ore predominantly primary varies from 200 to 350 meters. South of this point in the San Francisco and Dolores Primera mines it is found some 450 to 500 meters in depth. The Delirio and Constancia mines have encountered such ore at about 400 meters. As few mines of the district have reached a depth of 500 meters, evidently little primary ore has been extracted at Chañarcillo.

The depth at which this type of ore occurs is intimately related to the stratigraphy of the sedimentary rocks. In fact the statement is accurate that primary ore is to be found in the third limestone bed below the surface. Thus in the northern district, defined as above, this ore is met in depth first in the Delirio limestone. In the southern area at the depths noted it was developed in the lowest Delirio limestone and in the Azul limestone.

The veins of primary character found in these positions are usually somewhat narrower than on the levels above. They vary in width considerably, of course, but when minable are usually from 25 centimeters to one meter wide.

These widths are continuous laterally along the dip of the limestone strata often for 100 meters or more; but vertical changes in the width of the primary veins are sudden. A narrow cleft hardly traceable in the tuffs commonly broadens upon entering a limestone bed (panizo) and often attains a thickness of 75 to 100 centimeters upon penetrating a pure stratum (manto) of this bed. The stopes of rich ore at the horizons unaffected by superficial processes thus are usually narrow and low-backed (2-10 meters) but extend laterally often appreciable distances.

Two types of these primary veins are recognized in the district. They are composed of similar gangue minerals, calcite, siderite, barite and quartz. The first and less important type of the copper veins, however, contains more siderite. Accompanying the gangue in these veins are chalcopyrite, tetrahedrite, zincblende, galena, pyrite, arsenopyrite, and traces of the sulpharsenides and sulphantimonides of silver. The copper veins are narrow, lie in fissures striking about N. 15° W. and are found best developed in the Veta Atravieso and its neighbors in the southern area. The second type and that of which the rich silver veins of the district are representative differs from the first mainly in the quantitative relation of its component minerals. In the silver veins, with a gangue of calcite, barite and a little

siderite and quartz, small amounts of pyrite, galena, chalcopyrite and tetrahedrite occur. Zincblende and arsenopyrite are abundant constituents, however, and the silver minerals, pearceite, proustite, polybasite, pyrargyrite and perhaps miargyrite are in many places present in marked quantity. The usual narrow vein of this type in tuff or impure limestone, nevertheless, contains only calcite, barite and quartz with a sparse sprinkling of minute sulphide grains. Only upon its entering the purer limestone strata and upon its widening, do the sulphides of the base metals and their more complex accompanying silver compounds enter the vein. Here beside a vein of one to two meters thickness the hanging wall is often penetrated by many interlacing rich veinlets. In places ore is found away from the vein to several meters. The second vein, narrow but rich, characteristic of the hanging wall of the Corrida Colorado also is confined to these horizons. Rich ore, therefore, often extends into the hanging wall in limestone; but the footwall is polished, covered with clay-like gouge and is barren.

Such relations prove a definite and important effect upon the localization of ore shoots by pure beds of limestone. This feature is well illustrated by the section of the Constancia Mine (Plate IV). All of the primary ore of

Chañarcillo is contained in limestones and the better bodies of such ore are in the purer strata of the limestone. Of but little less efficacy in the determination of ore shoots are the intersections of veins. The rich zone of the northern district from the Candelaria and Manto Peralta properties, through the Descubridora, Esperanza, Colorada and Loreto claims appears to be connected with the cross-cutting Veta Candelaria. At its immediate crossing with the Veta Descubridora and the Corrida Colorada bodies of extreme richness were encountered. These pipe-like chimneys of high grade ore were called "bolsos" or pillows by the miners. Other vein intersections show similar effects, as in the case of the crossing of the Veta Descubridora and the Guias del Descubridora, of the various Loreto veins and of the branches of the Corrida. Dikes have also affected the concentrations of ore. Fractured somewhat during the folding, they seem to have offered channels subsidiary to those of the veins for the circulation of solutions. Their strong alteration and their mineralization offer proof of the passage of solutions. Where they are closely spaced as in the centre of the district near the Colorada Mine and where they have branched near veins they have probably been of importance in the mineralization of the veins. The fact that several of the better ore-producing areas are each upon a wedge shaped

block bounded by dikes dipping away from the area suggests the possibility of concentration of vein solutions in the blocks by the dikes. The effect of dikes at their immediate crossing with veins is obscured by the unfavorable composition of their rocks, as with the tuffs, for the precipitation of the silver minerals. The folds have been important factors determinant of ore shoots. This fact is evident from the discussion of the origin of the fissures. The bedding may, however, have served also to deflect rising solutions into the crests of the anticlinal arches. The cause of the difference in character between the ore shoots of the copper veins and those of the silver veins is a difficult matter. These copper or "atravieso" veins, however, approach more nearly than others Los Carros intrusion and, indeed, penetrate its zone of contact metamorphism. This fact is suggestive of a more intimate relation between the Los Carros igneous body and the copper veins than between it and the silver veins. The presence of copper in the inner and more intense zones of mineralization and of silver in the outer zones is characteristic of many mining districts. The copper veins of Chañarcillo are perhaps indicative of similar relations of intensity of mineralization.

Thus, while certain veins at about the strike N. 15° W. may contain predominant copper minerals due to

their proximity to an igneous body, the silver veins are not affected by this influence in known horizons. The parts of these veins carrying high concentrations of silver, however, appear to be due to definite causal factors. To reiterate, these factors effecting precipitation of silver minerals are (1) purer limestone strata, (2) intersections of veins or fissures, (3) intersections of dikes, of dikes and veins, and perhaps proximity of dikes to veins, and (4) the position of veins with regard to the axes of folds. Where one of these factors has been favorable, ore shoots have formed. Where more than one has been in a fortuitous combination, exceedingly rich masses of silver minerals are encountered in the vein.

In this primary ore, the mineralogic relations are of great interest. Finely crystalline calcite or platy barite composes the greater part of the vein material. In many places the two are admixed. Cavities are of usual occurrence in the vein and vary in size from the common few millimeters of diameter to those of a centimeter opening. They are seen with a hand lense to contain crystalline coatings of calcite, of quartz and silver sulpho-salts. Scattered throughout the gangue are small grains or more rarely massive aggregates of the metallic minerals. Zinc-blende may rarely be observed in disseminated grains. Arseno-

pyrite in interlacing crystals, in solid aggregates, and in hollow spheroidal forms is an ever present constituent. Ruby silver, pearceite and polybasite lie in the gangue in sharply outlined grains and masses, many of which are angular in shape and a few of which are of feathery margin. The gangue is in places banded with these grains; in places the sulphides are evenly disseminated, and elsewhere clean gangue is in serrated contact with massive sulphide.

Though such megascopic relations are of indefinite interpretation, under the microscope a sequence of mineral deposition is clearly to be observed. Calcite the first mineral to be precipitated in the veins is replaced by holohedral crystals of barite. Laths of barite penetrate coarsely crystalline aggregates of calcite grains regardless of contacts or structure. Where this replacement has reached a more complete stage masses of interlacing barite crystals are seen with residual calcite included. Quartz accompanied the barite and in aggregates of coarsely grained interlocking crystals occupies areas between laths of this mineral. The deposition of calcite and its replacement in this manner by barite and subordinate quantities of quartz comprised the first stage of primary mineralization.

The next stage, succeeding the first probably by an inappreciable interval, consisted of the precipitation of

sulphides. Zincblende filled certain cavities but more often replaced calcite in irregular areas along crystal boundaries. It was accompanied by ruby silver (proustite) which occurs in the blende in small irregular blebs. Galena, pyrite and chalcopyrite are rare components of the silver veins; but where they have been observed in polished sections they are seen to be intergrown with zincblende in an irregular manner typical of contemporaneity. This stage of the primary deposition, though characterized by the precipitation of traces of proustite, is on the whole a period of the formation of sulphides of the base metals.

Arsenopyrite in great quantity was introduced into the veins next in the succession. It was precipitated in cavities, usually but partly filling them. It replaced calcite along crystal contacts and along cleavage lines. Its acicular crystals commonly penetrate zincblende and veinlets of arsenopyrite cut the latter mineral. Ruby silver again was deposited in small amounts; and quartz was precipitated. This quartz is to be observed in microcrystalline masses replacing calcite and barite in halos about the arsenopyrite. It also is developed in holohedral crystals and fine aggregates along the contacts of calcite and barite and replaces both of these minerals. This stage, the third of the sequence, is again a predominantly barren mineralization

typified by the introduction first in great amounts into the veins of iron and of arsenic.

Arsenical minerals continued to characterize the early part of the fourth stage. Pearceite and proustite completed the filling of cavities partly occupied by arsenopyrite. They are to be seen in many places in vugs lying in the interstices of acicular arsenopyrite crystals. They also are deposited upon calcite in vugs and usually completely fill the openings. Replacement of gangue, principally of calcite, by these minerals occurred but was of subordinate importance to their filling of open spaces. Late in the fourth stage, antimony-bearing minerals appeared. Tetrahedrite, often of the variety freibergite, is found replacing calcite around the contacts of arsenopyrite crystals. Polybasite replaced the margins of pearceite grains; pyrargyrite affected similarly masses of proustite. Vugs were also filled by polybasite and pyrargyrite and small blebs of pearceite and proustite in the antimony minerals testify to the fact that locally the arsenical silver compounds were still stable. Replacement of calcite by veinlets and areas of polybasite and pyrargyrite is a feature commonly observed. Thus this fourth and last stage of the primary mineralization began with predominant open filling by arsenical silver compounds and closed with replacement by

antimonial silver sulphides. From (1) the character of the open fillings, (2) the former absence of antimonial minerals, (3) the replacements of gangue, (4) the mineral associations and (5) the absence of replacement of galena by ruby silver of this stage, the period is believed undoubtedly primary and is thus the last stage of the hypogene sequence preeminently important in the formation of the Chañarcillo veins.

PRIMARY MINERALIZATION

<u>Character</u>	<u>First Stage</u>	<u>Process</u>
Barren gangue minerals	Calcite	Filling
	(Siderite)	
	Barite	Replacement
	(Quartz)	
<u>Second Stage</u>		
Base metal sulphides (Traces of silver)	Pyrite	
	Zincblende (Proustite)	
	Chalcopyrite "	Replacement
	Galena "	(Filling)
<u>Third Stage</u>		
Arsenopyrite (Traces of silver)	Arsenopyrite (Proustite)	(Replacement)
	Quartz	(Filling)
<u>Fourth Stage</u>		
Sulpharsenides of silver	Pearceite	Filling
	Proustite	(Replacement)
Sulphantimonides of silver	Tetrahedrite (Freibergite)	
	Polybasite	Replacement
	Pyrargyrite	(Filling)

Faulting

At a time subsequent to the primary mineralization of the veins, but separated from it by an interval of indefinable length, the rocks and veins of the district were dislocated by faults. The early part of this period, characterized by faults of appreciable displacement, is represented at Chañarcillo by one fault only. This, the Loreto fault, strikes N.W. - S.E., dips to the southwest and is normal. The displacement upon it, downward on the southwestern side, is about of the magnitude of 50 meters. This fault separates what have been called the northern and southern areas of the district, in reality the northern and southern blocks, and the displacement upon it is the cause of the difference of mineralization of identical strata in these two blocks. Later faulting has produced no important displacements. The fault striking N. 55° W. in the north of the district and cutting the Bolaco Viejo shaft throws the Corrida and Manto de Ossa veins about 140 meters horizontally; but the vertical displacement is slight. This fault is distributive on at least four faults in the Candelaria claim. The San Francisco fault striking N. 75° W. through the central part of the district produced a predominant lateral displacement of about 30 meters. The San

Blos faults at the southern extremity of the area are of a similar nature. They caused marked horizontal displacement; but dislocated the strata but little vertically. During the faulting period small faults were formed on dikes and on veins. Veins were displaced on dikes, and more rarely on cross veins; dikes were opened to offer channels for downward percolating solutions; and the veins were universally fractured and reopened. After the first period of faulting, therefore, the rocks of the district were broken into two blocks of about 50 meters difference in elevation; after the second period the displacements though often great were unimportant; but the veins, dikes and rocks were shattered and opened in a manner to have a marked influence upon succeeding processes affecting the veins.

Erosion

The period of faulting was followed by erosion. The rocks of the district were slowly worn down from a horizon at least hundreds of meters above the present surface to their outcrops of today. Former cycles or stages of the physiography seem unimportant in connection with the veins. For long periods in the past the climate appears to have

been somewhat similar to that of today or to have been more arid and in consequence of this inference, the present processes of a superficial nature in the veins are believed to have been operative in the past. Whatever supergene concentrations of silver may have been formed during early physiographic stages, arid or wet, have certainly been modified and their minerals redistributed during the last stage of erosion.

Thus the discussion of the veins is concerned merely with the present erosive period and its variations. The topography of the district and its environs shows this period clearly to have been simple. Deep cañons and valleys lead the drainage of Chañarcillo southward to the broader valley of the Quebrada de Pajonales. This course, proceeding to the sea, is partly filled by alluvium. The topography, therefore, is young in the highlands about Chañarcillo, is more mature in the main valleys, and in the latter localities indicates a recent slight depression.

Such an interruption of erosion, however, has not affected the mountains of the district. Here the youthful stage has persisted from its beginning. The deep cuts of the cañons have, as they proceeded downward, stimulated the circulation of surface waters. Possible older concentrations of silver in horizons now removed have been carried downward

into the veins and precipitated anew. Erosion has not outstripped solution and deposition as sulphides are never exposed in the valleys, but the two processes have in an orderly manner kept in pace and as the youthful topography of the district was carved the present supergene concentration of silver in the veins progressed.

Enrichment

The primary ores are first found affected appreciably by supergene or secondary processes at a depth of 160 to 300 meters in the northern area and of 350 to 400 meters in the southern area. The zone of this first alteration in depth of the hypogene ore, or the zone of enrichment is at the north in the Negro limestone, at the south in the Delirio limestone. It thus varies in thickness in the north from 40 to 65 meters and in the south from 120 to 150 meters. It usually occurs in the second limestone horizon below the surface and separating it from the zone of unaltered, primary ore beneath, lie the Ahuesado tuff and the Constancia tuff.

In the enriched zone many of the structures and minerals of the primary zone remain. In the lower part of

the zone supergene effects have often been weak and the alteration has been slight. In the upper zone, however, and near faults and fractures, the enrichment has obliterated the primary sulphide mineralization. Thus, though the underlying and overlying beds of tuff give unusually sharp delimitation to the zone of enrichment, the zone, nevertheless, is defined rather by the processes involved in the formation of the ore than by the quantitative result of such processes.

The secondary deposition of silver is characterized by the predominance of replacement. The primary ore shoots are pseudomorphed by those of the enriched bodies; their shape, size and general relations as described above are unchanged; but by the precipitation of minerals containing greater percentages of silver than those of the hypogene deposition they have been appreciably increased in richness. Pearceite, proustite, polybasite and pyrargyrite in the relations typical of the primary veins have been replaced by stephanite, argentite, minor amounts of a second generation of pearceite and polybasite, and by much dyscrasite and native silver. Replacement of gangue minerals has rarely been noted in the ores developed during enrichment. The enriched ores of Chaffarcillo thus are due predominantly to the replacement of the sulphides of early deposition by supergene sulphides and native silver.

Under the reflecting microscope these relations are clearly to be observed. In the first stages of enrichment ruby silver is replaced by argentite, stromeyrite, stephanite and traces of polybasite and pearceite. The typical arrangement of the supergene minerals is in concentric bands about cores of the unaltered ruby silver. In this stage pyrargyrite is first affected by the secondary replacements; proustite is more resistant. Upon enrichment becoming more intense, dyscrasite and minor amounts of native silver and silver amalgam are introduced. The native elements, including dyscrasite, develop in irregular dendritic areas first in pyrargyrite, later in proustite, pearceite and polybasite. As their deposition proceeds they replace completely early sulphides and finally in the upper part of the enriched zone penetrate the earlier sulphides of enrichment, argentite, stephanite, pearceite and polybasite in feathery masses typical of replacement. The result of most intense enrichment is veins of massive dyscrasite and native silver. Rarely these two minerals are crystalline and have been deposited in open spaces; in places they have evidently in part replaced calcite and are found penetrating crystals of calcite along the cleavage; but the great part of the silver of these rich veins has replaced sulphides of earlier development. This last stage evidently involves a process of oxidation; but is distinctly a feature of the zone of enrichment.

ENRICHMENT

<u>Character</u>	<u>First Stage</u>	<u>Process</u>
	Stephanite	
Sulphides of silver	(Pearceite)	Replacement
(Sulphide enrich- ment)	(Polybasite) Stromeyrite)	of earlier sulphides
	Argentite	
	<u>Second Stage</u>	
Native elements	Dyscrasite	Replacement
(Oxidation of sulphides)	Native silver	of all earlier sulphides & (of gangue)
	Silver amalgam	(Open filling)

The copper veins in this zone show similar processes to have been acting upon them. Chalcocite and more rarely stromeyrite replace chalcopyrite, bornite and tetrahedrite in the crossing veinlets quite typical of secondary copper deposition; but strangely absent from supergene structures in the silver veins. No appreciable concentration of silver has taken place, however, in the copper veins in the enriched zone.

The enrichment has been affected less than the primary deposition by factors of environment. Enrichment, however, has proceeded more rapidly in the vicinity of faults, upon reopened veins and near fractures, porous dike rocks. Intersections of veins, with the consequent openings due to the post-primary movements, have offered excellent channels for the circulation of supergene solutions. The great part of enrichment is, nevertheless, determined by the primary ore shoots.

Oxidation

Above the enriched zone and separated from it by a bed of tuff, the Ahuesado tuff in the southern block and the Verde tuff in the northern, lies the zone of oxidation. This zone is found in the limestone outcropping at the surface or, where tuff is exposed, in the first limestone bed below. Thus in the north the Descubridora limestone is the country rock of the oxidized veins and in the southern area the Negro limestone is their usual horizon of deposition. The zone of oxidation attains in the north a thickness of 190 meters while in the south where it is found beneath the Verde tuff it is merely some 50 meters thick but extends to a depth below the surface of perhaps 100 meters.

This zone is characterized by the deposition of halides of silver and of oxides of iron. The latter minerals permeate the walls of the veins and lend their warm red colors to the rock. The miners have thus called the oxidized zone the "panizo calido" or "warm zone". The ore shoots here are quite different in size, shape and character from those of the primary and enriched zones. The veins have been appreciably widened and in places are observed of a width of 10 meters. The ore shoots have lost the elongated shape parallel to the limestone bedding so typical of the sulphide zones and are of irregular shape. They attain vertical dimensions of 30 to 50 meters and a horizontal extension of almost continuous ore of 200 meters or more. Assays were high in silver and have been reported of the richness of 2 to 2.5 per cent silver. The stopes in this zone are, therefore, wider, of greater vertical and horizontal extent and were composed probably of higher grade ore than those in the deeper productive levels.

The rich ore bodies, which have been extracted from the stopes of the oxidized zone, have apparently been concentrated, to judge from present available data, in definite connection with certain geologic factors. They first are confined, as the ores below, to limestone strata. Dikes have, where they cross the veins, evidently influenced

deposition and caused the extension of ore shoots to greater depths than where they are absent. This effect in some cases is due to the interruption of circulating surface waters; in others it is brought about by the fracturing of the dikes and the surrounding rock. Cross fractures of post-primary age produce similar local enrichments, but perhaps greatest in importance as an influence upon the precipitation of silver in the oxidized ore shoots are the fractures of latest age parallel to the veins and near their intersections. Where these factors have proved fortuitous in their connection with the earlier ore bodies, exceedingly rich masses of chlorides, bromides and iodides of silver, and of native silver have been formed.

Under the microscope the oxidized minerals in polished section show a typical and interesting sequence. Areas of native silver and dyscrasite of the last stage of enrichment are replaced at their contacts with gangue by halides of silver. The halides, usually a greenish mineral containing silver, iodine, bromine and chlorine, and identified as iodobromite, develops irregularly at the margins of the dyscrasite and penetrates the latter in blunt rough-edged veinlets. Many areas of seemingly pure iodobromite and cerargyrite contain smoothly rounded blebs of dyscrasite, minute specks or fine irregular lines of this

mineral to prove their origin by its replacement. Veinlets of native silver and of dyscrasite are interrupted by their entire conversion throughout short lengths to iodobromite. Where argentite, ruby silver or other silver sulphides have persisted unaltered to be exposed to the processes of oxidation, they are to be frequently observed replaced in part by halides of silver. Minute specks of ruby silver are, in many places, surrounded and indented by cerargyrite and iodobromite. Open filling by the halides is not unusual and cerargyrite, bromyrite and iodobromite are to be found coating fractures and filling vugs. Replacement, however, is the predominant process of the deposition of these minerals. Calcite has been partially replaced along cleavage lines by the common rouge-colored oxide of iron and these lines of rhombic shape are often to be seen in areas of silver halides. Veinlets of iodobromite also penetrate the twinning of calcite. From such relations the replacement of calcite by silver halides seems well proven, and no doubt explains in part the great width of the veins of the oxidized zone. In places, nevertheless, calcite is unaltered and dyscrasite lying on cleavage planes of calcite has been replaced. Thus under certain conditions calcite has been replaced by halides of silver, under others dyscrasite, native silver and earlier sulphides have been replaced, and under all circumstances a subordinate amount of

the filling of spaces has been accomplished by silver halides.

In the copper veins a different but probably parallel sequence has been inferred. Areas of native copper, no doubt derived from chalcocite of the complete enrichment of the primary ore, are replaced at their contacts with gangue by bands of native silver. The silver is, in turn, replaced at its immediate contact with the gangue by a narrow coating of cuprite, crystals of which project into the silver. The deposition of silver here seems of approximate contemporaneity with that of the halides of the silver veins.

As a next stage of the processes affecting the silver veins, the halides of the oxidized ores are replaced by native silver and by argentite. Narrow rims, represented in the polished section magnified 500 diameters by a mere line, lie at the contact of calcite and iodobromite and prove to be native silver. Feathery veinlets of native silver commonly penetrate areas of halides. Argentite as a coating of masses of iodobromite has also been observed. The development of these two minerals, however, closes the sequence of deposition in the Chañarcillo veins.

OXIDATION

<u>Character</u>	<u>First Stage</u>	<u>Process</u>
Halides of silver	Cerargyrite	Replacement of all earlier silver minerals and of calcite
	Iodobromite	
	Bromyrite	Open filling
	Embolite	
	Iodyrite	
	<u>Second Stage</u>	
Local enrichment due to reversal of oxidation re- actions	Native silver Argentite	Replacement of halides

ANALYSES OF VEIN AND WALL ROCK (MOESTA)OXIDIZED ZONE, CHAÑARCILLO

I		II	
SiO ₂	47.97	SiO ₂	22.82
Al ₂ O ₃	6.22	Al ₂ O ₃ + Fe ₂ O ₃	3.53
Fe ₂ O ₃	3.90		
MgO	16.71	MgO	11.46
CaO	9.65	CaO	29.73
CO ₂	11.64	CO ₂	31.09
K ₂ O + Na ₂ O	1.27	K ₂ O + Na ₂ O	1.69
AgCl	<u>1.55</u>	C	<u>0.93</u>
	98.91		101.25

I = Ore bearing altered rock of vein. (manto)

II = Unaltered wall rock.

The altered rock shows appreciable increase in SiO₂, Al₂O₃, Fe₂O₃ and MgO (BaO?), losses of CaO and CO₂, and the addition of AgCl.

ANALYSES OF HALIDES OF SILVER (MOESTA)OXIDIZED ZONE, CHAÑARCILLO

	I	II	III	IV	V	VI	VII
Ag	73.58	74.76	67.68	64.07	61.40	62.89	45.02
Cl	24.42	24.68	14.25	11.12	8.81	8.07	
Br			18.04	23.07	26.85	27.35	
I					tr.	1.73	54.25
Hg	<u>1.31</u>	<u>0.07</u>	_____	<u>1.78</u>	<u>2.99</u>	<u>tr.</u>	_____
	99.31	99.51	99.97	100.04	100.05	100.04	99.27

Subtracting Hg as chloride.

	I	II	III	IV	V	VI	VII
Ag	74.73	74.82	67.68	65.42	63.65	62.89	45.02
Cl	24.56	24.68	14.25	11.04	8.58	8.07	
Br			18.04	23.57	27.83	27.35	
I	_____	_____	_____	_____	_____	<u>1.73</u>	<u>54.25</u>
	99.29	99.50	99.97	100.03	100.06	100.04	99.27

ANALYSES OF HALIDES OF SILVER (MOESTA)

	Cerargyrite (Dana)	Iodyrite (Dana)
Ag	75.3	46.0
Cl	24.7	
I	—	<u>54.0</u>
	100.0	100.0

I and II therefore are cerargyrite.

VII is iodyrite.

The ratios of Cl, Br and I of the remaining analyses, taking Ag = 1, are as follows:

	III	IV	V	VI
Ag	1	1	1	1
Cl	0.6415	0.5132	0.4101	0.3904
Br	0.3599	0.4864	0.5902	0.5871
I	—	—	—	<u>0.0233</u>
	1.0014	0.9996	1.0003	1.0008

These ratios indicate distinctly the existence of isomorphism between cerargyrite, bromyrite and iodyrite and as the complex halide compounds of silver are quite homogeneous under the microscope at highest magnification such isomorphism is believed well proven.

THE MINERAL SEQUENCE OF THE CHAÑARCILLO VEINSSILVER VEINSCOPPER VEINSPrimaryPrimary

Calcite

Calcite

(Siderite)

Siderite

Barite

Barite

(Quartz)

(Quartz)

Pyrite

Pyrite

Zinblende (Proustite)

Zinblende

Chalcopyrite "

Chalcopyrite

Galena "

(Galena)

Arsenopyrite "

Arsenopyrite

Quartz

Pearceite

Proustite

Tetrahedrite (Freibergite)

Tetrahedrite

Polybasite

Pyrargyrite

Pyrargyrite

MINERAL SEQUENCE, CONT'D.SILVER VEINSCOPPER VEINSEnrichmentEnrichment

Stephanite

(pearceite)

(Polybasite)

(Stromeyrite)

Argentite

Dyscrasite

Native silver

Silver amalgam

Chalcocite

(Stromeyrite)

OxidationOxidation

Cerargyrite

Iodobromite

Embolite

Bromyrite

Native silver

Argentite

Native copper

Native silver

Cuprite

The Chemistry of the Vein Processes

The chemistry of the primary mineralization is to be inferred only in its generalities. Solutions containing carbonates of lime and iron were succeeded by those carrying sulphate of barium and a small amount of silica. Next base metal sulphides, sulphide of arsenic and iron, ^{Copper} quartz, sulpharsenides of silver and sulphantimonides of silver and copper were deposited in the order given from solutions of unknown composition. That the later sequence was precipitated from hot alkaline sulphide solutions is doubtful. Complex sulphides of silver are unstable in such solutions (IX, p. 375). The earlier series, including arsenopyrite, ^{Glaucochlorite or cobaltite} undoubtedly was formed during the existence of intense conditions of mineralization. The pressure was high and temperature perhaps between 150°C. and 300°C. The sequence of silver deposition appears probably to have had its origin under lower pressure and temperature.

The supergene processes, however, admit of more precise interpretations. Temperature and pressure are undoubtedly those existent in the mines today. (P = atmospheric, T = 20°C₊). Exact chemical research has been conducted regarding the reactions of silver oxidation and enrichment. The chemical character of the active solutions may be in-

ferred with some accuracy. The difficulties of this field of chemistry certainly are not insuperable; and, though many problems must remain for future solution, the sequence of the Chañarcillo veins offers excellent suggestions for their attack.

The solutions formed during the oxidation of the veins are determined principally in composition by the barren sulphides. Pyrite, so important a mineral in this connection in many silver veins, is by no means a common constituent of the Chañarcillo lodes. ^{Cooperation with MnO₂ and FeO} Arsenopyrite, however, is prevalent and it is believed this mineral, ^{oxidizing} may supply the sulphuric acid and ferric sulphate inferred to be essential in silver enrichment. The acids of arsenic formed from arsenopyrite ^{at} have been carried to an unknown end. ^{of which were precipitated} Mixed with sulphuric acid and ferric sulphate at the vein outcrops are sodium chloride, iodide and bromide perhaps wind-blown from the sea.

In the oxidized zone some of the ferric sulphate is removed, partly by its replacement of calcite as iron oxide, partly by hydrolysis due to the neutralization of sulphuric acid by calcium carbonate. Some ferric sulphate no doubt remains, however, and this salt and the halides of soda constitute the important components of the downward moving solution. Native silver and argentite of the latest

sequence under conditions as yet not elucidated are formed from halides of silver in the upper oxidized zone. They are soluble in ferric sulphate (X, p. 13) and add silver sulphate to the solutions. If the solution contains appreciable amounts of NaCl (more than 34.3 gm. per liter)(X, p. 19) the silver may exist in part in the solution as silver chloride. The great part of the halides of silver, however, are probably removed slowly from the oxidized zone as erosion proceeds by conversion first into native silver and by solution of this silver in ferric sulphate.

In the deeper oxidized zone solutions of ferric sulphate and sodium chloride encounter native silver and dyscrasite persisting from the zone of enrichment. The ferric sulphate dissolves silver; but probably as the residual silver is plentiful much will be reprecipitated immediately by NaCl, NaBr, or NaI, and thus cause the common replacement of native silver or dyscrasite by halides of silver. The equilibrium of halide and sulphate solutions of silver is, as yet obscure; but probably the solubility of AgCl will be little affected by ferric sulphate.

The halide radicals being fixed in this horizon, silver sulphate derived from the solution of silver by ferric sulphate is transported downward to the zone of enrichment.

Some of this silver is precipitated upon the reduction of ferric sulphate to ferrous sulphate (X, p. 26). Open fillings of silver are undoubtedly due to this cause. Upon solutions of high silver concentration calcite acts as a precipitating agent of native silver (IX, p. 372). Replacements of calcite by silver are thus readily explicable in their rarity at Chañarcillo. Hydrogen sulphide and alkaline sulphides are of doubtful efficacy as precipitants of the sulphides of the enriched zone; but metallic sulphides most certainly are active in the deposition not only of argentite and of more complex silver sulphides but of native silver from solutions of silver salts, probably sulphate. Such reactions are mentioned in discussions of the chemistry of silver enrichment (IX, p. 38; X, p. 24); but the precise nature of the replacements observed in the Chañarcillo veins are not at present known. Their further elucidation offers an attractive field of investigation for the future.

The Economic Importance of Supergene Processes

The mining of the veins of Chanarcillo has been greatly affected by the results of oxidation and enrichment. The methods of extraction of ore, the lack of mills for concentration of the valuable minerals and the long existent difficulties of transportation to the metallurgical plants of Pabellon and Copiapó combined to limit mining to ore of high grade only. Lack of the rich ore bodies of supergene origin would, therefore, have impeded the development of the district and would certainly have curtailed the remarkable profits obtained from the working of the bonanza ore near the surface.

But little of primary ore in the district has been developed or extracted. In part this fact is due to the flows of water encountered during deep exploration, in part to the universally acknowledged low grade of hypogene ores. The statement, however, is well founded that under former conditions of mining the deep, low grade veins of the district can not, in general, be worked at a profit.

The contrast of these ore shoots to those in the enriched zone is, however, marked. The latter, though in many places narrow and of slight vertical extension, were mined often with great returns. Throughout the well mineral-

ized veins of the district stopes are to be found in the enriched zone. The availability of these ore shoots to mining has been due to the replacement of the predominant primary sulphides, pearceite, proustite and pyrargyrite by argentite, dyscrasite and native silver. Though the ore shoots were unchanged by enrichment from their original size and shape, the silver content of the ores has by the replacements noted been increased from 25 to 80 per cent. Open filling by secondary minerals has often caused further additions to the values. Thus tenors of 2000 to 5000 grams per metric ton (60 - 150 oz. per ton) of primary veins have become valuable commercial ore at perhaps 3500 to 8000 grams per ton.

SILVER CONTENT OF MINERALS (DANA)

<u>Mineral</u>	<u>Per cent Ag</u>
Pearceite	55.2 - 56.9
Proustite	65.4
Polybasite	75.6
Pyrargyrite	59.9
Stromeyrite	50.2 - 52.7
Argentite	87.1
Dyscrasite	72.9 - 84.3
Silver	100
Cerargyrite	75.3
Iodobromite	60.2
Embolite	63 - 65
Bromyrite	57.4
Iodyrite	46.0

The replacements in the oxidized zone, however, were, where earlier silver minerals were affected, impoverishments. Losses of 20 to 35 per cent of silver content would have been caused if other factors had not entered. Replacement of calcite by oxidized silver minerals,

and appreciable filling of cavities by these minerals united to not only widen the veins and increase the horizontal and vertical continuity of the ore shoots but to raise the tenor of the ores. Veins were broadened from 1 meter to 3 and more rarely 10 to 20 meters. Ore shoots were consolidated into bodies extending tens of meters vertically and 100 to 200 meters horizontally. Ores were changed from a grade of 3000 to 5000 grams per ton to contents measured in per cents of silver. In this manner the oxidized zone became the horizon of bonanza ore of Chanarcillo.

THE FUTURE OF MINING IN THE DISTRICT

The exceedingly rich bodies of the superficial portions of the veins and the known ore shoots of high grade in the zone of enrichment have long been exhausted in the Chañarcillo district. The probability of encountering further ore of remarkable tenor by exploration is slight. The Chilean miner is thorough and keen. His crooked drifts and cross cuts follow every fracture or veinlet, and his work once done can be but little improved with regard to the finding of ore.

Present development is confined to the search for primary ore in the deeper mines. The Delirio Mine is said to have found ore containing 1500 to 2000 grams of silver per ton upon the 600 meter level; but the lower levels of the mine are now flooded and are inaccessible. The Bolaco Viejo has at a much less depth (180 meters) encountered a small body of rich primary ore. Few of the mines, however, have explored the deeper portions of their veins and the statement may merely be made that ore is known to occur in certain mines at horizons unexplored systematically throughout the district.

Some hope seems to be held in Chile that with deep mining Chañarcillo may return to her former richness. Upon geological considerations, this hope is unfounded. Due to economic causes, its realization will be at least long delayed. The installation of costly pumping equipment, the sinking of deep shafts, the high cost of mining at depths of 600 to 800 meters, and the difficulty of operating a concentrator in the district unite to discourage the attempt at development of low grade ore of unknown extent. The possibility, however, exists that, with consolidation of the mining interests and with proper management conducting a conservative system of exploration, bodies of ore may be discovered which will prove a sound basis for mining enterprise.

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ILLUSTRATIONS

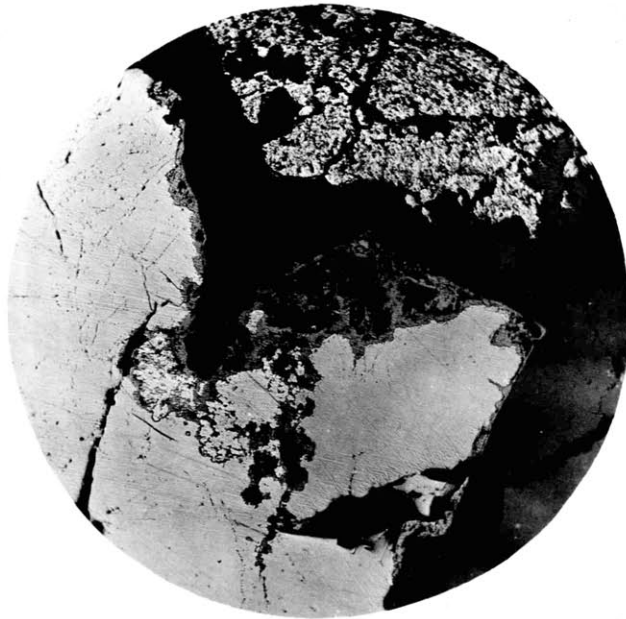
of

MINERAL PARAGENESIS

CHAÑARCILLO

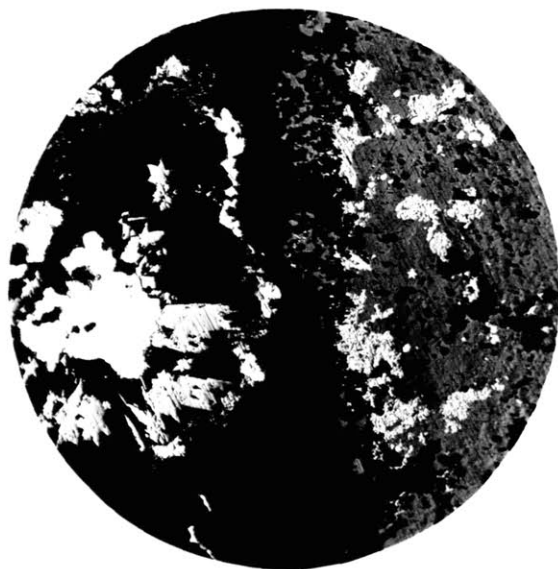
CHILE

PRIMARY SUCCESSION



Pyrite (upper pebbled gray) deposited in gangue (black) with later zinblende (dark gray) coating cavities. Zinblende is replaced by arsenopyrite (white, lower left centre) and the cavities are later filled completely by ruby silver, pyrargyrite and proustite (light gray).

Polished section (X 37)



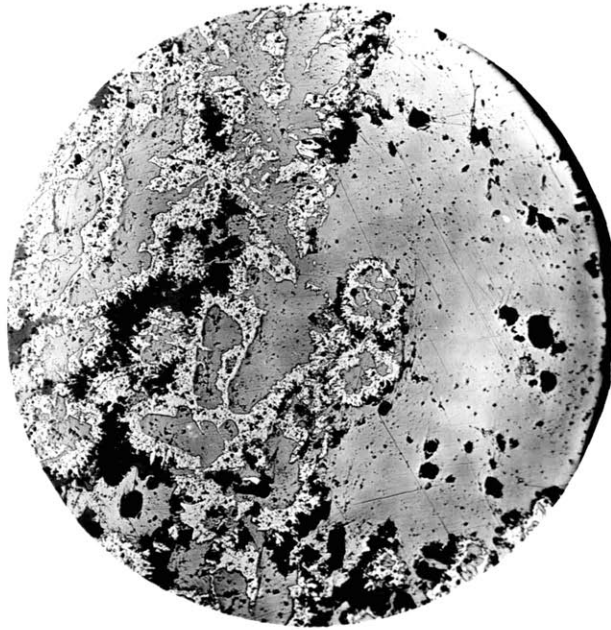
Arsenopyrite (light gray) in crystals in gangue (black) and replacing at margins zinblende (dark gray). Native silver (white) adjoins arsenopyrite crystals and replaces an earlier silver sulphide completely.

Polished section (X100)



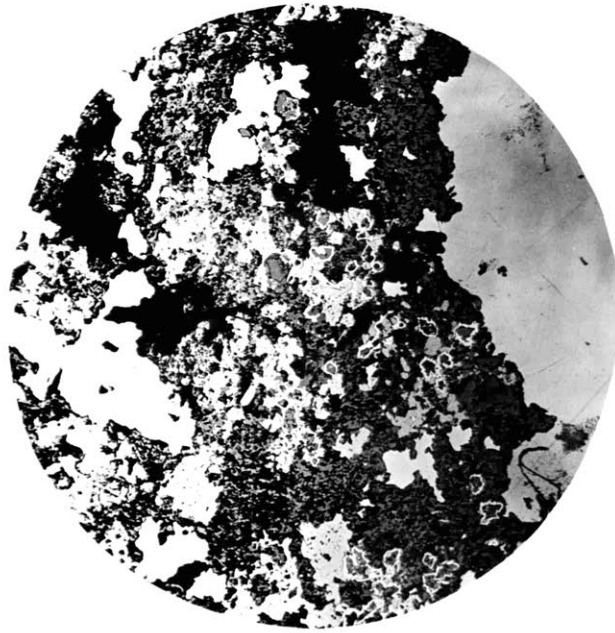
Ruby silver filling cavities coated by arsenopyrite (white). Nuclei of arsenopyrite crystallization are crystals of quartz (black).

Polished section (X 100)



Ruby silver (gray) filling interstices of
arsenopyrite (light gray). Black is gangue.

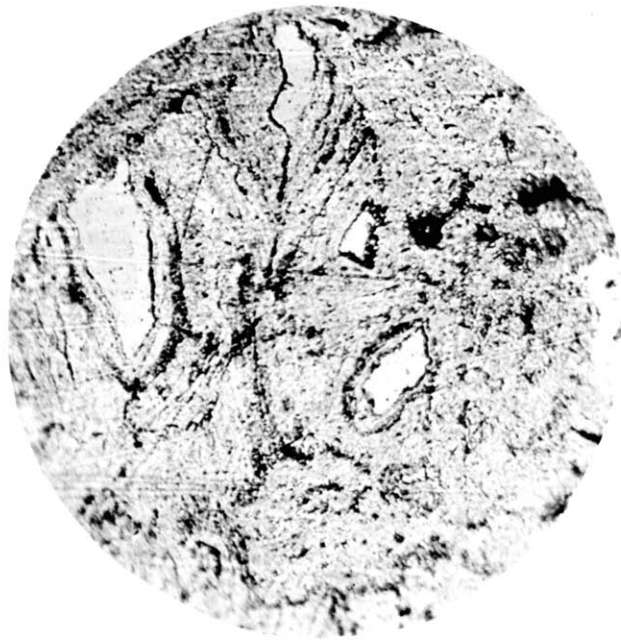
Polished section (X 37)



Typical structure of arsenopyrite (light gray)
ruby silver (gray), native silver (white) and
gangue (black).

Polished section (X 37)

ENRICHMENT SUCCESSION



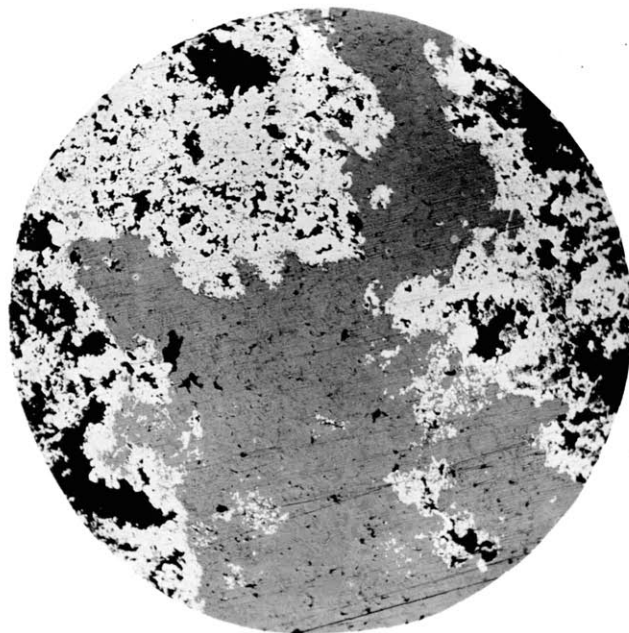
Residual cores of ruby silver (pyrargyrite)
(smooth white) surrounded by rough concentric bands
of argenticite and stephanite. Etched by light.

Polished section (X 850)



Ruby silver, pyrrargyrite (light areas) replaced
by concentric bands of stephanite and argentite.
Etched by KCN.

Polished section (X 850)



Dyscrasite replacing sulphides of silver (gray).

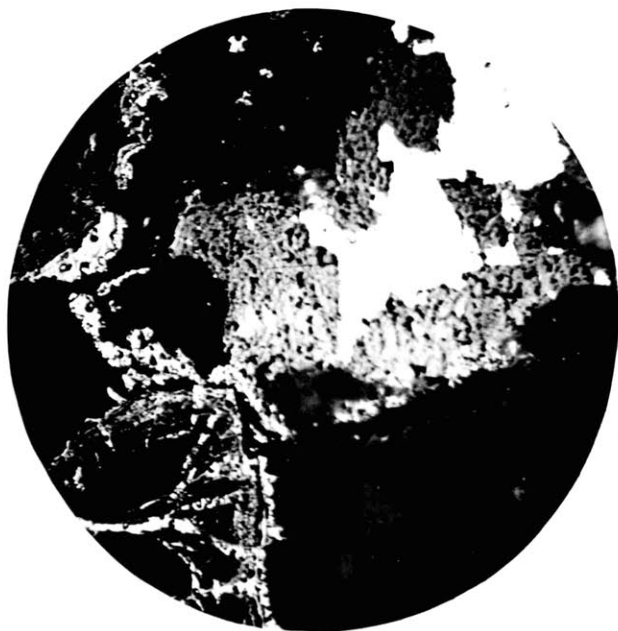
Polished section (X 37)

OXIDATION SUCCESSION



Native copper replaced by silver. Silver
replaced by cuprite.

Polished section (X 246)



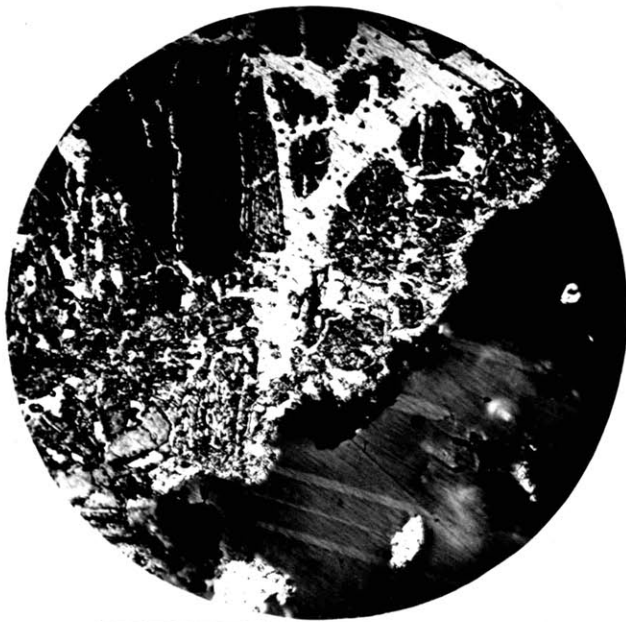
Native silver (white) replaced at margins by iodobromite (gray). Calcite at lower left is replaced by halide in typical concentric structures.

Polished section (X 246)



Veinlets of native silver and dyscrasite (white)
interrupted by replacement by halides of silver.

Polished section (X 480)



Dyscrasite (white) replaced by
halide of silver (pebbly gray).

Polished section (X 246)



Iodobromite replacing calcite along
twinning lamellae.

Polished section (X 246)



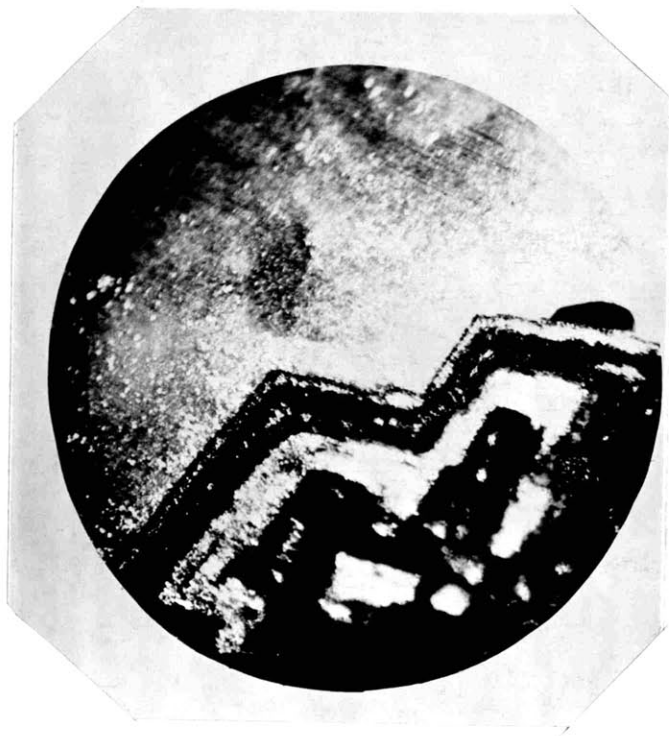
Iodobromite replacing calcite. (Dark Gray).
Note preservation of calcite structure by halide.

Polished section (X 480)



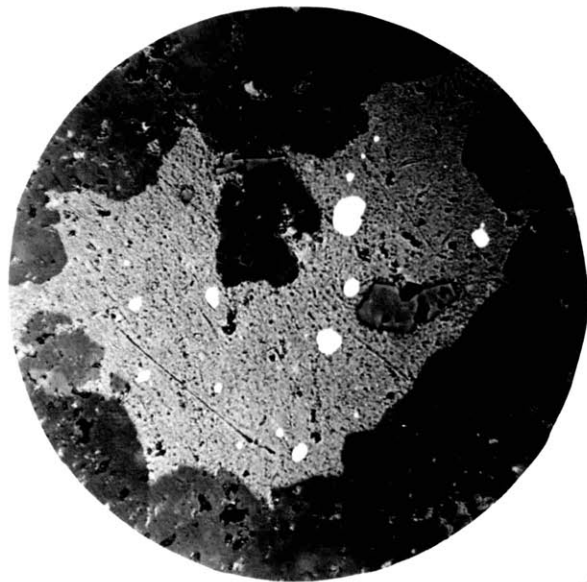
Iodobromite replacing calcite and leaving native silver unaffected. Note remnants of calcite cleavage preserved in the halide of silver.

Polished section (X 480)



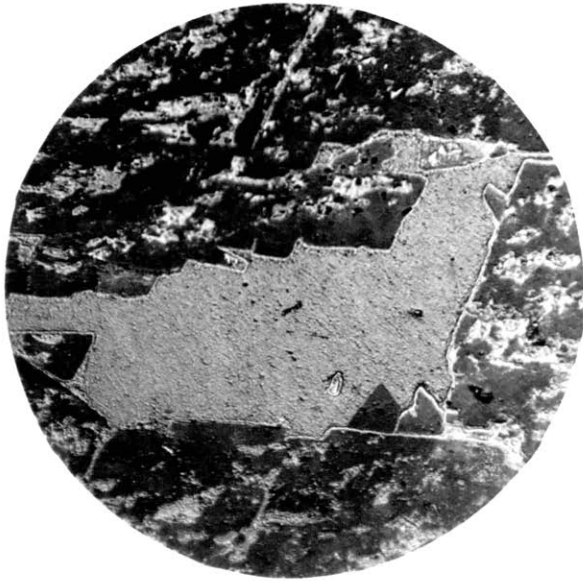
Calcite (black) replaced by iodobromite containing specks of dyscrasite (white).

Polished section (X 850)



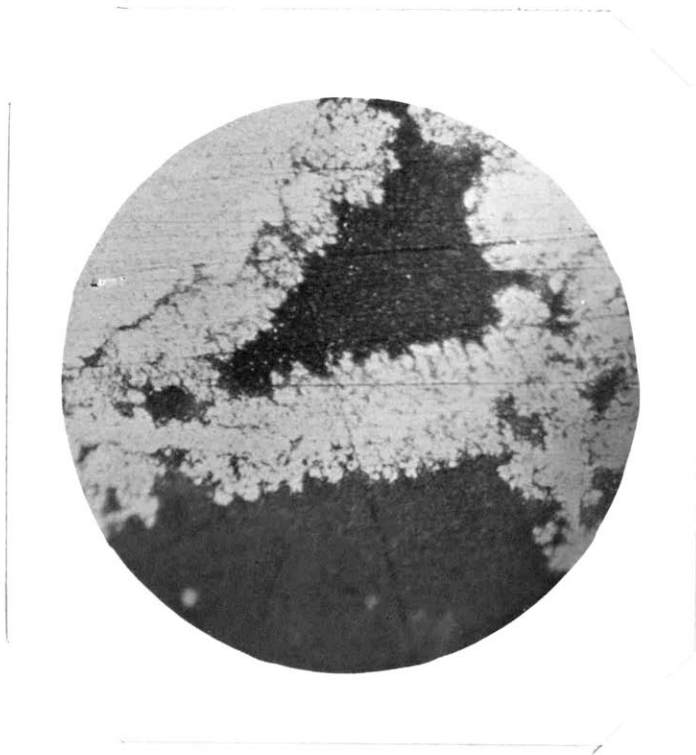
Residual rounded areas of dyscrasite in
silver halide (iodobromite).

Polished section (X 480)



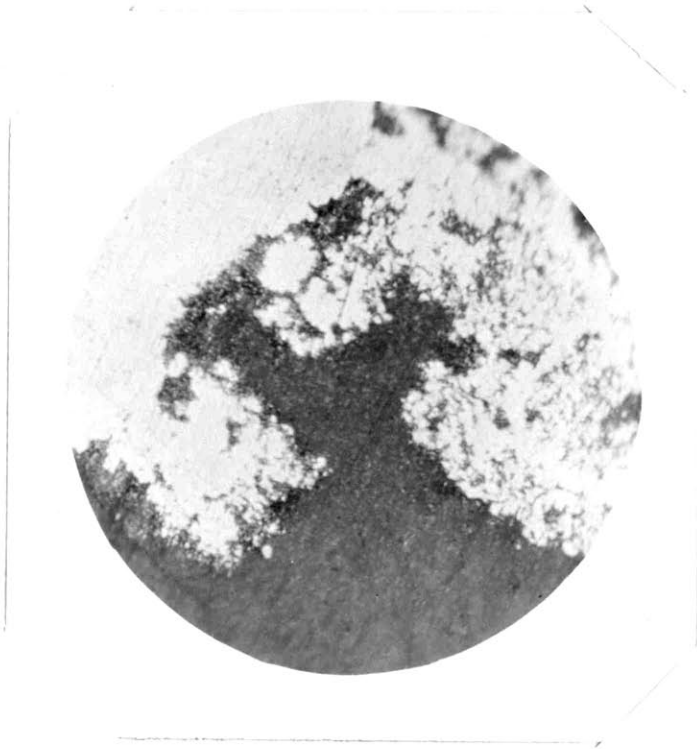
Iodobromite replaced by thin marginal line
of argenteite.

Polished section (X 480)



Native silver replacing silver halide (iodobromite).

Polished section (X 1000)



Native silver replacing silver halide
(iodobromite).

Polished section (X 1110)

PLATES AND ILLUSTRATIONS

THE VEINS OF CHAÑARCILLO, CHILE.

MAPS

and

SECTIONS

PLATE I.

GEOLOGIC MAP OF THE CHAÑARCILLO DISTRICT

CHILE.

Scale 1:3125

Contour Interval 10 meters

LEGEND

Red areas	Los Carros Intrusive.
Blue "	Descubridora limestone.
Orange "	Verde tuff.
Green "	Negro limestone.
Brown lines	Contours (interval 10 meters).
Black lines(light)	Boundaries of claims.
Black " (heavy)	Sections.
Circles	Mine shafts.
Vermilion lines	Faults.
Orange "	Veins.
Yellow "	Unproductive (copper) veins.
Red "	Dikes.

PLATE II

SECTION ON AB

CHAÑARCILLO, CHILE.

Scale 1:3125

LEGEND

Blue	areas	Descubridora limestone.
Orange	"	Verde tuff.
Green (dark)	"	Negro limestone.
Brown	"	Ahuesado tuff.
Green (light)	"	Delirio limestone.
Yellow	"	Constancia tuff.
Blue (pale)	"	Azul limestone.
Pink	"	Segundo tuff.
Vermilion	lines	Faults.
Orange	"	Veins.
Yellow	"	Veins (unproductive).
Red	"	Dikes.
Black (dotted)	"	Mine shafts near section.
Black (full)	"	Mine shafts on section.

PLATE III

SECTION ON CD

CHAÑARCILLO, CHILE.

Scale 1:3125

LEGEND

See Plate II.

PLATE IV

SECTION ON EF

CHAÑARCILLO, CHILE.

Scale 1:3125

LEGEND

See Plate II.

PLATE V

PROJECTION OF THE WORKINGS

of

CONSTANCIA MINE

CHAÑARCILLO, CHILE.

Scale 1:500

LEGEND

See Plate II

White areas represent portions of the vein removed
during mining.

PLATE VI

MAP OF SOUTH AMERICA

Scale 1:80,000,000

MAP OF CHILE

Scale 1:20,000,000

Area of Plate VII shown in red.



PLATE VII

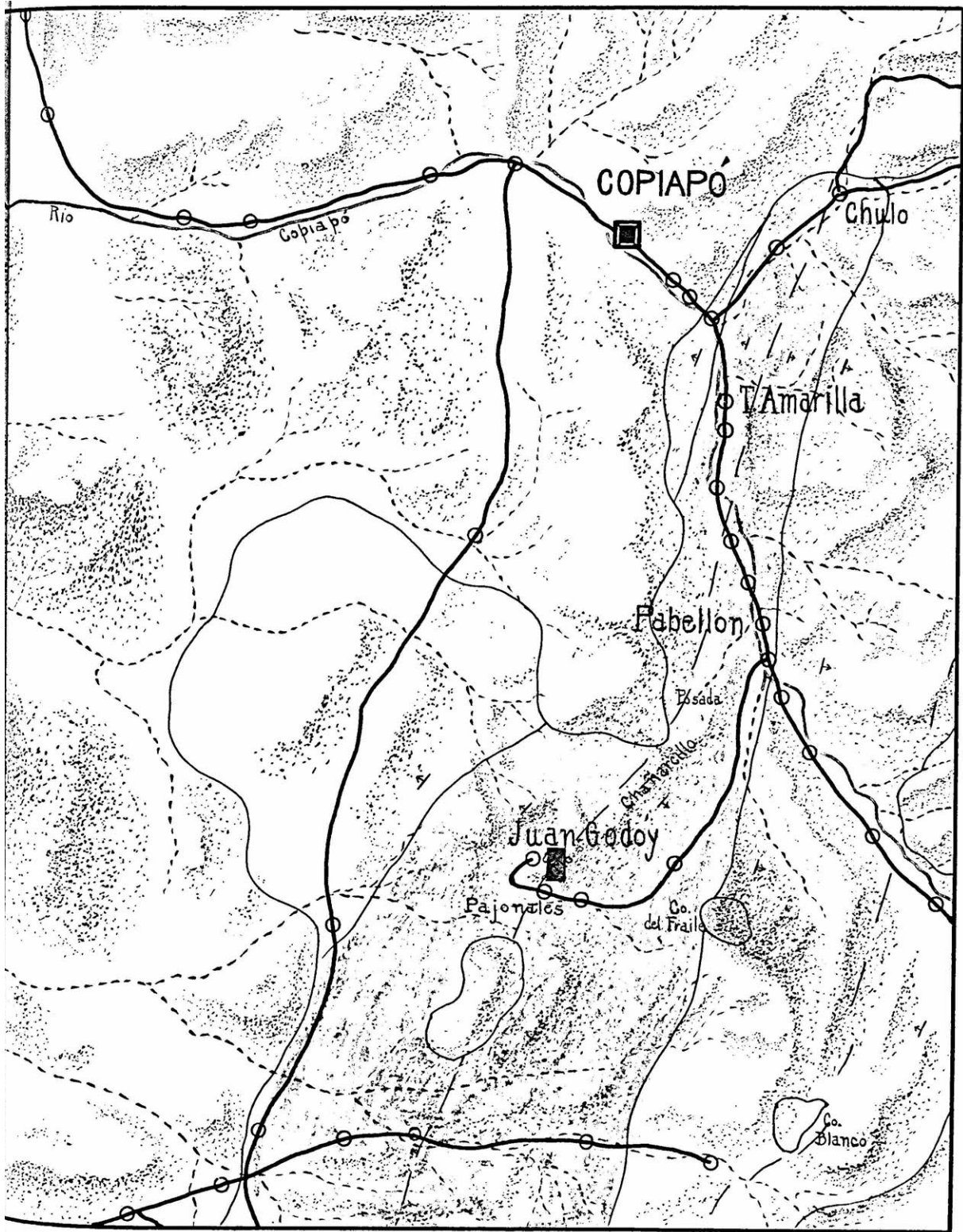
GEOLOGIC MAP OF THE COPIAPÓ AREA.

Scale 1:500,000

LEGEND

Brown areas	Copiapó undifferentiated igneous rocks.
Green "	Tierra Amarilla Formation.
Blue "	Chañarcillo Formation.
Red "	Chañarcillo District (area of Plate I).
Black full lines	Railroads.
Black dashed "	Axes of folds.
Blue full "	Rivers.
Blue dotted "	Dry river courses.

Map based on Chilean Government Surveys,
sections of Lorenzo Sundt and personal observations
by the author.



ILLUSTRATIONS

of the

NORTH REGION

of

CHILE

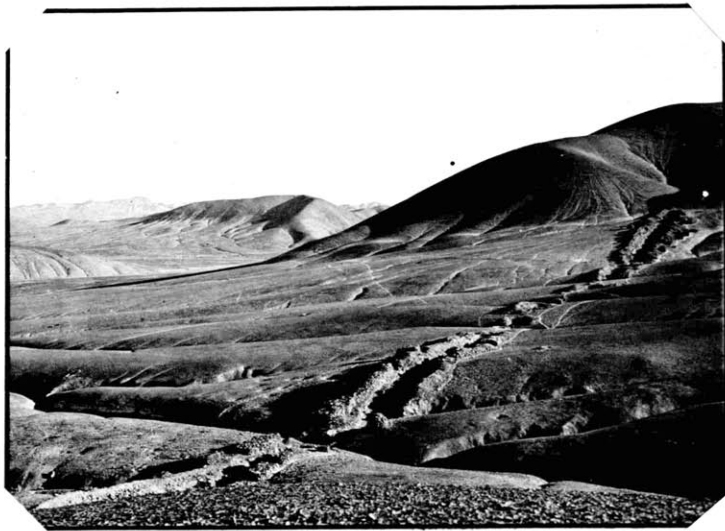


The Andes from the Cordillera Domeyko
Province of Antofagasta.



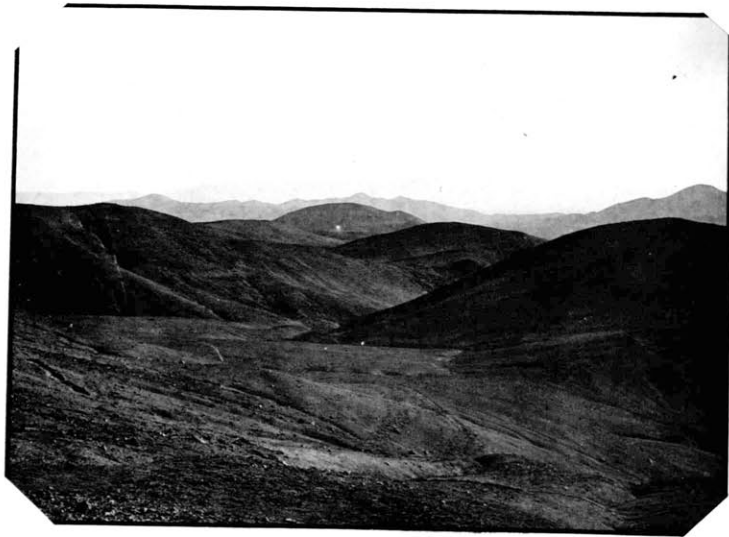
The Cordillera Domeyko

Antofagasta.



Typical desert view.

Antofagasta.



Rough desert topography

Antofagasta.



Desert Topography

Antofagasta.

ILLUSTRATIONS

of the

CHAÑARCILLO DISTRICT

CHILE.



The town of Juan Godoy and hills
west of the district.

View west from Cerros de Los Carros,
Chaffarcillo.



Low hills of Bocano and San Jose Mines.

Santa Rosa buildings at right.

Ruins of old town at left.

View east from Cerro de Los Carros,
Chañarcillo.



Constancia Mine (left), Quebrada de Pajonales
and mountains south of the district.

View S.E. from Cerro de Los Carros,
Chañarcillo.



Deep valley in Descubridora Limestone
leading to the Quebrada de Pajonales.

View S.E. from Dolores Primera,
Chañarcillo.



Typical outcrop of Descubridora limestone.
Bolaco Viejo dump at centre.

View S.E. from Jueves property,
Chañarcillo.



Outcrop of Descubridora limestone.
Bolaco Viejo surface stope.

Chañarcillo.