54

METALLOGENETIC PROVINCES OF CHILE, S. A.

CARLOS RUIZ F. AND GEORGE E. ERICKSEN

Reprinted from ECONOMIC GEOLOGY, Vol. 57, No. 1, January–February, 1962

Reprinted from
Vol. 57, 1962, pp. 91–106

METALLOGENETIC PROVINCES OF CHILE, S. A.[1]

CARLOS RUIZ F. AND GEORGE E. ERICKSEN

CONTENTS

ABSTRACT

The metalliferous deposits of Chile tend to be restricted to well defined metallogenetic provinces, each characterized by a dominant mineral or mineral assemblage. The most important ore deposits are those of copper, iron, silver, gold, and manganese. The primary minerals are few in number and most are simple sulfides and oxides; more complex sulfosalts are scarce. Secondary minerals in great variety are important constituents of the ores. Many of the ore deposits are situated along well defined structural lines, several hundred kilometers long, that parallel the structural grain of the Andes.

The deposits, with few exceptions, are found in sedimentary or volcanic rocks that range in age from Jurassic to Late Cretaceous or in intrusive rocks of Late Jurassic to Late Cretaceous age. Most deposits are genetically related to intrusive bodies, which have an average composition within the range of granite-diorite.

The metalliferous deposits can be classed as hydrothermal, sedimentary, contact-metasomatic and magmatic. Copper deposits are typically hydrothermal, manganese deposits are sedimentary, and most of the iron ore deposits are contact-metasomatic. A unique group of iron ore deposits apparently formed by near-surface intrusion and surface flows of a magma

[1] Publication authorized by the Director, U. S. Geological Survey.

consisting of iron oxides. Hydrothermal deposits, the most abundant and most important economically, were formed under conditions ranging from low to high temperature and pressure.

INTRODUCTION

A LONG-TERM systematic study of the ore deposits of Chile is at present being undertaken by the Instituto de Investigaciones Geológicas of Chile for the purpose of gaining information about habits, types, and epochs of mineralization, local and regional structural control, lithologic control, origin, and reserves. The present report is a synthesis of the knowledge of the ore deposits of Chile based on studies now being carried out and on published and unpublished reports. The information at hand is adequate to serve as a basis for a preliminary summary of the characteristics of the ore deposits.

Most of the known ore deposits of Chile are in the northern half of the country; relatively few have been found in southern Chile. The paucity of known deposits in the south reflects in part a lack of exploration caused by inaccessibility, adverse climate conditions, dense forest cover, and extensive overburden.

The following data on metal production for the year 1959 (Servicio de Minas del Estado, 1960) indicate the magnitude of present day mining in Chile:

Copper	548,528	metric tons
Molybdenum	2,297	metric tons
Lead	2,322	metric tons
Zinc	1,013	metric tons
Gold	1,821	kilograms
Silver	60,644	kilograms
Mercury	69,173	kilograms
Iron ore	4,649,048	metric tons, 63.2% Fe
Manganese ore	38,777	metric tons, 46.3% Mn

Most of the gold and silver and all the molybdenum produced during 1959 were by-products of copper ores.

A full review of the literature on Chilean ore deposits is not within the scope of this report. However, during preparation many published and unpublished reports were consulted; those that proved to be of most aid are as follows: general characteristics of Chilean ore deposits—Little (11), Domeyko (2, 3), Miller and Singewald (14), and Kuntz (9); copper—Flores (4) and Ruiz (16); iron—Ruiz (17); gold—Flores (4) and Flores and Ruiz (7); cobalt—Hornkohl (8); tungsten—McAllister and Ruiz (12); silver—Flores (6) and Whitehead (20); mercury—McAllister, Flores, and Ruiz (13); lead and zinc—Flores (5); and manganese—Biese (1).

METALLOGENETIC PROVINCES

The metallogenetic maps of Chile (Figs. 1, 2) were prepared from an ore deposit map (scale 1:1,000,000) on which most of the mining districts of Chile had been plotted. Areas which had known concentrations of certain metals were outlined on this map and then were transferred to a base (scale

1:5,000,000) for the present report. Deposits of iron, copper, silver, manganese, and lead and zinc were readily adaptable to this type of treatment. On the other hand, gold, generally found in recoverable quantities in most copper ores, did not lend itself to such a simple representation; instead it was necessary to delimit the gold provinces as those areas containing mines that were worked primarily or exclusively for gold. Mercury, cobalt, tungsten, and molybdenum, not shown on the metallogenetic maps, have come from isolated mining districts or are by-products of copper ores.

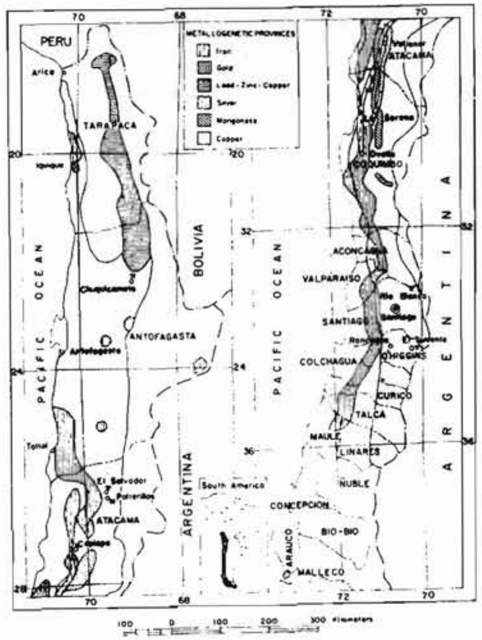

FIG. 1. Metallogenetic provinces of northern Chile.

The most extensive metallogenetic province in Chile is that of copper, which extends from Perú southward to about the southern border of the province of Linares (Fig. 1). Figure 3 shows lines along which certain types of copper deposits are particularly abundant. In this province copper mines and prospects number in the thousands, and copper minerals are found in nearly all other metalliferous deposits. The porphyry-copper deposits rank among the world's largest of all types. Only a few copper deposits exist in other parts of Chile; a few small deposits have been found in the eastern part of the province of Aysen and in the extreme southern part of the continent, and on the neighboring islands of the province of Magallanes.

Iron ore, which ranks second to copper ore in terms of tonnage and value of production, is for the most part restricted to three regions (Fig. 1). The first is a narrow belt, comprising several tens of relatively small high-grade deposits, along the coast extending from near Ovalle northward to near the southern border of the province of Antofagasta. The second, in the eastern part of the province of Antofagasta near the Argentine border, has recently discovered deposits that may have very large reserves of high-grade iron ore. The third, in the province of Arauco, may have moderately large reserves of a low-grade, itabirite type of ore. Itabirites have also been reported as occurring in the province of Valparaíso. All iron ore now being produced in Chile comes from the first of the above regions.

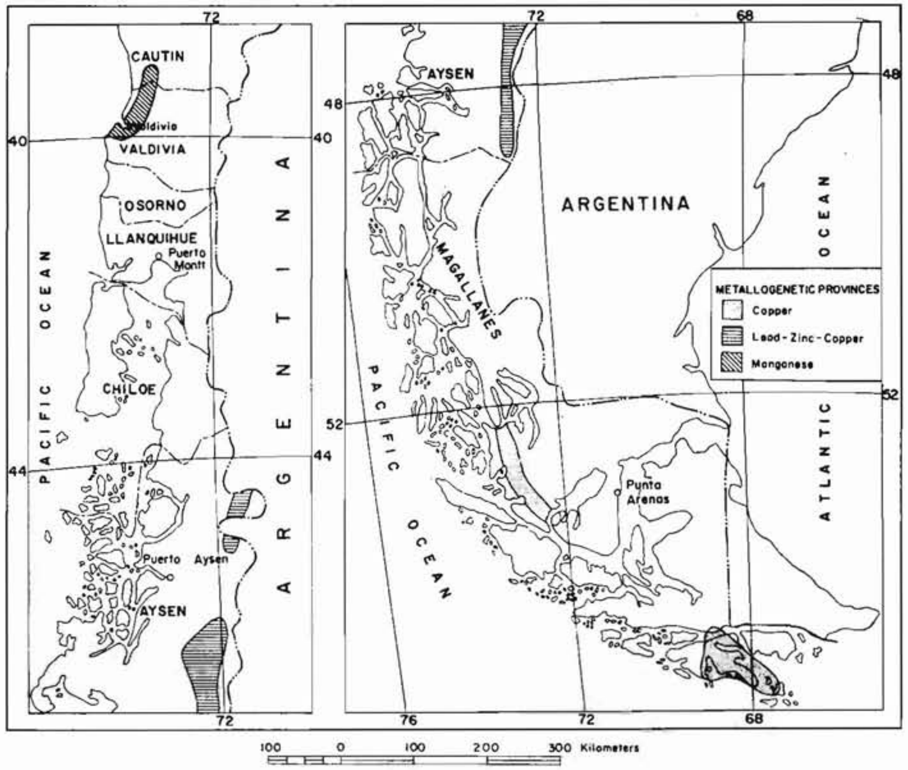

FIG. 2. Metallogenetic provinces of southern Chile.

Gold deposits are mostly in a belt extending from the province of Maule northward into the province of Antofagasta (Fig. 1) and near the western border of the copper province. Gold placer deposits are found in this same region as well as many other places in Chile. Inasmuch as the present report is concerned mainly with primary ores, the gold placer deposits are not shown on the metallogenetic maps and they are not described.

Silver deposits, which accounted for a moderately large production of high-grade ores during the last century and the early part of the present century, are found in the following areas: near Iquique (province of Tarapacá); northeast of Antofagasta; northeast of Copiapó (Atacama); and in a belt extending

from near Copiapó to La Serena (Coquimbo) (Fig. 1). In addition, a few copper deposits and most of the lead and zinc deposits of Chile contain silver that is recoverable as a by-product.

Manganese, which has been produced in moderate quantity, has come principally from mines in a belt extending from near Vallenar (Atacama) to Ovalle (Coquimbo) (Fig. 1). Manganese is also found in a number of deposits in the southern provinces of Cautín and Valdivia (Fig. 2) and in scattered deposits in northern Chile, these deposits are few in number and are of little or no economic importance; nearly all the present day production is from a region near La Serena.

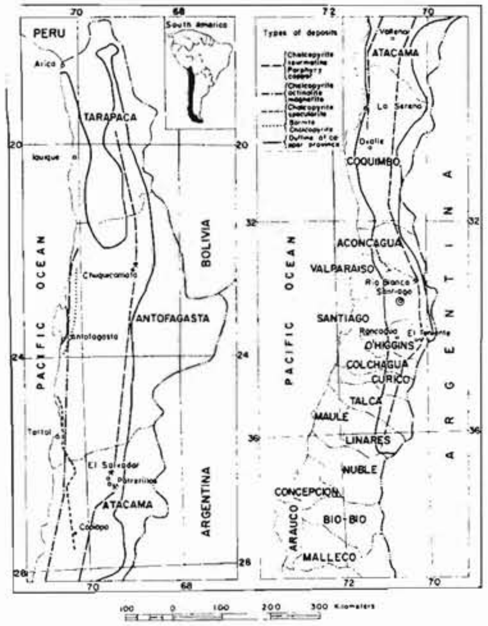

FIG. 3. Map of northern Chile showing lines along which certain types of copper deposits are most abundant.

The metals that have had a small and intermittent production are lead, zinc, cobalt, mercury, tungsten, and molybdenum. Only the lead-zinc provinces are shown on the metallogenetic maps; inasmuch as the copper deposits in these areas are of equal or more importance than the lead-zinc deposits, the provinces are shown as lead-zinc-copper (Figs. 1, 2). Lead-zinc deposits are found principally in two places in northern Chile, one in the eastern part of Tarapacá and northeastern Antofagasta and the other in the eastern part of Coquimbo, and in southern Chile, in the eastern part of Aysen. Cobalt has been recovered from several deposits distributed through the area extending from about the latitude of the city of Rancagua (O'Higgins) to near Copiapó. Mercury mines are in two areas, one near Ovalle and the other near Copiapó.

A few small tunsten deposits occur in the region of Vallenar and Salamanca (Coquimbo) and in Tarapacá and Aysen. Molybdenum is associated with certain of the copper deposits and is also found in small veins consisting chiefly of quartz and molybdenite, scattered throughout the length of Chile.

GEOLOGY OF THE HOST ROCKS

The host rocks of the ore deposits of the northern half of Chile are volcanic, sedimentary, contact-metamorphic, and plutonic rocks. Most deposits are found in andesitic volcanic rocks, including lavas, tuffs, and tuffaceous breccias, in sedimentary rocks, including limestones and sandstones, and in plutonic rocks. The host rocks are principally of Jurassic and Cretaceous age and only a few deposits are in younger or older rocks. In southern Chile most of the deposits are found in regionally metamorphosed rocks, for the most part schists, phyllites, and marbles of Precambrian (?) age.

Most of the ore deposits are spacially related to granite, granodiorite, or diorite plutonic rocks. Regional geologic studies and lead-alpha dating of the plutonic rocks of Chile (18) indicate that most of these rocks were emplaced during three periods, one near the end of the Paleozoic, a second near the end of the Jurassic, and the third during Late Cretaceous time. Most of the metalliferous deposits of Chile appear to be genetically related to plutonic rocks of Cretaceous age, some may be related to plutonic rocks of Jurassic age, but so far as is known none are related to earlier plutonic rocks.

The Mesozoic rocks of Chile are characterized by north-trending structures, including folds, faults, and elongate plutonic masses, that were the principal regional controls of mineralization. Folds tend to be broad open structures in which the stratified rocks dip at angles of less than 45°. Faults have a wide range in lengths and amounts of displacements; the largest faults are several hundred kilometers in length and have displacements of several hundreds or thousands of meters. Plutonic masses range in size from those having an outcrop area of only a few square kilometers to those that crop out over areas of many thousands of square kilometers.

The veins of individual deposits are generally localized along steeply dipping faults that have strikes corresponding to one, two, or three systems. A large number of the major veins in Chile trend near north, a smaller number trend N 45–70° E, and relatively few trend west or west northwest.

MINERALOGY AND PARAGENESIS

The accompanying paragenetic diagram (Fig. 4) shows most of the hypogene minerals found in the ore deposits of Chile and the types of deposits, listed in order of decreasing temperature of formation, that can be distinguished. In the diagram the height of the blocks is indicative of the relative abundance of minerals in each type of deposit. The representation of the paragenetic sequence is a compromise that fits the known paragenesis of many ore deposits. However, the sequence does not fit all the known deposits. The picture is generally more complicated than illustrated, for many of the minerals were

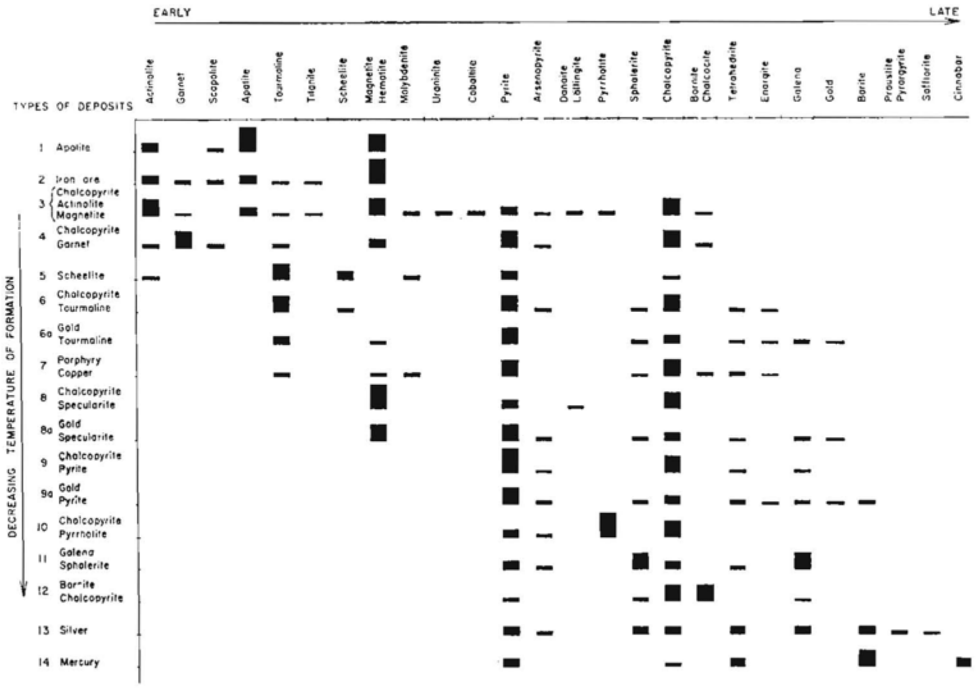

FIG. 4. Paragenetic diagram showing types of deposits and primary minerals.

deposited during two or more phases or were deposited jointly with other minerals. Pyrite, for example, formed in some veins during several phases that ranged from earliest to latest. However, pyrite generally is the earliest of the sulfide minerals. Quartz, the most abundant gangue mineral, is not shown because it apparently formed at any and all times and temperatures. Calcite is also an abundant mineral in many deposits but is not shown in the paragenetic diagram for the same reason, although in contrast to quartz, calcite generally did not form during the earliest part of the paragenetic sequence.

The most abundant and widespread metallic hypogene minerals found in Chilean ore deposits are pyrite, chalcopyrite, magnetite, and hematite (including specularite). The iron ores consist mainly of medium to coarsely crystalline magnetite and lesser amounts of hematite. Chalcopyrite is the most abundant copper mineral of copper deposits and furthermore occurs in varying quantities in nearly all metalliferous deposits. Recoverable gold is almost entirely in the native state. Pyrite is found in varying quantities in almost all deposits.

Oxidized copper minerals are widespread and in great variety; among those that are the most important constituents of ores are cuprite, malachite, atacamite, chrysocolla, brochantite, and antlerite. The abundant supergene copper sulfide ores consist mainly of chalcocite and to a lesser extent of covellite.

Most of the other minerals shown on the paragenetic diagram are less widespread and tend to be restricted to certain types of deposits. Lead-zinc deposits contain galena and sphalerite in more or less equal quantities and subordinate to minor amounts of chalcopyrite. As a general rule the galena is argentiferous. Cobalt deposits have cobaltite, cobaltiferous arsenopyrite (danaite), and löllingite as the principal cobalt-bearing minerals. Silver deposits have a wide variety of silver-bearing minerals, but the most abundant are argentiferous galena and tetrahedrite, argentite, proustite, and pyrargyrite. Mercury minerals are principally cinnabar and mercurial tetrahedrite. The only tungsten minerals that occur in commercial quantities are scheelite and wolframite. The most abundant manganese minerals are braunite, pyrolusite, and psilomelane.

TYPES OF DEPOSITS

The fourteen types and three sub-types of deposits shown on the paragenetic diagram (Fig. 4) and the manganese deposits represent the dominant ore types that can be recognized at present. A few other types can be recognized but are not discussed here because they are represented only by rare or anomalous deposits.

In the following discussion the deposits are grouped according to the principal exploitable metals. For purpose of reference, examples of mines or mining districts are given for each type of deposit. Of these, only the porphyry copper deposits are shown on the accompanying maps.

Iron

Iron deposits of three distinct types can be recognized in Chile; those in the provinces of Coquimbo and Atacama represent a dense, hard iron ore; the Laco deposits in the Andean region in the eastern part of the province of Antofagasta contain vuggy to cavernous ores; and those in the provinces of Valparaíso and Arauco are itabirites.

Individual deposits in the region between Ovalle and Taltal have reserves ranging from about 500,000 M.T. to approximately 15,000,000 M.T. In addition, each of the three largest deposits, Algarrobo, El Tofo, and Romeral, have or have had reserves ranging from about 30,000,000 to 100,000,000 M.T. Recent magnetometer surveys of the region between Copiapó and Vallenar indicate the presence of unexposed magnetite deposits that may be as large or larger than any of these three deposits. The deposits consist of hard ores of magnetite and lesser amounts of hematite which is mostly of secondary origin. Selective mining produces a shipping ore having an iron content of more than 60 percent. The principal contaminating elements are Al, Si, Mn, P, S, and Cu.

Apatite deposits, found in the same region, represent a special type of iron deposit which is high enough in apatite (21–33% P_2O_5) to make feasible exploitation for phosphate rather than for iron.

The Laco deposits are apparently unique in that they are the only known metalliferous deposits of magmatic origin and also the only primary (magmatic or hypogene) deposits occurring in rocks younger than Late Cretaceous age. The host rocks are dacite and rhyolite tuffs considered to be of Late Tertiary or Quaternary age. The ores, occurring in four deposits within an area of only a few square kilometers, consist of high-grade (about 65% Fe), hard and soft, and porous to cavernous magnetite-hematite that have many structural features indicative of near-surface intrusions or flows. Cavities ranging from less than a centimeter to nearly a meter in longest dimension, are circular to lenticular and irregular in shape and are lined or partly filled with octahedral crystals of martite or magnetite, or more rarely, hexagonal crystals of hematite. Crystals in the larger cavities are as much as five centimeters in diameter. At places the surfaces of the deposits are marked by irregular to elongate, cavernous, blister-like masses of iron ore, that appear to have formed by extrusion of a plastic material.

Park (15) briefly described the Laco ores and noted the presence of crystal-lined tubes that he interpreted to be gas escape tubes, and surface structures that he noted were similar to aa and pahoehoe lavas. He further concluded that the ore solidified from a magma highly charged with gas and consisting almost entirely of iron oxides, that was probably intruded at shallow depths and at places broke through to the surface to form flows. Our limited observations confirm the magmatic origin of the deposits but it seems more probable that each of the four deposits represents an intrusion that may have broken through to the surface but that the actual surface flow from these centers was insignificant.

The iron ore of Arauco (Fig. 1) occurs in a sequence, about 20 m thick, consisting of one to three-meter layers of itabirite separated by nearly barren layers of schist or quartzite of comparable thickness. The sequence is within and parallel to foliation of mica schist. The itabirite is finely banded and consists principally of magnetite partly altered to hematite, and quartz. Highest grade ore ranges from 30 to 40% Fe.

Copper

The following types of hypogene copper deposits are recognized: chalcopyrite-actinolite-magnetite, chalcopyrite-garnet, chalcopyrite-tourmaline, porphyry-copper, chalcopyrite-specularite, chalcopyrite-pyrite, chalcopyrite-pyrrhotite, and bornite-chalcopyrite.

The chalcopyrite-actinolite-magnetite deposits are moderately widespread; chiefly in a belt near the coast, extending from near La Serena to about the latitude of Chuquicamata (Fig. 3). Many contain cobalt minerals and a large part of the cobalt produced in Chile came from deposits of this type. The deposits are typically fissure-filling and replacement veins along fractures that trend N 45° E to east, thus cutting across the structural grain of the Andes. The veins are generally within but near the borders of intrusive rocks that range from diorite to granodiorite; a few veins are in the contact-metamorphic rocks bordering the intrusions. Many are associated with diabase dikes. The veins are as much as 3 km in length, and values extend to depths of 500 to 700 m. Mines on veins of this type in general are the deepest in Chile, and were of primary importance in the latter half of the last century when Chile was the world's major producer of copper. The principal deposits are in the districts of La Higuera (Coquimbo); Carrizal Alto, Quebradita-Labrar, and Las Animas (Atacama); and Gatico and Tocopilla (Antofagasta).

Deposits of chalcopyrite-garnet are found in contact-metamorphosed limestone near diorite or granodiorite intrusives. The copper ores occur in the form of replacement bodies, including low-dipping mantos and irregular masses, in which the sulfide minerals occur as pods, blebs, veinlets, and disseminated grains. In general, the deposits range from small to medium in size. The principal mining districts are Pintadas (Atacama), Panulcillo and San Antonio (Coquimbo), and Los Maquis (Aconcagua).

Chalcopyrite-tourmaline and gold-tourmaline deposits are two related types; the first contain abundant chalcopyrite, and the second contains less chalcopyrite and moderately abundant gold. The deposits are typically lenticular to circular breccia pipes, within granodiorite plutonic masses, that range from a few meters to about 100 m in longest dimension and extend to depths of as much as 200 m. Quartz and coarsely crystalline tourmaline cement and partly replace wall rock breccia fragments. Chacopyrite and other sulfide minerals fill fractures and cavities within the quartz and tourmaline and replace minerals in the breccia fragments. The gold generally occurs as blebs in the chalcopyrite. As a general rule, the highest grade gold and copper ores are found in zones where the host rock has been most intensely sericitized. Characteristic chalcopyrite-tourmaline deposits are San Pedro de Cachiyuyo, Cabeza de Vaca, El Orito, and Llamuco (Atacama); the mine El Chivato (Talca) is the typical gold-tourmaline deposit.

The porphyry-copper deposits are characterized by small stock-like intrusions of porphyritic rock of a composition near that of granodiorite, and the ores occur in these intrusions or in surrounding rock, principally andesitic lavas, tuffs, and tuffaceous breccias. At least part of the porphyry-copper deposits have pipe-like breccia bodies. The host rocks are hydrothermally altered to a light-gray or white rock that contains much sericite and kaolin and varying amounts of secondary quartz. The typical deposit is capped by a leached zone ranging from a few meters to more than 100 m in thickness, under which is an enriched zone containing abundant oxidized minerals such as antlerite, brochantite, and atacamite, and many other oxidized minerals of copper and iron in lesser to minor quantity. Below the oxidized zone is a supergene sulfide zone that contains secondary chalcocite in association with primary chalcopyrite and pyrite. This zone grades downward into protore containing chalcopyrite and pyrite. The total thickness of oxidized ore and enriched sulfide ore is generally more than 100 m. Copper minerals are disseminated through the host rock, for the most part as veinlets, blebs, and grains in zones that have been intensely fractured.

The porphyry-copper deposits are related to the chalcopyrite-tourmaline deposits in that they represent hypogene mineralization, including chalcopyrite and tourmaline, of an intensely fractured and altered igneous rock. However, the porphyry-copper deposits contain tourmaline as a minor constituent, and the copper content is lower than in the chalcopyrite-tourmaline breccia pipes.

The deposits now being exploited in Chile are very large; probable total reserves are in excess of 3,000 million tons of ore, ranging from 1.3 to 1.9 percent copper. They are found along the western front of the Andes, at altitudes between 2,000 and 4,000 m, from El Teniente in the south to Chuquicamata in the north (Fig. 1). Furthermore, deposits of the porphyry-copper type are found even farther northward in Chile and in southern Perú. The deposits in Chile that have been worked on a large scale are Chuquicamata, El Salvador, Potrerillos, and El Teniente. Figure 3 shows the axis along which most of the porphyry copper and chalcopyrite-tourmaline deposits are located.

Chalcopyrite-specularite and gold-specularite deposits are related types found many places in Chile. The gold-specularite deposits differ from the chalcopyrite-specularite deposits mainly in having a higher gold content, relatively little copper, and by the presence of minerals such as galena and tetrahedrite that were deposited late in the paragenetic sequence. Some of the deposits also contain magnetite and others contain calcite, which, in contrast to the condition in most deposits, was the earliest mineral to be formed. Most of the deposits are veins localized along relatively large north-trending faults. The host rock is granodiorite or andesite. Examples of the chalcopyrite-specularite deposits are the Cerro Negro and Manto Verde mines of the El Salado district, San Francisco and Tránsito mines of the Ojancos district, and the Castilla mine (Atacama); and La Africana mine (Santiago). The principal mines of the gold-specularite type are found in the districts of Los Mantos de Punitaqui and Canelillo (Coquimbo). Figure 3 shows the axis along which a number of the chalcopyrite-specularite mines are located.

The chalcopyrite-pyrite and gold-pyrite deposits are related types that are numerous and widespread in northern Chile. The gold-pyrite deposits are the most numerous of all the gold deposits; they differ from the chalcopyrite-pyrite deposits principally in having relatively high gold and low copper values. Both types of deposits generally occur as narrow fissure-filling veins consisting principally of quartz, pyrite, and chalcopyrite, localized along faults of small horizontal and vertical extent; gold-pyrite replacement deposits represent an exceptional type found in the Andacollo region of Coquimbo. Primary ore is generally low-grade, and at most deposits exploitable ores occur only in the oxide and supergene sulfide zones. Important deposits of the gold-pyrite type are in the district of Andacollo and Las Vacas and Jolie mines in Coquimbo, and El Bronce de Petorca mine in Aconcagua. Examples of chalcopyrite-pyrite deposits are Galleguillos, Checo de Cobre, and Cerro Blanco (Atacama) and Delirio Punitaqui (Coquimbo).

Chalcopyrite-pyrrhotite deposits are relatively scarce; the best known examples are those in southern Chile, particularly in the region of Lago General Carrera. Deposits are represented by well defined fissure-filling veins and by irregular to lenticular or tabular replacement bodies. The ores consist principally of dense, fine-grained pyrrhotite and chalcopyrite; pyrite is abundant in some deposits. A typical deposit is the Las Chivas mine at Lago General Carrera in Aysen.

Bornite-chalcopyrite deposits are small to medium in size and are found principally in the provinces of Aconcagua and Antofagasta (Fig. 3). The ores consist of finely disseminated bornite and varying but generally lesser amounts of chalcopyrite; part of the ores, particularly those from mines in Antofagasta, contain primary chalcocite as an abundant ore mineral. The copper minerals fill cavities in favorable beds such as amygdaloidal andesite flows, tuffs, and tuffaceous breccias, or partly replace these rocks and limestone. Fissure filling veins or impregnations of fault breccia zones are relatively scarce. Typical deposits are El Soldado and La Patagua in Aconcagua, Teresita and Frankenstein in Atacama, and Portezuelo and Santo Domingo in Antofagasta.

Cobalt

Cobalt deposits, exploited since about the middle of the last century until the 1940's, include fissure filling veins and mantos in which cobalt minerals were deposited by impregnation and replacement. There are two types of deposits, those in which cobaltite is the principal or only recoverable metallic mineral and those having cobalt minerals, generally cobaltiferous arsenopyrite and löllingite, in recoverable amounts associated with copper ores such as the chalcopyrite-actinolite-magnetite and chalcopyrite-specularite types. In addition, cobalt minerals occur in nearly all of the silver mines of northern Chile but in such small quantity as to have no economic importance. Important deposits of cobaltite occur at El Buitre and Minillas mines in Coquimbo and in the San Juan mining district in Atacama. Cobaltiferous copper deposits of the chalcopyrite-actinolite-magnetite type are in the district of Carrizal Alto (Atacama). The Mercedita mine (Santiago) is an example of the cobaltiferous chalcopyrite-specularite type deposit.

Tungsten

Small amounts of tungsten ore have been produced from mines in the regions of Vallenar and Salamanca. Only a few deposits are found outside these regions. Scheelite, the only important tungsten mineral, occurs as disseminations in granitic rock, generally along joints and small faults, aplite dikes, or tourmalinized breccia zones. Ore bodies are small, generally only a few meters in length; the largest bodies are irregular in shape and have a maximum dimension of 20 to 30 m. The Llamuco mine near Salamanca is a typical scheelite deposit.

Recently deposits containing wolframite have been discovered in the province of Aysen but the quantity and grade of ores is not known.

Gold

Gold deposits, next to copper deposits, are the most numerous and widespread in Chile but whereas the total gold production is moderately large, the amount produced by any one deposit has been relatively small. Most of the gold has come from oxidized zones of fissure-filling veins, from placer deposits or has been a by-product of other ores, such as copper and silver. The three principal types of gold deposits, gold-tourmaline, gold specularite, and gold pyrite, are similar to certain copper deposits and have already been described.

Molybdenum

Molybdenite, in the form of disseminations and veinlets, occurs in recoverable amounts in most if not all the porphyry-copper deposits of Chile. Furthermore, part of the chalcopyrite-actinolite-magnetite deposits and tungsten deposits contain small amounts of molybdenite and in a few regions, particularly in Aysen, small, fissure-filling veins of molybdenite and quartz occur within large granodiorite or diorite plutonic masses. Practically all molybdenum production has come from the porphyry-copper ores.

Lead-zinc

The lead-zinc deposits of Chile are relatively small and few in number; production of lead-zinc ore has been correspondingly small. Deposits include impregnations of stratified rocks such as volcanic tuff (mina Galena, Coquimbo), lenticular to irregularly shaped bodies in limestone (mina Silva, Aysen), and as fissure-filling veins (Jauja mine, Tarapacá, and Guadal mine, Aysen), Galena and sphalerite are the only important hypogene lead and zinc minerals; at some mines secondary ores have been exploited for cerussite. Some mines contain recoverable amounts of chalcopyrite whereas others are nearly barren of copper minerals. Nearly all the lead-zinc ores contain silver, generally in quantities on the order of several hundred grams per metric ton, as well as a few grams of gold.

Silver

The silver deposits are along fault or shear zones, or along favorable horizons in stratified rocks where silver and associated minerals fill open spaces and partly replace the host rock. The most favorable rock type is limestone, but some deposits are in tuff, tuffaceous breccia, intrusive andesitic porphyry, and conglomerate. Deposits are of two general mineralogical types, one having argentite and argentiferous galena and tetrahedrite, and the other with the ruby silver minerals proustite and pyrargyrite predominating. Generally the highest-grade ore is found in the oxidized and enriched portions of the veins, which contain a wide variety of silver minerals. In some mines secondary ores were found at depths of more than 400 m. The most important mining districts are Huantajaya and Santa Rosa in Tarapacá, Caracoles in Antofagasta, and Chañarcillo and Tres Puntas in Atacama.

Mercury

Chile has had a small and intermittent production of mercury that started during the latter part of the 18th century and has continued until the present. The mercury occurs in fissure-filling veins of limited horizontal and vertical extent and generally less than a meter in width. Within the veins, the distribution of the mercury minerals is sporadic and ore shoots are relatively small. The principal mercury mines are in the Punitaqui district, Coquimbo.

Manganese

Four types of manganese deposits can be recognized, mantos associated with tuffaceous sandstones of Cretaceous age, mantos associated with quartzite layers in mica schists of Precambrian (?) age, lacustrine deposits of Pliocene or Quaternary age, and vein deposits.

The largest and most productive manganese deposits are those of Coquimbo, which consist of low-dipping mantos of sedimentary manganese ore in a unit of continental sediments, principally tuffaceous sandstones but also having layers of tuffaceous breccias and limestones, within a thick sequence of volcanic rocks of Lower Cretaceous age. The deposits generally comprise two to four mantos, which together with interstratified sandstone make up a stratigraphic unit ranging from about 3 to 20 m in thickness. The mantos are variable in thickness, ranging from as little as a few centimeters to as much as three meters; however, most are between 50 cm and a meter in thickness. The most abundant manganese minerals are braunite, pyrolusite, and psilomelane.

The manganese deposits of the province of Valdivia have only recently been discovered and little is known of their extent or economic possibilities. Manganese oxide, mainly pyrolusite, occurs as disseminations, films on joints, pods, and irregular to lenticular masses generally less than 5 m in longest dimension, in 1-to-2-m quartzite layers within a sequence of Precambrian schist. One deposit contains rhodonite and it is evident that the manganese oxide here as well as at the other deposits formed as the result of oxidation of this mineral.

Lacustrine deposits of manganese are found at high altitudes, near the border of Perú. The manganese, occurring chiefly as pyrolusite, is in layers associated with semi-consolidated tuffaceous sandstones and siltstones; one deposit consists of narrow layers, generally less than 5 cm thick, of manganese oxide in a deposit of kieselguhr. At least one of the deposits shows well-defined slump structure developed during the period of deposition.

Manganese deposits of the vein type are found at several places in northern Chile, including the areas described above. These deposits are small generally consisting of irregular masses only a few meters long and less than a meter wide, localized along fault zones. Pyrolusite is the principal manganese mineral.

CLASSIFICATION AND GENESIS

The metalliferous deposits of Chile can be divided into four classes as hydrothermal, contact-metasomatic, magmatic, and sedimentary. The deposits of copper, gold, and silver are hydrothermal. Most of the iron ore deposits are contact-metasomatic and most of the manganese deposits are of sedimentary origin.

The close association of hydrothermal deposits with the igneous intrusive rocks is indicative of a genetic relationship. It is probable that these intrusive rocks were the source of the mineralizing solutions that were released after emplacement of the intrusive body, and when upper portions of the intrusives had become solid enough to deform by fracturing. Most of the hydrothermal deposits are in the form of well-defined, steeply dipping fissure-filling veins

and tabular to irregularly shaped replacement bodies in which hypogene minerals were deposited by cavity filling or replacement. The metallic minerals of the deposits range from solid masses to fine disseminations.

The hydrothermal deposits probably formed under conditions ranging from high to low temperature and pressure, or, according to the Lindgren (10) classification, they range from hypothermal to epithermal. In a general way, deposits can be classified as follows: silver and mercury deposits are epithermal; lead-zinc deposits are in the range between mesothermal and epithermal; copper and gold deposits are mostly mesothermal, but some are hypothermal; tungsten and molybdenum deposits are hypothermal.

The contact-metasomatic iron ore deposits of the region between La Serena and Taltal are irregularly shaped, lenticular and tabular bodies that generally occur in metamorphic rocks near or at the contacts with diorite or granodiorite plutons. The iron oxides were emplaced largely by replacement. The newly discovered deposits near the Argentine border east of Antofagasta probably solidified, as intrusions and flows, from a magma that consisted almost entirely of iron oxides and which was highly charged with gas. The itabirite deposits in the provinces of Arauco and Valparaíso consist of banded ores in Precambrian (?) metamorphic rocks. They are probably of sedimentary origin.

The lacustrine manganese deposits of northernmost Chile and the layered deposits of the province of Coquimbo are clearly of sedimentary origin. The isolated manganese veins of northern Chile are of hypogene origin, but it is not known whether the manganese oxides were the primary minerals or whether they formed as the result of oxidation of manganese carbonate or silicate. The manganese oxides of the deposits in the province of Valdivia evidently formed by near surface oxidation of rhodonite which in turn may have formed by metamorphism of arenaceous manganese oxide deposits of sedimentary origin.

SUMMARY

1. Deposits of copper, iron, gold, lead-zinc, silver, and manganese in Chile occur in certain well-defined regions that are designated as metallogenetic provinces. Nearly all known deposits are in the northern half of Chile. Copper deposits are the most numerous and widespread of all metalliferous deposits; gold deposits rank second to copper in abundance, and other deposits are fewer in number.
2. At least 14 types and 3 sub-types of hypogene metalliferous deposits can be distinguished on the basis of metal or mineralogical content.
3. Hypogene minerals of most Chilean ore deposits are few in number; most abundant are the simple sulfides and oxides such as pyrite, chalcopyrite, magnetite, hematite, and quartz.
4. Metalliferous deposits, such as copper, gold, lead-zinc, etc., are hydrothermal; most iron ore deposits are contact-metasomatic; and most manganese deposits are sedimentary.
5. Hydrothermal and contact-metasomatic deposits appear to be genetically related to Late Cretaceous plutonic rocks of granite-diorite composition; some may be related to intrusive rocks of Late Jurassic age.

ACKNOWLEDGMENTS

We are indebted to señorita Sonia Mehech of the IIG for compiling much of the data used in preparation of the paragenetic diagram. The following persons read the manuscript and made many valuable suggestions: Kenneth Segerstrom and W. D. Carter, U. S. Geological Survey, Prof. Hector Flores, University of Chile, and Pierre St. Amand, China Lake Naval Ordnance Testing Station.

DIRECTOR, INSTITUTO DE INVESTIGACIONES GEOLÓGICAS, SANTIAGO, CHILE,
U. S. GEOLOGICAL SURVEY, SANTIAGO, CHILE,

Aug. 24, 1961

REFERENCES

1. Biese, W. A., 1956, Los yacimientos de manganeso de Chile: XX Congreso Geológico Internacional, Symposium sobre yacimientos de manganeso, tomo 3, p. 377–416, México.
2. Domeyko, Ignacio, 1897, Mineralogía: Minerales metálicos: tomo 2, Imprenta Cervantes, Santiago, Chile.
3. ——, 1900, Mineralogía: Memorias mineralógicas: tomo 4, Imprenta Cervantes, Santiago, Chile.
4. Flores W., Héctor, 1942, Geología de los yacimientos de cobre y oro de Chile: Anales del Primer Congreso Panamericano de Ingeniería de Minas y Geología, tomo 3, p. 1145–1185, Santiago, Chile.
5. ——, 1944, Antecedentes geológicos sobre los yacimientos de plomo de Chile: Bol. Minero de la Soc. Nac. de Minería, N° 526, p. 173–180, Santiago, Chile.
6. ——, 1946, Estudio geológico sobre las minas de plata de Santa Rosa, provincia de Tarapacá, Chile: Anais do Segundo Congresso Panamericano de Engenharia de Minas e Geologia, v. 2, p. 223–241, Petropolis, Brasil.
7. —— and Ruiz F., Carlos, 1946, Estudio geológico del distrito de Inca de Oro, provincia de Atacama, Chile: Anais do Segundo Congresso Panamericano de Engenharia de Minas e Geologia, v. 2, p. 243–273, Petropolis, Brasil.
8. Hornkohl, Herbert, 1942, El cobalto en Chile: Anales del Primer Congreso Panamericano de Ingeniería de Minas y Geología, tomo 4, p. 1602–1625, Santiago, Chile.
9. Kuntz, Julio, 1928, Monografía minera de la provincia de Antofagasta: Bol. Soc. Nac. de Minería, v. XL, N° 348, p. 190–209; N° 349, p. 253–275: and N° 350, p. 301–334.
10. Lindgren, Waldemar, 1933, Mineral deposits: 4th ed., McGraw-Hill Book Co., New York.
11. Little, J. M., 1926, The geology and metal deposits of Chile: The Branwell Co., New York.
12. McAllister, J. F., and Ruiz F., Carlos, 1948, Geology of tungsten deposits in north-central Chile: U. S. Geol. Survey Bull. 960-C, p. 89–106.
13. ——, Flores W., Héctor, and Ruiz F., Carlos, 1950, Quicksilver deposits of Chile: U. S. Geol. Survey Bull. 964-E, p. 361–400.
14. Miller, B. L., and Singewald, J. T., 1919, The mineral deposits of South-America: McGraw-Hill Book Co., New York.
15. Park, C. F., 1961, A magnetite "flow" in northern Chile: ECON. GEOL., v. 56, p. 431–436.
16. Ruiz F., Carlos, 1942, Estudio geológico de la región Ojancos-Punta del Cobre: Anales del Primer Congreso de Ingeniería de Minas y Geología, tomo 3, p. 1186–1225, Santiago, Chile.
17. ——, 1943, Los yacimientos de hierro de la región noroccidental de Copiapó, un tipo no descrito de yacimientos de contacto-metamórfico: Bol. Minero de la Soc. Nac. de Minería, N° 522, p. 820–887; N° 523, p. 906–915, Santiago, Chile.
18. ——, Segerstrom, Kenneth; Aguirre, Luis; Corvalán, José; Rose, Jr., H. J.; and Stern, T. W., 1960, Edades plomo-alfa y marco estratigráfico de granitos chilenos: Inst. Inv. Geol. de Chile, Bol. 7, 26 p.
19. Servicio de Minas del Estado, 1960, Estadística minera y metalúrgica de Chile del año 1959: Imprenta Wilson, 55 p., Santiago, Chile.
20. Whitehead, W. L., 1925, Las vetas de Chañarcillo, Chile: Bol. Minero de la Soc. Nac. de Minería, N° 309, p. 34–41; N° 310, p. 81–91; N° 311, 134–142; N° 312, p. 195–201; N° 313, p. 269–275; N° 314, p. 353–359, Santiago, Chile.