THE MINERAL DEPOSITS
OF
SOUTH AMERICA

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BY
BENJAMIN L. MILLER, PH. D.
PROFESSOR OF GEOLOGY, LEHIGH UNIVERSITY
AND
JOSEPH T. SINGEWALD, JR., PH. D.
ASSOCIATE PROFESSOR OF ECONOMIC GEOLOGY, JOHNS HOPKINS UNIVERSITY

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PREFACE

This book is the outcome of an extended trip through South America made by the authors in 1915. Many of the mineral deposits of Brazil, Chile, Bolivia, and Peru were visited, and the results of the observations have been presented in a number of articles in scientific and technical journals, particularly in the Engineering and Mining Journal. Not only was the trip an intensely interesting one, but the authors encountered an equal interest among the mining people whom they met to know about the mining districts that had been visited. The suggestion was made more than once that their observations should be assembled in book form.

It was obvious that of more value than a mere assembling of their writings on the districts with which they were personally familiar, would be a comprehensive treatise on the mineral deposits of the entire continent. Accordingly the present volume was planned. To supplement their own experience, the authors compiled a bibliography of the literature dealing with the mineral deposits of each of the South American countries. The chapters of this volume are consequently a digest of available information covering the mineral deposits of those countries.

The chapter on the economic geology of South America is a résumé of the characteristics of the mineralization of the continent as a whole. The chapters on Brazil, Chile, Bolivia, and Peru are based on the authors' joint personal observations, supplemented by data obtained from published descriptions and from persons familiar with those countries. The chapters on Argentina, Ecuador, and Uruguay written by Mr. Singewald are based, in part, upon casual observations made by the authors in rapid trips across those countries, but mainly upon published data. The chapters on Guiana and Venezuela prepared by Mr. Miller and those on Colombia and Paraguay by Mr. Singewald are based on the literature listed in the bibliography, supplemented by information obtained from persons who have examined the mineral deposits of those regions.

An outstanding feature of the trip and the preparation of the book, was the hearty spirit of coöperation and genuine interest in their purposes that the authors encountered. It would be almost impossible to enumerate all who in some measure contributed to the success and comfort of the trip. To numerous friends in South America, the authors owe a great debt of gratitude, and they wish to express to all their keen sense of appreciation. The selection of a few names from among the many for special mention will be understood as a matter of necessity and not lack of appreciation of the courtesies accorded by the others.

In the first place, the authors are indebted to Mr. Henry G. Ferguson, of the U. S. Geological Survey, who had just returned from a similar trip, for much first-hand information, travel notes, and introductions to people in the countries visited. Similar information was obtained from Mr. Franklin Adams of the Pan American Union. Mr. W. L. Cumings has contributed useful data concerning a number of iron and manganese deposits of several countries. The agencies of W. R. Grace & Co. were always willing to be of assistance and were called upon repeatedly.

Conversations with Dr. H. Keidel in Buenos Aires, chief of the geologic section of the Division of Mines, Geology, and Hydrology, were of considerable value in orienting us as to the geology and mineral deposits of Argentina.

In Bolivia we were particularly indebted to Mr. Jorge Zalles and Mr. Arturo Posnansky in La Paz; at Huayna Potosi to the owners of the mines, the Huet Brothers, and Mr. Ernesto Martinet, Superintendent of La Union mill; at Corocoro to Mr. Fernando Dorian, General Manager, Mr. Adrian Barton, Chief Engineer, and Mr. Rodolpho Michels, all of the Corocoro United Copper Mines, Ltd., and Mr. F. A. Sundt, Manager of the Compañia Corocoro de Bolivia; at Huanuni to Mr. Carlos E. Michels, General Manager; at Uncia to Mr. Maximo Nava, General Manager, Mr. Alexander Grosberg, Mill Superintendent, and Mr. Jorge Bastide, Mine Superintendent; at Oruro to Mr. P. F. Bliek, Manager, and Mr. Heinrich F. Grondijs, Consulting Engineer, of the Compañía Minera de Oruro; at Potosi to Mr. José Aguirre Achá, prefect of the department, Messrs. Louis Soux and Eduardo Soux and Mr. Jorge W. Kohagen, their Chief Engineer, Mr. Joseph Richards, Manager of the Anglo-Bolivian Mining Syndicate, Mr. Alfredo Delgado of Bebin Hermanos, and Mr. Van Antes Simons; at Porco to Mr. Harold A. Lewis, Manager of the Porco Tin Mines, Ltd.

In Brazil, we were fortunate in having our trip through the country outlined and planned for us by Mr. Orville A. Derby, who for forty years had been engaged in the study of Brazilian geology and was at that time the director of the geological work of the Government. Dr. John C. Branner, President Emeritus of Leland Stanford Junior University, furnished us with valuable information in preparation for the trip and has critically examined the manuscript of the chapter dealing with that country. Dr. E. C. Harder furnished important data in regard to Brazil and criticized the manuscript of that chapter. In Rio de Janeiro we were assisted by Mr. Raymundo Floresta de Miranda, Federal Delegate of the Brazilian Railways; at the Morro Velho Mine by the able Superintendent, Mr. George Chalmers and other members of his staff; at Passagem by Mr. Arthur J. Bensusan, Superintendent of the Ouro Preto Gold Mines; at Lafayette by Dr. Joaquim de Almeida Lustosa, Manager of the Companhia Morro da Mina; at Miguel Burnier by Mr. Carlos da Costa Wigg, Manager of several manganese mines of that section; at Diamantina by Mr. Nelson F. Humphrey, Mr. Wm. O. Taylor and Mr. George Smith. Through the courtesy of the Brazilian Iron and Steel Company we were enabled to visit many of the iron-ore deposits of Minas Geraes under the guidance of the Resident Manager, Mr. J. E. Carney.

In Chile we were indebted for many favors to Mr. William Braden, Mr. Lorenzo Sundt, Dr. E. Maier, and Dr. Johannes Brüggen of Santiago; to Mr. A. A. Sorenson, General Manager, and Mr. L. E. Grant, Mr. H. W. Jones, Mr. H. K. Graham, Mr. A. T. Ward, and other members of the staff of the Braden Copper Company; to Mr. Hubert Merryweather, General Manager of the Bethlehem Chile Iron Mines; to Mr. W. A. Perkins of Chuquicamata; to Mr. Adolf Garni, Managing Director of the Nitrate Agencies Company, Iquique; to Mr. O. R. Witt, General Manager and Mr. T. E. Davies of the Oficina Paposo, La Noria; to Mr. S. W. Hunt, General Manager of the Central Lagunas Oficina, Lagunas; to Mr. Carlos A. Outram, General Manager of the Agna Santa Oficina, Negreiros; and to Mr. Humberto Vaccaro of Tacna.

We wish to express our thanks to Prof. Tulio Ospina for a critical reading of the manuscript for the Colombia chapter, and likewise to Dr. Joseph E. Pogue of Northwestern University for the same service.

In Peru, we were indebted to Mr. Sidney Jennings, Vice-president of the U. S. Smelting and Refining Company and Mr. E. E. Marshall representing the same company, and Mr. W. J. Hamilton, Manager of the Cerro de Pasco Mining Company; at Cerro de Pasco to Mr. Hugh Joy, Superintendent of the company's railroad, Mr. P. S. Couldrey, Superintendent, Mr. Reginald Leonard, Chief Engineer, Mr. James H. Smith, Jr., Mining Engineer, Mr. C. O. Stee, Foreman of the Excelsior mine, Mr. Charles R. Atkinson, Assistant Superintendent of the smelter, and Mr. Bartholomé Novoa of the San Expedito mine; at Goyllarisquisga to Mr. Charles Emerson; at Quishuarcancha to Mr. W. A. J. Murdock; at Colquijirca to Mr. Julio N. Arce; at Minasragra to Mr. Antenor Rizo Patron and Mr. Frederico Garcia; at Morococha to Mr. Theodore Herchmer, Acting Superintendent, Mr. John G. Baragwanath, Mine Captain, Mr. Herbert Lesh, Captain of the San Francisco mine, all of the Morococha Mining Company, and Mr. A. S. Howie, Superintendent of the Backus and Johnston Company's mines; at Casapalca to Mr. Joseph A. Irving, Superintendent of the Backus and Johnston Company's mines.

The authors are fully cognizant of the fact that in the preparation of a book of this sort, errors and omissions are inevitable. They will count it a favor to have their attention called to such and will cheerfully receive suggestions for improvement. The subject of the book is one of increasing interest and importance to American mining men and students of ore deposits the world over, and such coöperation on the part of its readers will aid in any revision or rewriting of the volume that may be called for in the future. Their own experience in preparing for their trip assures them that in the completion of their task, they have filled a genuine want in the literature of economic geology, irrespective of the measure of success they may have achieved.

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MINERAL DEPOSITS OF SOUTH AMERICA

CHAPTER I

ECONOMIC GEOLOGY OF SOUTH AMERICA

The distribution and occurrence of the mineral deposits of South America are intimately connected with the physiographic and geologic features of the continent. Likewise the development of the mineral resources has been influenced by the physiographic and geologic features. For example, the Western Cordillera or Andes Mountains, forming the longest continuous range of high mountains on the globe, contain most of the important mineralized areas and they have also been the chief factors influencing the exploration, settlement, and development of the continent. There can be no question but that the whole history of South America would have been far different if this great area of uplands had not existed or if it occupied another part of the continent. Each of the various physiographic provinces possesses distinct geologic characteristics which are responsible for the mineral deposits. For these reasons a brief sketch of the physiography and geology of the continent is given in this introductory chapter.

PHYSIOGRAPHIC DIVISIONS

The great physiographic divisions of South America are the following: (1) Guianan Highlands, (2) Brazilian Highlands, (3) Cordilleras, (4) Llanos and fluviatile plains of the Orinoco River, (5) Amazon River Plains, (6) Plains of the Paraguay and Paraná rivers, (7) Patagonian Pampas, and (8) Coastal Plains (Fig. 1).

The first three divisions constitute the highlands and contain nearly all the mineral deposits of economic importance, while the remaining divisions form the lowlands with enormous agricultural possibilities.

The Guianan and Brazilian highlands are sometimes considered as constituting a single physiographic unit, although separated by the Amazon River basin, and called the "Eastern Highlands." The various plains mentioned, with the exception of the Coastal Plains, are all connected and are sometimes regarded as a single unit, termed the "Central Lowlands." In the discussion of the physical features of each of the countries more detailed descriptions will be given than are included in this chapter.

Guianan Highlands.—Lying between the Orinoco and Amazon River basins and bordered by them on the north, west, and south sides is an area of highlands known as the Guianan Highlands. They are included within the southern parts of Venezuela, and the Guianas (British, Dutch, and French) and the northern part of Brazil. The region has never been thoroughly explored and contains few permanent settlements. Indian tribes, some of which are scarcely known, are almost the sole inhabitants, except near the borders of the uplift and along some of the navigable streams where the gold seekers have penetrated.

The region is one of great irregularity, the isolated hills and ridges revealing little orderly arrangement or alignment and winding streams have cut wide valleys between them. The elevations in this area are moderate, although a few of the highest points, which occur in the western portions, rise to about 11,000 feet above sea level. The highlands lie within the belt of the northeast trade winds so that the northern slopes have heavy rainfall while the southern slopes draining into the Amazon River receive very little rain.

These highlands are mainly composed of early Paleozoic or pre-Cambrian metamorphic crystalline rocks, overlain in places by practically horizontal strata of Mesozoic age. The structure and relations of these rocks are as complex as that of the ancient crystallines of other continents and in very few places have they been worked out and then only in restricted areas where minerals of economic importance are found.

The economic mineral resources of the Guianan Highlands are neither varied nor rich, with the exception of the famous El Callao gold mine of Venezuela. Gold is widely distributed throughout the entire region but has been found in payable quantities in few places. On account of the depth of rock decomposition and, in places, the dense plant growth, lodes are not readily discovered. Placer gold deposits have been worked

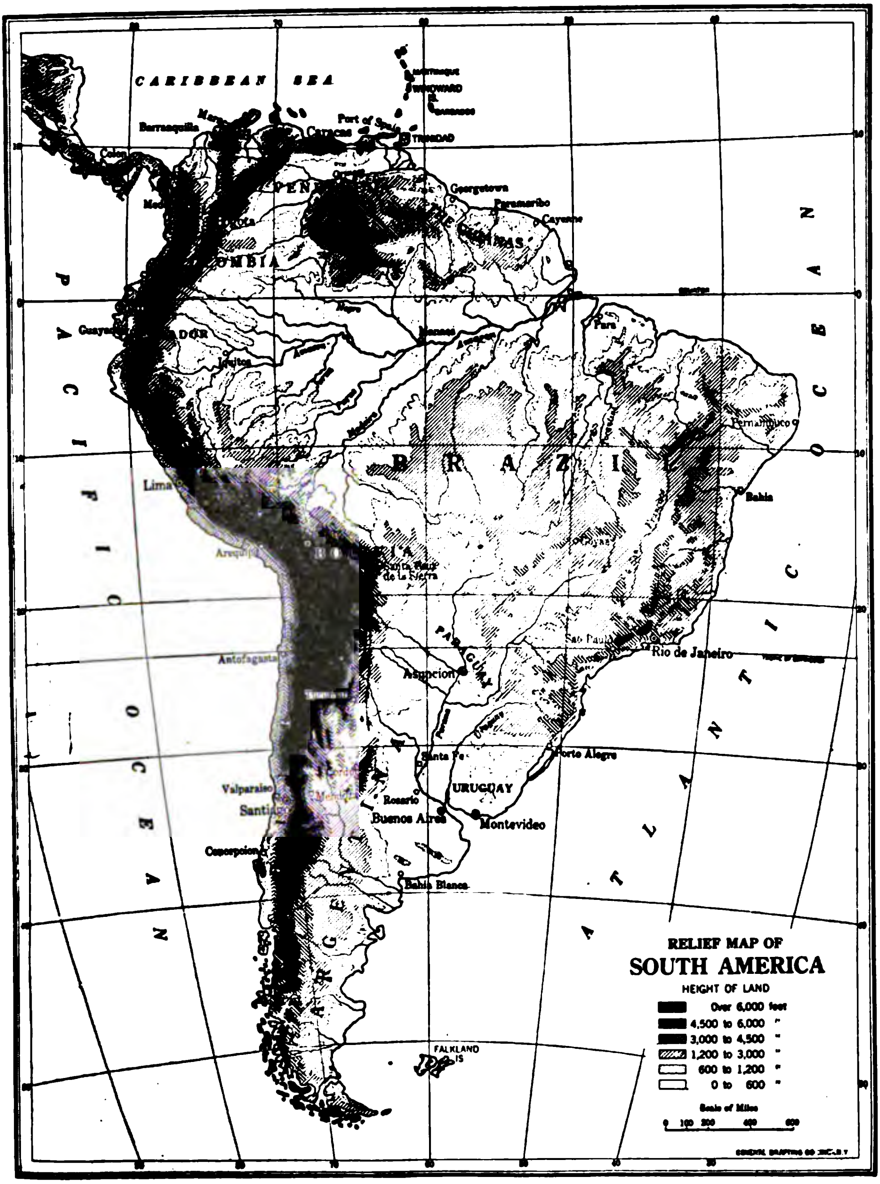
CARIBBEAN SEA
Barranquilla
Caracas
Port of Spain
TRINIDAD
Colon
Georgetown
Paramaribo
Cayenne
Para
Manaos
Iquitos
Pernambuco
Bahia
Lima
Arequipa
Santa Cruz de la Sierra
Antofagasta
Asuncion
Rio de Janeiro
Sao Paulo
Porto Alegre
Santa Fe
URUGUAY
Rosario
Buenos Aires
Montevideo
Valparaiso
Santiago
Concepcion
Bahia Blanca
FALKLAND IS
B R A Z I L
PACIFIC OCEAN
ATLANTIC OCEAN
RELIEF MAP OF
SOUTH AMERICA
HEIGHT OF LAND
Over 6,000 feet
4,500 to 6,000 "
3,000 to 4,500 "
1,200 to 3,000 "
600 to 1,200 "
0 to 600 "
Scale of Miles

Fig. 1.

along many streams while diamond placers also exist in the Guianas.

The mineralization in most cases seems to be an accompaniment of igneous intrusion, part of which is at least late-Triassic and perhaps even more recent, since some of the intrusives cut the Mesozoic rocks which overlie the older crystallines. Probably the mineralized dikes and quartz veins are of various ages from pre-Cambrian to Mesozoic time as there is no basis for determining the age of the intrusives or of the veins where they cut only the ancient schists, granites, and other crystallines.

Brazilian Highlands.—The Brazilian Highlands, almost entirely embraced within the great country of Brazil, but extending into the eastern part of Uruguay, are described in the chapter on Brazil. They begin a short distance south of the Amazon River and extend through the eastern portions of Brazil and Uruguay almost to the city of Montevideo.

As in the case of the Guianan Highlands, the Brazilian Highlands are now but the remnants of much higher mountains that formerly existed here. The average elevation is between 3,000 and 4,000 feet above sea level, with an extreme elevation of approximately 10,000 feet. There are occasional sharp rugged peaks in the eastern portion, especially in the Serra do Mar in the vicinity of Rio de Janeiro, but for the most part the Brazilian and Uruguayan Highlands consist of well-rounded hills or low mountains covered with vegetation, which in many places is dense though not so luxurious as in the more tropical and humid district of the Amazon Valley.

The basal rocks of this physiographic division are ancient pre-Cambrian and early Paleozoic igneous and metamorphic rocks of various kinds—gneisses, schists, phyllites, quartzites, marbles, granites, porphyries, etc. The structures of these basement rocks are complicated in the extreme. Overlying these ancient rocks in many places are sedimentary rocks ranging in age from Permian to Cretaceous according to different investigators.

The mineral deposits of economic importance of the Brazilian Highlands are varied and include a number of unusual value. The immense bodies of high-grade iron ores of Minas Geraes are of prime importance, although as yet undeveloped, while the gold, diamond, manganese, and monazite deposits have long been worked. A great variety of gem minerals has been found and some silver, copper, mercury, and other metallic substances;

coal beds are present in southern Brazil and extend across into Uruguay. In fact, practically all the mineral substances of value of both Brazil and Uruguay are contained in the rocks of the Brazilian Highlands.

The Cordilleras.—The mountains of the western portion of South America, grouped under the title of the Cordilleras, extend from Tierra del Fuego to Panama. Although forming a continuous belt of elevated land, these mountains are, by no means, a unit. Instead they consist of several fairly distinct ranges, most of which have a north-south trend.

The Cordillera of Argentina and Chile consist of two parallel mountain ranges, between which is a depressed area, forming the Longitudinal Valley of northern and central Chile and the inland waterway of southern Chile where the valley is invaded by the ocean. The western range of mountains, the Coast Range, borders the coast as a rocky wall rising precipitously from the shore almost continuously through northern and central Chile. In few places does this range exceed 3,000 feet in altitude. In southern Chile the Coast Range has been depressed so that only the highest portions appear above the ocean waters, forming a series of islands. North of Chile the Coast Range is less continuous and not recognizable in many places. For the greater part the Coast mountains consist of folded and faulted sedimentary rocks of Mesozoic and Tertiary ages, together with some ancient crystalline rocks, in the main of igneous origin, but, in part, metamorphosed sediments.

The higher ranges of the Cordilleras lying farther inland, of which the most elevated portions form the boundary between Chile and Argentina, consist of a single mountain range as far north as northern Argentina, but with numerous counterforts or spurs. There the mountains divide into two distinct ranges between which lies the Bolivian *altiplanicie* and the basin of Lake Titicaca. From central Peru northward there are occasional knots or groups of mountains that connect the ranges, while in other places there are a number of parallel ranges between which are narrow elongated plateaus.

In Colombia the Cordilleras divide into four distinct ranges. The western one with a north-south trend lies between the depression of the Atrato and San Juan River valleys and the Cauca River basin; the second lies between the Cauca and Magdalena Rivers; the third diverges eastward, bordered on the west by the lowlands of the Magdalena River and on the east by the depression occupied in part by Lake Maracaibo; while the eastern range runs northeastward into Venezuela and forms a dividing line between the drainage basins of Lake Maracaibo and the Orinoco River.

The high Cordilleras or Andes Mountains are rugged and rise with precipitous slopes from the bordering lowlands on either side, thus constituting a much greater obstacle to transportation than if they were less compressed and possessed gentler slopes. There is only one low pass or break in this wall and that is in Colombia. In elevation they culminate in Mt. Aconcagua in Argentina with an elevation of 23,080 feet.

In the southern part of Chile and Argentina the mountains have been extensively modified by glacial erosion and numerous large glaciers still exist there. That is the only part of South America where lakes are abundant. Elsewhere glaciation has had but little effect in determining the present configuration of the mountains although small glaciers are found on the upper slopes of many of the higher peaks even well within the tropics.

The Andes Mountains are responsible for the climate of South America to a marked degree. The southern part of the range, lying within the belt of prevailing westerly winds, has an extremely heavy rainfall due to the precipitation of the moisture as the air from the ocean strikes the high mountains. Naturally the bulk of the precipitation occurs on the western slopes and gives to southern Chile a cold, rainy, and inhospitable climate. Farther north in the belt of southeasterly trade winds the mountain ranges abstract the moisture from the air moving from the lowlands of Argentina, Brazil, and Paraguay. The result is that through northern Argentina, Bolivia, and Peru, there is considerable precipitation along the eastern slopes of the mountains, the high-lying inter-mountain plateaus have little rainfall and sparse vegetation, while the western slopes, almost devoid of rainfall, are so extremely arid that plant growth is absent over wide areas.

The high Cordillera are composed of various kinds of rocks and present many different phases throughout their wide extent. Generalizing, they may be described as primarily composed of sedimentary rocks, mainly of Mesozoic age, but with some Paleozoic strata, particularly Devonian fossiliferous rocks, and some early Tertiary rocks. Through these sediments which were uplifted by profound faulting and folding, effusive igneous materials have been poured out in great masses and volcanic peaks are numerous throughout the Andes from Colombia to Argentina and Chile. In general the highest elevations are the active or recently extinct volcanoes although some of the highest peaks such as Illampu (Sorata) and Illimani in Bolivia consist entirely of sedimentary and deep-seated igneous rocks. In addition to the sedimentary and effusive igneous rocks which constitute the bulk of the Andes, granites and other deep-seated igneous rocks have been revealed in many places where extensive erosion has removed the overlying rocks.

The Cordilleras of western South America are everywhere rich in minerals and in some of the countries of the West Coast, particularly Chile and Bolivia, the mining far exceeds in importance all other industries. Gold is found all the way from Tierra del Fuego to northern Colombia and in many sections so widely disseminated that the gravels of practically every stream will show some gold on panning although in the great majority of cases the gold content is too low to justify exploitation. Copper and silver ores are widely disseminated through the Cordilleras; Chile, Peru, and Bolivia being especially rich in these. Coal is also present in many of the Cordilleran countries, particularly in Chile, Peru, and Colombia, although only developed to any extent in Chile where the deposits are found along the coast. Adjacent to the active or recently extinct volcanoes, sulphur is found in many places. Chile, Bolivia, and Argentina contain great deposits of salt and borax, and Chile possesses immensely valuable sodium nitrate deposits in the regions of scant rainfall. The tin and antimony ores of Bolivia, the bismuth of Bolivia and Peru, the vanadium and mercury of Peru, and the platinum placers of Colombia practically complete the list of the most valuable mineral resources of the Cordillera, but there are many others of lesser importance found here and there throughout these great mountains, and no doubt there are numerous rich and extensive deposits still to be discovered.

The Llanos and Orinoco River Plains.—The Llanos of Venezuela sloping down to merge with the alluvial and delta plains of the Orinoco River are low-lying featureless areas with a maximum elevation of about 800 feet above sea level. Heavy forests or high coarse grasses cover the more humid portions while those

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parts with scant rainfall are typical deserts of shifting sand dunes and barren surfaces.

The rocks of the Llanos and the Orinoco River plains consist of loose sediments of Quaternary age resting upon older sedimentary strata belonging to the Tertiary and probably Cretaceous ages, of which all the materials have been derived from the bordering highlands, a prolongation of the Cordilleras on the northwest and north and the Guianan Highlands on the south.

These plains contain but few deposits of economic minerals. The most important are the rich deposits of asphalt, and petroleum seepages in places, especially near the highlands, reveal the presence of this valuable substance.

Amazon River Plains.—The great basin of the Amazon River and its tributaries constitutes about two-fifths of the entire continent of South America and is included within the countries of Brazil, Venezuela, Colombia, Ecuador, Peru, and Bolivia. Lying entirely within the Tropics, most of it subjected to heavy rainfall, and the low-lying lands covered with dense tropical forests, it remains undeveloped and imperfectly explored. The rubber industry is almost entirely responsible for the few permanent settlements of the entire district. As the population of the South American countries increases, however, there can be no question about the establishment here of extensive lumbering and agricultural industries which as yet have scarcely started.

In isolated places erosion along the streams has revealed the presence of underlying rocks belonging to the Paleozoic and pre-Cambrian periods although in general the strata of the Amazon Valley represent loose or imperfectly consolidated sediments deposited during Mesozoic and Cenozoic times Recent fluviatile deposits cover large areas adjoining the major streams to an appreciable but unknown depth.

The mineral resources of the Amazon region are practically unknown but are probably insignificant with the possible exception of petroleum. In the area forming the lower slopes and foothills of the Cordilleras oil seepages have been reported in several places, but little accurate information is available.

Plains of the Paraguay and Paraná Rivers.—The plains constituting the drainage basins of the Paraguay and Paraná Rivers are included within Brazil, Bolivia, Paraguay, Uruguay, and Argentina. In many respects these resemble the Amazon River plains but differ from them in climatic features. These lowlands lie mainly in the temperate zone and in regions of moderate rainfall so that extensive areas are covered with grass. The section is well adapted for cattle raising and the cultivation of grains, as shown so well in that portion of Argentina adjoining the Paraná River, although the lack of transportation facilities has retarded its development and large portions have scarcely been utilized up to the present.

The rocks consist of sediments ranging in age from the Mesozoic to Recent. There has been little mineralization of the region although some iron and manganese deposits have been discovered while a few oil seepages are reported from those portions lying near the base of the Cordilleras.

Patagonian Pampas.—The lowlands of Argentina lying to the south of and merging with the plains of the Paraná River valley consist of rolling to flat surfaces suitable for cattle raising which is the main industry of the region.

The rocks consist principally of gently dipping Tertiary strata with some ancient crystalline rocks appearing at the surface. Deposits of economic minerals are few and of little importance. Petroleum seepages have been discovered near the Cordilleras.

Coastal Plains.—The South American continent is unique in the very slight development of coastal plains. Steep coasts, hills, or mountains border the Pacific Ocean almost continuously from Panama to the Straits of Magellan In Ecuador a true coastal plain belt is present with a maximum width in the vicinity of the Gulf of Guayaquil of about 80 miles. Peru has a narrow coastal belt, but throughout Chile mountains border the coast, except in the southern portion where numerous islands of Tertiary sediments represent the coastal plain. Along the Atlantic Ocean a coastal plain is present throughout Argentina merging with the Patagonian pampas and Paraná River plains. Uruguay and Brazil contain disconnected patches of coastal plains of narrow width. Bordering the Caribbean Sea a narrow coastal plain extends throughout the Guianas and is practically the only portion of those countries under cultivation. In Venezuela, excluding the Orinoco River delta, the coastal plain does not attain any considerable size except in the western part of the state where the Gulf of Maracaibo is located.

The rocks of the coastal plains are mainly composed of Tertiary and Quaternary sediments although some Cretaceous rocks are present. Almost the only mineral deposits of economic importance which they contain are sands, clays, and marls except in western Venezuela, Ecuador, and northern Peru where petroleum and asphalt deposits are found and in a portion of the Brazilian coast where the rich monazite deposits are present in the beach sands.

GEOLOGICAL DEVELOPMENT OF THE SOUTH AMERICAN CONTINENT

Sources of Information.—Geological investigations in South America have been confined largely to reconnaissances of explorers such as von Humboldt and Darwin or to detailed studies of small areas where deposits of economic value have been worked. In no country of South America is the geology as well worked out as on the continent of North America and Europe. For more than 40 years Orville A. Derby carried on his geological researches in Brazil but even then his work consisted mainly of reconnaissances and he did not even visit large areas of that great Republic. Most of the time he had only a small corps of scientific men to assist him. Brazilian geology has also been investigated by other able geologists such as von Eschwege, Mawe, Branner, White, Clarke and others; yet in this vast country several generations of such workers will be necessary before the many baffling geological problems are solved.

With Brazilian geology imperfectly understood, although studied for so long a time, it is apparent that other countries where until recently no systematic geological work had been undertaken must be still more deficient. Argentina, Chile, and Uruguay at present maintain geological organizations that are doing excellent work although greatly handicapped by the meagerness of the funds placed at their disposal. An active mining society in Peru has published valuable bulletins on the mining districts. In Ecuador and Colombia the governments have subsidized special geological researches but have not supported any general bureau for geological examinations. British Guiana likewise subsidized an investigation of the gold fields which contributed much valuable information not directly connected with the immediate problem. The remaining countries have been investigated solely by private individuals or by mining companies and the scattered information, if ever published, is contained in various scientific and technical journals of all countries.

As the South American republics increase in population and wealth geological researches will no doubt become an established part of the recognized activities of the governments as in the countries of North America and Europe. However, for many years, we must expect many geological problems to remain unsolved, especially in the unexplored or thinly inhabited sections.

Pre-Cambrian History.—As in all other continents our knowledge of the physical geography of South America during the pre-Cambrian periods is indefinite. Many changes occurred during this long interval of time of which we have definite information in only isolated sections where rocks of that age are now exposed, but from them we cannot even approximately determine the continental outlines of that time. The highlands of the eastern portion of the continent contain the greater portion of the pre-Cambrian crystallines, although they occur in many detached or isolated sections of the western Cordilleras. Gneisses, schists, granites, marbles, quartzites, and other classes of rocks, representing both igneous and sedimentary rocks, are characteristic of the pre-Cambrian of both North and South America. The only peculiar feature of the South American pre-Cambrian rocks are the great beds of iron ore of Minas Geraes, Brazil, which are believed to be the result of the precipitation of iron oxide from solution through the agency of micro-organisms.

The basis for the determination of most of the pre-Cambrian rocks is primarily negative—the absence of recognizable forms of life—so that there remains the possibility of some of the ancient crystalline rocks being of more recent origin in which the fossils have been destroyed by metamorphic action. The additional criteria for correlating these rocks with the pre-Cambrian of other continents are the lithologic similarities and the extreme metamorphism and deformation which they have undergone, but such evidence is obviously not conclusive.

Paleozoic History.—During the early part of the Paleozoic era there seems to have been a large land mass in that portion now included within southeastern Venezuela, the southern portion of the Guianas, and northern Brazil, while another still larger area extended through eastern Brazil and Uruguay, practically to the La Plata River. Detached land masses, islands of various sizes, formed a chain along the western portion of the present continent. Cambrian, Ordovician, and Silurian strata containing marine fossils have been found both in Brazil and in various parts of the Andes indicating the presence of ocean waters in the interior of the continent, extending westward to the present site of the high Cordillera, and also occupying the present basin of the Amazon River. The interior sea shrunk during the Devonian and Carboniferous periods, yet marine Devonian fossils, resembling those of the Hamilton and Oriskany formations of North America, have been found in large numbers in the Andes, especially in Bolivia, and marine fossils of Carboniferous age have been obtained from the lower part of the Amazon River basin.

The most important change of the Permian was the glaciation of southern Brazil, where deposits of undoubted glacial till are found, although the source of the glaciers is conjectural. Also in the same section marshes were developed in which vegetable débris accumulated to form the present coal beds of Brazil. Great outpours of lava took place in Paraguay and southern Brazil at the close of the Permian.

Mesozoic and Tertiary History.—The Triassic and Jurassic rocks of the South American continent are not well known and have been confused with the Permian in some places. Steinmann reports marine strata of these two periods in the Cordilleras between 5° and 35° S. latitude.

Cretaceous rocks are found so generally distributed over South America that it seems that practically the entire continent was submerged beneath the ocean waters during at least a part of that period. The water was probably shallow so that some of the higher portions remained above the water, forming islands. Cretaceous strata are especially well represented in almost all portions of the Cordilleras.

During the latter part of the Cretaceous and the earliest portion of the Tertiary the South American continent seems to have been much larger than at present and to have been connected with Africa by a land connection between Brazil and western Africa, with Australia and New Zealand by means of an enlarged Antarctica, and with North America. During later Eocene, a submergence carried a large portion of the continent beneath the ocean waters and divided it into several separate land masses. Marine sediments of Eocene, Miocene, and Pliocene age in the Orinoco, Amazon, and Paraná River valleys, in the Patagonian pampas, and in both the eastern and western ranges of the Bolivian Andes indicate the extent of the ocean waters during the Tertiary.

The latter part of the Tertiary or the earliest part of the Pleistocene was the great mountain-building epoch of the South American continent as it was during that time that the Andes were uplifted. It has been generally believed that these mountains were developed during the late Cretaceous but the study of fossils collected at different localities indicates a more recent age. The writers made small collections of plants from the volcanic tuffs of Potosi Mountain and from the sandstones of Corocoro, Bolivia, which have been studied by E. W. Berry.(3)[1] The following paragraph is taken from this article.

"From a consideration of all the evidence available it is concluded that the flora is Pliocene in age and that the major elevation of the eastern Andes of Bolivia and the high plateau took place in the late Pliocene and throughout the Pleistocene and that the extensive mineralization of this region also took place during this same period."

Near the base of Potosi Mountain the writers obtained a number of specimens of a brachiopod which Professor Schuchert states is closely related to *Discinisca lamellosa* (Broderip), a shallow water form now found in the Pacific waters from Panama to Chile. He says that the fossils cannot be older than the Miocene and may even be as recent as the Pleistocene.

This evidence points conclusively to the relatively recent age of the Andes and it is believed that much additional data confirming this view will be brought to light as further geological studies are made in the Andes of Bolivia and Peru.

The formation of the Andes involved much folding and faulting of the sedimentary strata of which beautiful examples are afforded in southern Bolivia between La Quiaca and Atocha and also in the region of Potosi. Accompanying these great uplifts there was marked volcanic activity which extended throughout the entire range of the Andes from Venezuela and Colombia to the southern parts of Argentina and Chile and even to parts of the Patagonian pampas and the Paraná River plains. Batholithic masses of plutonic rocks, mainly diorite and grano-diorite, have been exposed by erosion in the Andes in several places and the effusive and extrusive rocks from the great reservoirs are widespread in all parts of the great uplift. This great period of

[1] Numbers in brackets refer to articles in bibliography at close of chapter.

vulcanism, though doubtless waning, has not yet entirely ceased as many active volcanoes still exist, especially in Ecuador, and, with few exceptions, the highest mountains of the Cordillera are composed of volcanic material and many of them still contain well-preserved craters. A great part of the mineral deposits of the West Coast countries is due to these great extrusions and intrusions of volcanic materials.

Quaternary History.—During the Pleistocene the southern portion of the South American continent was extensively glaciated by great glaciers which originated in the high mountains and flowed eastward across the Patagonian pampas and westward to the Pacific Ocean. As far north as Copiapo practically all of Chile was covered by the ice, but northward from this place the ice did not extend far into the bordering lowlands.

Within recent times the western part of the continent from Valdivia northward seems to have been gradually uplifted and probably is still in process of elevation. The frequent earthquakes which are experienced throughout central and northern Chile, Peru, Ecuador, and Colombia, indicate instability of the earth's crust and consequent crustal adjustments. Also the comparatively recently elevated beach deposits of the coast and the few coastal embayments bear witness to late uplifts.

The central and eastern portions of the continent present a striking contrast to the western part as they are relatively stable everywhere. Such movements as have taken place in recent times seem to have been downward and the excellent harbors of Bahia and Rio de Janeiro are attributed to such depressions of the coast.

RELATION OF THE MINERAL DEPOSITS TO THE GEOLOGY

The mineral deposits of South America are closely related to the geology and owe their origin to the operation of the various geologic processes of the past. This relationship can best be brought out by a discussion divided into three sections as follows:

Mineral deposits of the sedimentary rocks.

Mineral deposits of the ancient crystalline (metamorphic) rocks.

Mineral deposits of the younger igneous rocks.

Mineral Deposits of the Sedimentary Rocks.—The mineral deposits of economic importance found in the sedimentary rocks of South America are not extensive. The principal ones are coal, petroleum, natural gas, asphalt, sodium nitrate, iodine, potash, salt, borax, diamonds, and placer deposits of different kinds. While diamonds have been found in the sandstones of Brazil yet their original source is believed to be in undiscovered pipes of igneous rock. Likewise the borax deposits of the Andes, although found in encrusting layers in the dessicated lake beds (*salares*), are closely associated with the adjacent recent volcanoes as described in a later chapter. The common minerals of the placer deposits are also of secondary origin. This leaves a small number of syngenetic mineral deposits of the sedimentary rocks.

South America, as a whole, is deficient in the mineral fuels and most of the countries will probably continue to be dependent upon foreign countries for their supplies of coal. Moreover the coals are mainly of Cretaceous or Tertiary age and of poor quality. Most of them are semi-bituminous or lignitic and in some cases are unusually high in ash and sulphur. Some anthracite coal is found in the Andes of Peru.

Chile, Colombia, Peru, and Brazil are the only countries where coal deposits of any economic importance are found although coal or lignite is known to occur in the other countries. The coal measures of Brazil are referred to the Permian, those of Peru and Colombia to the Cretaceous-Tertiary, and those of Chile to the Tertiary. Paleozoic coals have been reported from Colombia, Peru, and Bolivia. The coal resources of South America have been inadequately developed mainly because of their inferiority in comparison with foreign coals and the inaccessibility of the deposits in all cases except those of Chile.

The petroleum, natural gas, and asphalt resources of South America are as yet imperfectly known. With the exception of those of southern Brazil and of eastern Argentina, these materials are found in the sections adjoining and closely associated with the great Cordilleran uplifts. On the eastern flanks of the Andes and in the plains nearby, indications of petroleum have been reported in numerous places all the way from Tierra del Fuego to Venezuela, but only in the latter country have many test borings been made to determine the available supplies. Venezuela also possesses large and valuable deposits of asphalt. On the western slopes of the Cordilleras and close to the ocean are the developed oil fields of Peru and the undeveloped but promising districts of Ecuador. Indications of petroleum have been found in many places in southern Brazil although little hope is offered to oil producers by Dr. White who has studied the geology of that section.

The oil-bearing strata of the South American countries seem to belong to the Cretaceous or Tertiary with the exception of Brazil where they are of Permian age, and possibly some of upper Jurassic age in Argentina.

The great nitrate fields of northern Chile containing sodium nitrate, iodine, and potash salts have unchanged sedimentary rocks, mainly alluvial materials exposed at the surface. These owe their origin to precipitation from shallow underground waters which have collected them over wide areas and brought them to the arid regions where rapid evaporation has taken place. The porosity of the alluvial or other enclosing rocks has facilitated rapid escape of the water to the atmosphere and has been a determining factor in the precipitation of these soluble salts in commercial quantities. These deposits are probably unique only because no other known region in the world happens to possess a similar combination of geographic and climatic environment.

Rock salt has been found and, to a limited extent, mined in some parts of South America. Also considerable salt has been obtained by the evaporation of the brines of salt wells or salt springs. The most extensive deposits of salt, however, and all of the borax of the South American continent, are located in the arid regions of the inter-Andean plateaus and on the western slopes of the Andes in Chile, Bolivia, Peru, and Argentina, and in some desert places in Venezuela. The salt and borax occur in *salares* or "salt pans," depressions where waters collect during rainy seasons or, in some cases, the sites of former lakes that have disappeared by evaporation. Some of the *salares* of Chile in which a great layer of salt covers the surface, have been formed by precipitation from underground waters. The water brought to the surface by capillarity has precipitated the salt contained in solution.

Placer deposits of various kinds are found in many parts of the South American continent. These include the following economic minerals: gold, platinum, monazite, tin, gem minerals, cinnabar, etc. In most cases the placer minerals of importance are likewise mined as lodes and are frequently obtained in the same section by both lode and placer operations. In fact, of those mentioned, monazite is the only one in which the entire production is derived from placers.

Gold is the most important of the placer minerals of South America and has been obtained on a commercial scale in every country with the exception of Paraguay and, even in that country, it has been reported to occur in some of the stream gravels. Notwithstanding the fact that South America has had a large gold production from a few famous gold quartz mines, the bulk of the gold of the continent thus far won has undoubtedly been derived from placers. The gold of the Incas and other early Indian tribes was probably derived almost entirely from stream gravels while the same is true of most of the gold obtained by the early Spaniards in Peru, Bolivia, and Chile and by the Portuguese in Brazil. The extent of the old placer workings observable in the latter country is a surprise to the traveler and affords some basis for the stories of the great wealth secured by the early settlers.

While in most countries, placer mining has long been on the decline, there are many who believe that the introduction of dredging machinery may again bring the gold placers into the prominence they deserve. The important operations of recent years have been mainly confined to Colombia and the Guianas.

The distribution of placer gold in South America is closely associated with the areas of highlands. From the extremely large number of occurrences reported, it seems that there is little exaggeration in the statement that the gravels of every river flowing outward from the Guianan Highlands, the Brazilian Highlands, or the Cordilleras contain gold. Naturally, in most instances, the gold does not occur in sufficient concentration for commercial operation under the present state of transportation facilities. In the absence of railroads, or even good wagon roads, and with little available fuel, some of the promising placers, especially along the eastern flanks of the Andes of Bolivia, Peru, Ecuador, and Colombia, must be regarded as reserves for the future.

In the Choco district of Colombia, the gold placers have also yielded appreciable amounts of platinum and in some instances platinum is the chief mineral sought.

The monazite sands of Brazil, which are of such great importance to the users of thorium the world over, are entirely of placer origin. The grains of monazite in the crystalline rocks of the Brazilian Highlands are too sparingly distributed to be of importance in their original habitat. As the enclosing rocks decayed the monazite particles freed from the other minerals have been transported and concentrated by the streams and in some cases re-concentrated by the waves on the ocean beaches to form workable deposits.

Although Bolivia contains many important tin-mining districts, the tin placers are of minor importance. In the Potosi region, where the cassiterite was discarded in the tailings by the early silver miners, the stream gravels have yielded considerable quantities of tin ore, but elsewhere they have only been worked on a small scale.

Among the gem minerals of placer deposits, the diamonds of Brazil and the Guianas are of the greatest importance. They are almost aways found in association with gold, but in some instances the gold recovery in the diamond workings is negligible. Diamonds have also been found in sandstones in Brazil although all the diamond workings are in the recent alluvial débris of the present or former streams. Though the suggestion has been made that the diamonds have originated in the sandstone, it seems more probable that they have had their primary origin in igneous rocks of basic character as in other parts of the world. The agates of the State of Rio Grande do Sul, Brazil, and Uruguay are mainly derived from the stream gravels.

Near Ouro Preto, Brazil, a cinnabar placer deposit has been investigated but, as yet, has not been developed.

Mineral Deposits of the Ancient Crystalline (Metamorphic) Rocks.—Of the economic minerals of the crystalline rocks of South America, certain ores occur mainly or exclusively in association with the ancient crystalline rocks, others mainly in association with the younger igneous rocks, and still others are about equally well represented in both the older and the younger crystalline rocks. Any classification with arbitrary separation into distinct classes cannot fail to meet with some objections because of numerous exceptions to the general rule. Nevertheless, it is frequently advisable for the prospector or mining engineer to know the probability of finding deposits of importance in any particular region and for this reason the following generalizations are offered.

The ancient crystalline rocks, as described on a previous page, consist in the main, of the igneous rocks of deep-seated origin and the metamorphosed igneous and sedimentary rocks belonging principally to the granites, syenites, gabbros, serpentines, gneisses, schists, phyllites, etc. They compose the bulk of the highlands of the eastern portion of the continent and are well represented in the Coast Mountains of Chile and in isolated areas throughout the high Cordillera. The mineral deposits of economic importance which they contain are the ores of iron, manganese, gold and silver, and copper of the metallic class and gem minerals, monazite, mica, graphite, feldspar, kaolin, bauxite, talc, etc., among the non-metallic products.

Iron-ore deposits of prime importance are found in Brazil and Chile with less important ones in the other countries. Practically all classes of iron ore are known—magnetite, hematite, limonite, and siderite. Almost all the important deposits are found in association with the ancient crystalline rocks, a relationship which has been recognized in other parts of the world. Gossan ores are represented among the younger igneous rocks, but seldom are they of sufficient thickness to be of especial value.

The great Brazilian iron ore deposits, unequalled in any other part of the world, are the result of regional metamorphism of ferruginous sediments and are interbedded with schists and quartzites. Some of the hematite ores of Venezuela seem to belong to the same class. The magnetite ores of Chile, found in association with basic igneous rocks, seem to have been formed by magmatic differentiation.

The important manganese ore deposits of South America appear to have been formed by the replacement of limestones or other rocks or by the surface oxidation of crystalline rocks containing manganese minerals. The extremely valuable deposits of Brazil represent both methods of formation. Except that the formation of manganese deposits by oxidation at or near the surface is a slow process, there is no especial reason why the ancient crystalline rock masses should contain the principal manganese deposits. So far as the South American continent is concerned, however, it is probable that the deposits to be discovered in the future will be mainly confined to the regions of the old metamorphic rocks, as are the leading ones of the present time.

Gold and silver-bearing veins are found in the pre-Cambrian schists, gneisses, granites, etc., of Venezuela, the Guianas, Brazil, Uruguay, and in many places in the Cordilleras. In some instances the veins are closely allied to pegmatite dikes. In some of the mines the values decreased rapidly in depth but in others remarkable persistence has been proved to exist. The Morro Velho mine in Brazil from which ore averaging $11.00 a ton is being mined at a vertical depth of more than 6,000 feet is an illustration of the latter class.

Copper minerals have been found in many places in the pre-Cambrian crystalline rocks of South America but, as yet, few deposits of any consequence are known.

The metamorphic rocks of Brazil have furnished many gem minerals of value including aquamarine, sapphire, topaz, tourmaline, and garnet, whereas the diamonds have probably been derived from ancient igneous rocks. With the exception of the diamond. all of these minerals of gem value are contained in pegmatite dikes.

A group of rock-forming minerals some of which occur in other kinds of rocks but seldom present in economic quantities except in the ancient metamorphic rocks are monazite, mica, graphite, feldspar, kaolin, and talc. As yet few deposits of any of these minerals have been actively worked but promising deposits have been prospected and lead one to believe that important mines may be developed. The monazite-bearing rocks of Brazil in themselves are of no value but they have contributed the monazite to the valuable monazite placers.

Mineral Deposits of the Younger Igneous Rocks.—The mineral deposits associated with the younger igneous rocks are mainly limited to the western part of the South American continent and it is to these great masses of igneous material that the bulk of the mineral wealth of the Andes Mountains owes its origin. In many instances the economic minerals are actually found in other rocks but the mineralizing solutions were given off from the magmas.

The igneous rocks of the Andes belong to many different groups but as pointed out by Iddings, (12) "the main mass of the lavas of all the volcanoes of the Andes is andesite, of variable composition in all localities. It grades into basic varieties, approaching basalt, in some places, and into acid varieties which are dacites, in others." The end products of differentiation, the rhyolites on the one hand and the basic basalts on the other are poorly represented. From this Iddings infers "that the general differentiation of the magma supplying the lavas of the Andes has not reached its final stages, in which great volumes of extremely differentiated material will have been developed."

Porphyritic varieties of andesites and dacites are especially abundant.

The deeper-seated equivalents of the andesites and dacites grouped under the diorites and grano-diorites are also present in many places forming batholithic masses of large size from whence came the effusive rocks and dikes of intermediate character. Quartz porphyries are also fairly common.

Although the mineral deposits of the Andes are found in association with many different kinds of igneous rocks, nevertheless, there seems to be a marked relationship existing between most of them and the andesites or their plutonic equivalents, the diorites. However, this general rule is not without many exceptions. Steinmann (19) has called attention to this association and also the recent age of the ore deposits which seem to be mainly Tertiary or even later. He says that:

"The ore deposits appear to be especially concentrated in the upper peripheral portion of the intrusions and in the immediately adjacent enveloping sediments. In depth, on the other hand, they generally diminish both in number and ore content. It is possible from this relationship and on consideration of the variable and marked alteration of the original vein complex to estimate approximately the quantity of ore still remaining."

The data available from the leading mining districts of the Andes seem to verify Steinmann's conclusions. In many places enrichment in the oxidized or secondary sulphide zcnes have alone made the deposits of economic importance, but it is well to remember that in many of the South American mines the impoverishment of the ore bodies at depth was not the main reason for abandoning the mines. The difficulties encountered in the operation of deep mines without special equipment and the cost of installing the necessary machinery in many instances have been the determining causes for failure to explore the lower portions of ore deposits.

The most important economic products of the younger igneous rocks are gold and silver, copper, tin, bismuth, antimony, sulphur, and gem minerals, besides numerous less important ones.

Character and Distribution of the Mineral Deposits.—The mineralization of the Andes is strikingly distinct in different sections and with an increase of our knowledge of the various mineralized portions it will no doubt be possible to recognize several well-defined metallogenic provinces, as described in succeeding chapters. The gold quartz lodes of Colombia, the argentiferous lead and copper deposits of Peru, the tin-silver-bismuth deposits of Bolivia, and the argentiferous copper deposits of Chile seem to have fairly definite geographic limits and probably represent distinct metallogenic epochs following the intrusion or extrusion of igneous rocks of the later geologic periods.

The great majority of the gold and silver deposits of the North and South American continents have been formed during the late Mesozoic, Cenozoic, or Recent epochs. Lindgren (14) summarizing says that "they were formed on the whole, nearer to the surface than the old deposits of the pre-Cambrian, or at least under conditions of more moderate temperature. Many of them, indeed, were formed very close to the present surface. Following intrusions or lava flows, hot waters loaded with gases and metals of igneous origin rose toward the surface, and, in cooler regions of the crust, deposited their load of metals. In part the gold and silver occur in minute quantities associated with copper and lead minerals, and are recovered from the base bullion. Much silver is obtained in this manner, but most of the gold is derived from gold quartz deposits, properly speaking, or from placers caused by the wearing down by erosion of these deposits."

The gold and silver deposits of this class are found all the way from the Straits of Magellan to Panama. All the countries lying between contain both gold and silver deposits of importance, although the northern countries—Colombia and Ecuador—seem to be especially rich in their gold resources and to contain few silver deposits of consequence whereas Peru, Bolivia, Argentina and Chile contain extremely rich silver deposits and few valuable gold deposits.

The copper deposits of the younger igneous rocks of South America are found in all the Cordilleran countries but are particularly abundant in Chile and Peru with a few important deposits in Bolivia. They present wide diversities in their geological occurrences and characteristics. The most common type consists of replacements of country rock near intrusions of igneous material. The replaced rocks are of various kinds. Limestones are more easily replaced than any other kind of rocks and many important copper deposits have been formed by their replacement. The enormous deposits of low-grade copper ores of Potrerillos, Chile, are examples of this kind. Other sedimentary rocks and different kinds of igneous rocks, composed of less soluble minerals, have likewise been partially replaced by copper minerals, particularly so when the rocks have previously been shattered or brecciated, thus forming many passage channels for the mineralizing solutions given off from the igneous magmas. The copper minerals also fill the cracks and openings in such rocks, with little or no replacement. The Braden and Chuquicamata copper deposits of Chile have been formed in this manner.

In depth many of the copper deposits change in composition. There are many examples of rich silver ores near the surface giving place to copper ores at lower levels. The Cerro de Pasco, Peru, deposits are the best illustrations of this kind.

Although chalcopyrite is the most important of the sulphide copper minerals, there is an unusually large number of deposits in which the chief copper mineral is enargite. Famatinite, chalcocite, bornite, and tetrahedrite are other common sulphides. In the oxidized ores of the desert regions of Chile several unusual minerals—atacamite, brochantite, chalcanthite, and kröhnkite—are important ore minerals. Though native copper in small quantities is common in the oxidized zone there are few deposits in the entire continent where it is the chief ore mineral. The most important occurrence is at Corocoro, Bolivia, where native copper is disseminated through gray sandstones.

It is probable that the majority of the workable copper deposits of the South American continent are due to secondary enrichment although, in some places, the evidence is not conclusive.

The tin deposits of economic importance are confined to Bolivia so that a summary at this place would be merely a repetition of the discussion given in a later chapter dealing with the ore deposits of that country. Suffice it to say that they represent true fissure veins or disseminations along joint and bedding planes, filled by emanations from igneous intrusives. The rocks containing them are various kinds of igneous and sedimentary rocks. Cassiterite is the chief tin mineral although some stannite is found.

The occurrence of the bismuth ores is practically the same as that of the tin deposits and most of the bismuth is obtained from the tin districts of Bolivia. Native bismuth and bismuthinite are the principal ore minerals, although the oxide is also common near the surface and in an important deposit near Cerro de Pasco, Peru, the oxide is the only bismuth mineral thus far recognized.

TABULATED SUMMARY OF THE PRINCIPAL MINERAL DEPOSITS OF THE SOUTH AMERICAN COUNTRIES

	Argentina	Bolivia	Brazil	Chile	Colombia	Ecuador	Guianas	Paraguay	Peru	Uruguay	Venezuela
Antimony		**X**	X	X					X		X
Bismuth		**X**	X	X					**X**		X
Cobalt	X			X							
Copper	**X**	**X**	X	**X**	X	X		X	**X**	X	**X**
Gold	**X**	X	**X**	**X**	**X**	**X**	**X**		**X**	**X**	**X**
Iron	X		**X**	**X**	X			X	X	X	**X**
Lead	**X**	X	X	X	X	X			X	X	X
Manganese	X		**X**	**X**				X		X	X
Mercury			X	X	X	X	X	X	**X**		
Molybdenum				X					X		
Nickel			X	X					X		
Platinum			X		**X**	X					
Silver	**X**	**X**	X	**X**	**X**	X			**X**		X
Tin	X	**X**	X								
Tungsten	**X**	**X**							X		
Vanadium				X					**X**		
Zinc	X	X	X	X	X	X		X	X		
Asphalt	X				X	X			X		**X**
Asbestos			X							X	
Bauxite							**X**				
Borax	**X**			**X**					**X**		
Coal, lignite, peat	X	X	**X**	**X**	**X**	X			**X**	X	**X**
Feldspar	X			X							
Gems			**X**		**X**		**X**			**X**	X
Graphite			X	X				X		X	
Gypsum	X					X		X			
Iodine				**X**		X					
Kaolin			X					X			
Mica	X		X								
Monazite			**X**								
Nitrates			X	**X**							
Petroleum and natural gas	**X**	X	X		X	X	X		**X**	X	**X**
Potassium salts			X	X		X					X
Salt	**X**	**X**	X	**X**	**X**	X			**X**		**X**
Sulphur	X	X	X	**X**		X			X		X
Talc			X					X		X	

Occurrences are marked X. Important deposits are marked **X**.

The antimony deposits are less definitely associated with the younger igneous rocks than most of the ores already described in that many stibnite veins are found in shales where no igneous rocks are exposed. However, they owe their origin to magmatic solutions. Until the present war created a great demand for the metal, little attention was given to the stibnite veins which are fairly common in parts of Bolivia. In several places the antimony and tin minerals are closely related and occur in the same vein.

Although sulphur of the gypsum type has been reported to occur in a few places in South America, all of the commercial sulphur deposits thus far known are intimately connected with the recent volcanic activities of the Andes. Many of the volcanoes of Chile, Peru, Ecuador, and Colombia have passed through the stage of lava eruptions and are now emitting sulphurous materials, steam, and other gases. From the sulphurous gases, sulphur is being deposited in cavities of the porous volcanic rocks near the surface. Great deposits of sulphur are found in the slopes of the volcanoes, or even in their craters, and they are still in the active process of formation.

The only gem minerals of the younger igneous rocks that deserve mention are the agates and amethysts of the amygdaloidal Permian basic rocks of Southern Brazil and the emeralds of Colombia. The agates and amethysts have formed in the cavities of the vesicular lavas and the emeralds of Colombia occur in an unusual type of pegmatites.

HISTORY OF THE DEVELOPMENT OF THE SOUTH AMERICAN MINERAL INDUSTRY

Even before the advent of the Spaniards in the early part of the 16th century, the aborigines of the Andes had learned to utilize some of the mineral wealth of the continent. Gold ornaments have been found in the graves of the former inhabitants of Colombia and Peru and articles of copper have been discovered in the pre-Inca ruins of Tiahuanaco, Bolivia. The Incas had worked many of the precious metal deposits of Peru before the arrival of Pizarro and the story of the wealth of gold and silver with which the ruling Inca tried to purchase his freedom is well known. It is generally believed that the gold of the Incas was mainly obtained from stream placers, but the silver and copper must have come from mineral lodes. Native silver and native copper are found in many of the mines of the Andes but usually in such small quantities that it seems that metallurgical processes of extracting these metals from various ore minerals were employed by the Incas.

The chief motive in the exploration and early settlement of South America was the search for the precious metals. The mythical El Dorado, the city of gold, supposed to be situated in the northern part of the continent, was the goal which inspired Spanish, Portuguese, and English explorers many of whom were lured on by cleverly contrived tales of the Indians only to die of tropical fevers or at last compelled to abandon the vain search after undergoing hardships that only the hardiest adventurers could endure. Several like Francisco Pizarro, undaunted by failures, returned to the search time and again until success was attained. The bravery and unbounded optimism of these early explorers have left their impress upon the present inhabitants of the continent.

The settlement of North America and that of South America present striking contrasts. In the former the early settlers emigrated to foreign shores to obtain religious freedom and to make homes where they could carry on the same kinds of occupation they had followed in their native land. No such motives influence the explorers and early settlers of South America who mainly sought riches of gold and silver with which they might return to their former homes to lead lives of luxury and idleness. In some cases, the mere spirit of adventure was perhaps dominant. For these reasons the mining industry of South America from the earliest days of exploration was the leading one, whereas in North America mining was practically unknown during the first two centuries of occupation by the white settlers.

When Pizarro conquered the Incas of Peru in 1532, he acquired large amounts of gold and silver which the Indians had accumulated through long years of arduous labors. Having possessed themselves of the wealth on hand, the explorers sought the source of the precious metals and not in vain. Hundreds of the old Spanish workings, *antiguas*, have been re-opened and explored in all the Andean countries. What mines were first exploited is not known, but there is unquestioned evidence to prove that the silver mines of Porco, Bolivia, now worked for tin, were in operation prior to 1544, the year in which the immensely valuable silver deposits of Potosi Mountain were discovered.

The search for gold and silver deposits extended both north and south, into Colombia in the one direction and into Chile in the other. Fruitless expeditions were also sent down into the Amazon River basin. For more than 250 years a continuous stream of gold and silver flowed from the South American Colonial possessions to Spain to enrich both the mother country as well as many of the prominent families.

Somewhat later the Portuguese in Brazil followed a similar course although there several settlements of considerable importance had been made before the discovery of the gold placers of Minas Geraes.

The baser metals—copper, iron, tin, etc.—and also the non-metallic mineral products, attracted very little attention during the Colonial regime in the Spanish-speaking countries and with the exception of the diamonds were almost entirely ignored in Brazil. Soon after the various Spanish colonies attained their independence in the early part of the 19th century the copper mining industry came into prominence in Chile and somewhat later in Peru and Bolivia. Up to about 1850, however, the rich and numerous deposits of copper minerals were only worked in a small way to furnish material for local use. Gradually the mining and exportation of copper increased until Chile became the world's leading copper producer, a position which it long maintained. During the last quarter of the 19th century, the copper production of the continent declined. This decline has now been checked and the past decade had shown a remarkable advance which will doubtless continue for many years to come. This revival of copper mining has again put South America in a prominent position, second only to the North American continent.

The nitrate industry of Chile developed at about the same time as that of copper and from the earliest days of the nitrate operations down to the present time nearly all the material has been exported to foreign countries. Although there have been fluctuations in the output from year to year there have been few years in which the production has decreased and it is certain to continue to increase. For many years the value of the nitrate far exceeded that of any other mineral product of South America but the development of the great copper mines of Chile and Peru are destined to cause the copper output of the continent to surpass that of nitrate in value.

The tin industry of South America, although entirely confined to Bolivia has increased to such an extent that the world looks to that Andean country for a large part of the amount required in the various manufacturing industries. Tin mining is new, however, and scarcely antedates the last decade of the last century.

The coal industry of South America has never achieved prominence and active operations have been almost entirely confined to Chile and Peru. The inaccessibility of the deposits as well as the inferior quality of most of the coals are the main causes why the South American countries in the Past have been largely dependent upon foreign supplies. There are no prospects for any decided change of this situation in the immediate future.

The remaining mineral products of South America, which together form a long list, have been mined in many different places and in the aggregate represent an annual production of great value. With the exception of manganese, which has been mined in Brazil in increasing amounts since the outbreak of the Great War, no other mineral product forms the basis for an important industry. A large part of the world production of monazite, iodine, borax, and various kinds of gem stones, comes from South America, yet the demand for all such products is limited.

RELATION OF THE SOUTH AMERICAN MINERAL INDUSTRY TO OTHER INDUSTRIES

As stated above the development of South America has progressed along different lines than that of North America, Europe, Asia, or even most parts of Africa and Australia, in that the mineral industry was the first one to be developed. In most countries the early settlers developed the agricultural industry and the mineral resources were not exploited until manufacturing establishments requiring mineral products were started and no country has ever had an important manufacturing industry during its early history. Only as the population becomes denser and labor more plentiful are conditions favorable for manufacturing.

If one considers the list of the economic minerals of South America it will be seen that the fertilizers, guano and nitrate, are practically the only substances that can be used directly. The others require more or less manipulation to convert them into usable articles; while even the nitrate may be said to require some work of elaboration to separate it from other compounds that are destructive to plant growth. Therefore, in the absence of local manufacturing plants, South America's mineral production has largely been shipped to other countries from the earliest period. In some sections manufacturing has been developed rapidly during the past decade, as for example in São Paulo, Brazil, and in a few other cities but even there it is mainly the agricultural rather than the mineral products that have been so employed while the utilization of the raw minerals within the countries where they are obtained is everywhere secondary to their exportation. This condition is partly due to the lack of labor, as every one of the South American countries is very thinly populated in comparison with Europe and the United States, and also to the deficiency in the fuel supply. It is obvious that no country can ever expect to have its mineral wealth developed to its fullest extent so long as the bulk of the production must be sold in its raw state in foreign markets in competition with similar materials obtained nearer at hand. The increase in South American manufactures would do much to still further stimulate the mining industries of the various countries.

Another obstacle in the exploitation of the mineral wealth of the continent has been the lack of adequate transportation facilities. Mineral deposits, the world over, are mainly confined to the regions of uplift, as those are the places where the mineralizing processes have been most active. As mentioned above, the mineral deposits of the continent are more abundant in the high Andes or in the mountainous sections of Brazil, Venezuela, and the Guianas, places where navigable streams are absent and where the difficulties of railroad construction are excessive. That such obstacles can be overcome, however, has been demonstrated and several railroads in the Andes exceed in height above sea level the railroads of any other part of the world. The highest point reached is on the branch line running to Morococha, Peru, which attains an altitude of 15,865 feet above sea level. At the present time there is only one transcontinental railroad line, that which connects Buenos Aires and Santiago, and it is usually closed for several months each winter. Another one, which starting at Buenos Aires runs by way of northwest Argentina, southern Bolivia, and northern Chile to Antofagasta, is approaching completion, but at present lacks a short link in Bolivia. Northward a railroad from Arica, Chile, goes to La Paz, Bolivia. In Peru there are two railroads that go to the crest of the Andes but do not descend the eastern slopes. One of them starting at Mollendo goes to Cuzco and Lake Titicaca and the other one connects Callao and Lima with Oroya and Cerro de Pasco. In Ecuador a railroad connects Guayaquil and Quito.

All of these railroads, particularly those of northern Chile, Bolivia, and Peru have been of the utmost service in the development of the mineral resources of the Andes, but they are inadequate and there are numerous promising or even rich deposits that await improved means of transportation before they can be developed. Indeed, it is almost marvelous to see how some mining districts of Bolivia and Peru, remote from railroads, in high and rugged mountains, and in sections practically devoid of vegetation, have been successfully operated for many years. Only the richest mines can survive with such difficulties while the others are reserved until improved conditions prevail.

The mineral districts of Brazil are more favorably located for the construction of railroads and yet only one line, starting at Rio de Janeiro, crosses the region and it is not suitable for the transportation of large quantities of the baser minerals such as iron ore. Another railroad with its terminus at Victoria, is being built into the region.

In addition to the topographic obstacles in the way of railroad construction in South America, the lack of local supplies of coal has been almost as great. The cost of foreign coal at the sea ports is high while the consumption on the steep grades is excessive in proportion to the hauling capacity. Likewise the thinly settled sections of country through which the lines pass, considerable stretches where no freight originates, has discouraged the building of other lines by means of private capital. It seems as though it will be necessary for the governments of the various countries to build the railroads for the development of the country and, for a time, operate them at a loss. This policy pursued by Chile to a greater degree than any other country of South America has been one of the most potent factors in the progressive development of that country.

FUTURE DEVELOPMENT OF THE MINERAL RESOURCES

The résumé of the mineral wealth of South America already given and the detailed descriptions of the different countries which are given in the following chapters show that the continent possesses both varied and rich mineral deposits. Although important mines have been exhausted and abandoned, it is nevertheless obvious that the mineral industry as yet has not reached the state of development of that of Europe and the United States.

In addition to reasons given above this seems to be due to two other causes—lack of exact information and lack of capital. Geological surveys adequately supported by the governments of the different countries would undoubtedly justify the necessary expenditures within a very few years. The preëminence of the mining industry of the United States in comparison with that of other countries is due in a large measure to the dissemination of accurate information concerning the mineral resources of the country by the Federal geological organization. Every one of the South American countries has failed to fully appreciate the value of such work and in those countries where a geological organization is maintained, it is inadequately supported. An able staff of geologists engaged in the study of the country's mineral deposits would do more to encourage the development of promising sections and to discourage the investment of capital in unlikely districts than any other factor. The latter is equally important as unnecessary failures injure the industry and interfere with the development of promising deposits.

The lack of capital for mining ventures has been deplored by the leaders in the different countries. Although there are persons of wealth in every country, there are fewer great fortunes than in Europe and North America. The opportunities for investment in land and the agricultural industry are numerous and have appealed to the residents more than the mines. The result is that while the smaller mines are largely owned and operated by local capital, the most important mining ventures demanding a large amount of capital for proper development, have been mainly financed by foreigners; British, German, French, Belgian, and North American capitalists have been responsible for the successful operation of many mines and it seems that foreign capital must still be sought for the development of other regions.

In some countries in former years the instability of the governments tended to discourage foreign investors but this now applies to very few, the others having as strong governments as any of the European countries. Foreign capital is welcomed and given adequate protection.

The mining industry of South American countries seems destined to progress and will do so as the obstacles which have retarded development in the past are gradually overcome.

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Emphasizes the association of the ore deposits of the Andes with the andesites, their recent age, and the abundance of such minerals as enargite, rare elsewhere.

CHAPTER II.

ARGENTINA

RÉSUMÉ OF MINERAL PRODUCTION

In relation to the size of the country and the widespread mineralization of its mountainous regions, the mineral production of Argentina is exceedingly small, and this is true particularly of its metallic output. In the earliest days of mining, gold and silver were the metals sought, and many mines were worked for these metals by the Jesuits from the latter half of the 16th century to the time of their expulsion in 1767. It seems that mining then practically ceased until the arrival of the Lay Jesüits about 1777 or 1803. The political difficulties and turmoil of the next decades, however, prevented any stable development of the mineral industry. From 1850 to the early nineties was a period of considerable activity, marked especially by the production of argentiferous ores of copper and lead. The total output of these years was probably not very great, but a large number of small mines in the western and northwestern parts of the country were in operation and numerous mills and smelters were erected. The decline in the price of silver a quarter century ago forced most of these operations to close and there has not been much activity since. Difficulties of transportation and increase in operating expenses that followed in the wake of the European war in 1914 further paralyzed the mineral industry of the country, so that with the exception of a relatively small tungsten output, the production of metals has almost ceased during the past three years.

In the years immediately preceding 1914, the gold output ranged between 5,000 and 14,000 ounces, averaging about 10,000 ounces annually. The silver production in those years was about 200,000 ounces.

Of the common base metals copper is produced in largest amount, but the annual exports of copper smelter products and ores declined from 2,000 tons in 1911 to 310 tons in 1913.

The average copper content of these exports ranged from 50 per cent to 80 per cent. One-third or more of the gold output comes from the copper ores, and nearly nine-tenths of the silver output is from the same source. Lead and zinc ores are produced in very small quantity and primarily for their precious metal content, which is chiefly silver. There is no production of iron and manganese.

Until 1913 there was a small production of argentiferous lead vanadates. A few tons of tin ore are produced in some years, and there is a regular production of tungsten ores amounting to a few hundred tons of concentrates annually. In 1916 the production of tungsten concentrates amounted to 700 tons.

There is no coal production. The petroleum output has been increasing rapidly since a regular production was established in 1907, and in 1916 it amounted to nearly 1,000,000 barrels.

Among the non-metallic products of present importance are borates, mica, "onyx," gypsum, lime, salt, and sulphur. The four last named are produced chiefly for domestic and local consumption. About 600 tons of borates have been exported annually, 200 to 400 tons of "onyx," and a few tons of mica. A cement plant with an annual capacity of 1,000,000 barrels is under construction by American capital at Sierra Baya in the province of Buenos Aires.

TOPOGRAPHIC AND GEOLOGIC FEATURES

The greater part of Argentina consists of a vast plain which rises gradually from the Atlantic coast to an elevation of 2,000 to 3,000 feet at the foot of the Andes. This plain is broken at intervals by groups of mountains which generally have a north-south trend. The most important and numerous of these, known as the pampa ranges are in northeastern San Luis, western Córdoba, the greater part of La Rioja, and Catamarca, and the western edge of Tucuman provinces. The southernmost ranges, the Sierra de San Luis and the Sierra de Córdoba, rise to elevations of 7,000 and 9,000 feet respectively; toward the north higher elevations are attained, reaching 18,000 feet in the Sierra de Aconquija along the boundary of Catamarca and Tucuman and nearly 20,000 feet in the Sierra de Famatina.

The western edge of Argentina consists of the Andes Mountains, or Cordillera, which are at many points flanked by spurs and outliers called the pre-Cordillera. From the southern extremity to about latitude 20° S. this mountainous belt is relatively narrow, but further north it begins to spread out and bifurcates in the territory of Los Andes into an eastern and western range with a high plateau between known as the *puna de Atacama.* The elevation of the plateau ranges from 12,000 to 13,000 feet; the passes of the Western Cordillera average about 15,000 feet and the peaks rise to elevations of over 20,000 feet; the passes of the Eastern Cordillera range from 16,000 to 17,500 feet but the peaks rise only to 18,000 to 20,000 feet in elevation. The Eastern Cordillera is not a single well-defined chain of peaks but a series of ridges with intervening valleys that spread over western Salta and Jujuy and which merge toward the south into the northernmost of the pampa ranges.

The major geologic features of Argentina have been summarized by Keidel[1] and the following description is based mainly on his interpretations.

The vast pampa country is underlain by Cenozoic strata, consisting almost entirely of continental Quaternary deposits through which there emerge at numerous points Tertiary beds. The pampa ranges differ geologically from the Andes by the much greater prominence and extension of slates and various types of gneisses and schists which are chiefly pre-Cambrian in age, though in part also early Paleozoic. These rocks are intruded by later granites and diorites which at many places have greatly metamorphosed them, and cut by apophyses of them in the form of pegmatitic, aplitic, and lamprophyric dikes. Discordantly overlying, are continental deposits ranging in age from late Paleozoic to upper Triassic; and without marked unconformity, lying upon the latter, are Cretaceous red sandstones. These sediments occupy only isolated patches in the pampa ranges. In the Tertiary there were intrusions and eruptions of porphyritic rocks, andesites, trachytes, and rhyolites, and also more basic representatives.

[1] H. Keidel: Die neuren Ergebnisse der staatlichen geologischen Untersuchungen in Argentinien. Compte Rendu, XI Congrès Géologique International, pp. 1127–1141, 1910, Stockholm.

H. Keidel: Über das Alter, die Verbreitung und die gegenseitigen Beziehungen der verschiedenen tektonischen Strukturen in den argentinischen Gebirgen. Compte Rendu, XII Congrès Géologique International, pp. 671–687, 1913, Ottawa.

In northwestern Argentina, in the provinces of Salta, Jujuy, and Tucuman, and the territory of Los Andes, the basement of the Eastern Cordillera and the extensive pre-Cordilleras is made up of pre-Cambrian mica schists, graywackes, quartzites, and less altered marls, and ancient granites. These rocks reach in places even to the highest peaks. Discordantly overlying them in long north-south belts, are Cambrian to Silurian sandstones and slates, and with similar relations lower Cretaceous fossiliferous beds and gypsiferous marls, and upper Cretaceous red sandstone. The *puna* of Atacama is underlain by the same pre-Cambrian rocks with a thin covering over much of the area of the red Cretaceous sandstone and extensive flows of Tertiary to almost recent lavas.

In the main range of the Andes, Paleozoic slates and graywackes of Silurian and Devonian age are exposed on the western edge and in the deep valleys of the principal chain. At numerous points they have been altered to hornfels by granitic and dioritic intrusions. Lying immediately upon these strata are middle and upper Jurassic marine strata, which, however, do not extend eastward into the region of the pre-Cordillera and the pampa ranges. Then follow in order limestones and marls of lower Cretaceous age and the upper Cretaceous red sandstone. The entire red sandstone area is characterized by large flows of basic rocks, chiefly melaphyres. During Tertiary time, especially in the first half, and continuing to a very recent period, there were enormous outpours of acid and intermediate rocks.

Keidel recognizes four tectonic structures in the regions described. In the northern part of the Argentine Andes, there is evidence of pre-Cambrian folding. There was folding in the early and middle Paleozoic in the pampa ranges. In the pre-Cordillera of the central Andes, in San Juan and Mendoza, folding occurred in late Paleozoic time. Finally the Mesozoic strata of the main range were folded during the Tertiary. These Tertiary movements, he says, took place in two phases. First the sediments of the Andes belt were folded in depth; and in the second phase of the movement, the mountains themselves were formed. The Tertiary and Quaternary deposits of the pampa represent to large extent the material carried down from the range in the course of the erosion to which it has been subjected. The pampa ranges presumably shared in the Tertiary uplifts of the Andes.

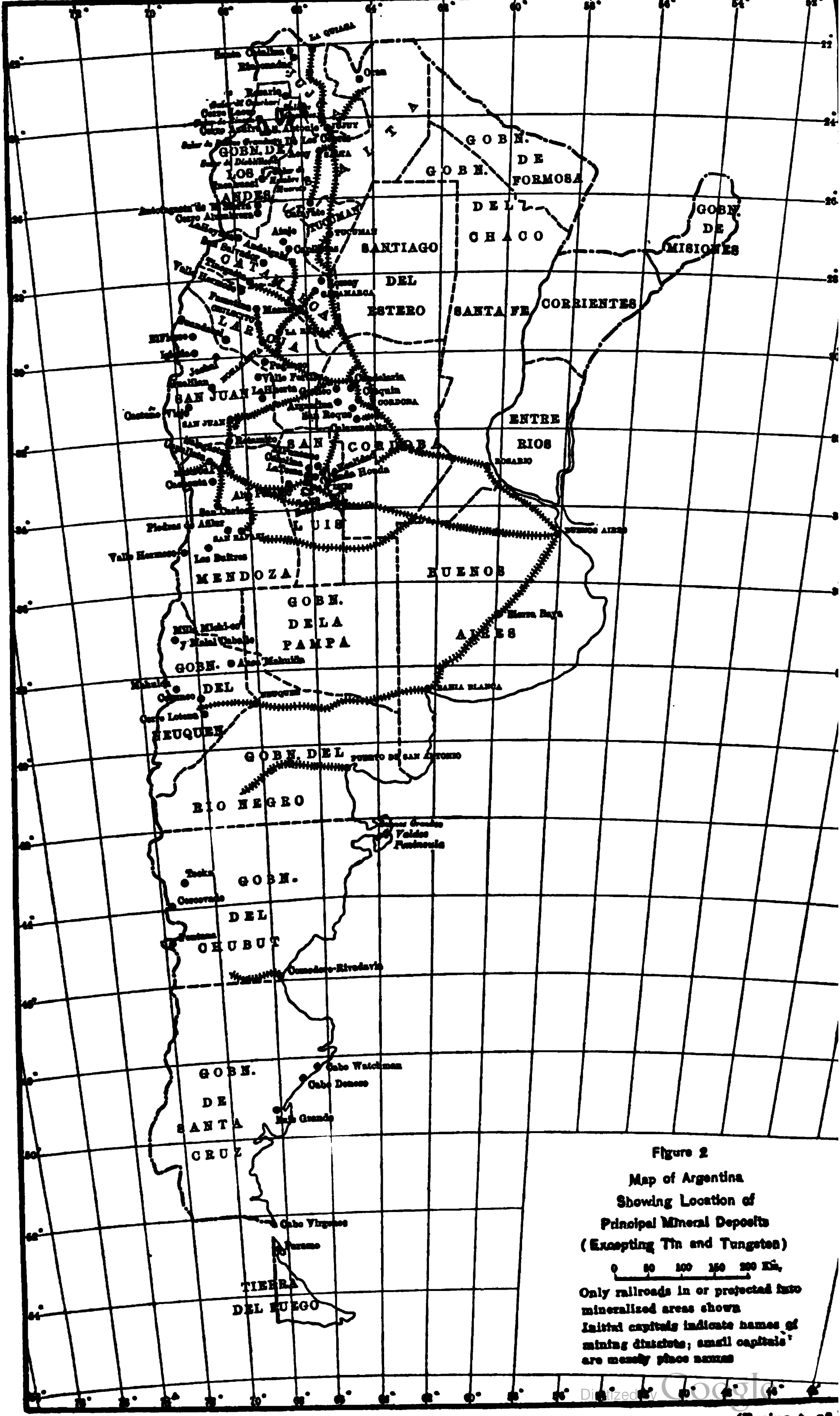

Fig. 2.

(*Facing p.* 38.

Two periods of igneous activity seem to be of importance in connection with the mineralization of the Argentine mountains. The magmas of the younger granites, which are probably of Paleozoic age, seem to have been responsible for the tin and tungsten deposits of the pampa ranges and for some of the gold deposits of the country. The most widespread mineralization, consisting of gold, silver, copper, and lead ores principally, is associated with the Tertiary igneous activity.

DISTRIBUTION OF THE MINERAL DEPOSITS

With the exception of petroleum and salt, the mineral deposits of Argentina are coextensive with and practically restricted to the Cordillera, the pre-Cordillera, and the pampa ranges. Furthermore, the mineralization of the northern half of the Andes appears to have been more widespread, more intense, and more diversified than that of the southern half, though the contrast may not actually be as marked as it now appears for the reason that the northern region is better known and explored than the southern. The most important mineralized region of Argentina is consequently that embraced by the territory of Los Andes and the provinces of Jujuy, Salta, Catamarca, La Rioja, San Juan, Mendoza, San Luis, and Córdoba. The location of the principal mineral deposits is indicated on the two maps, figure 4 which shows the distribution of the tin and tungsten deposits in the pampa ranges and figure 2 the distribution of other occurrences.

GOLD

Gold is found throughout the length of the Andes from the Bolivian boundary to Tierra del Fuego and in the pampa ranges; and both vein and placer deposits have been worked. In the southern half of the country not many vein deposits have been discovered, and the production has been derived from placers. In the northern half are many gold veins. The country rock of the gold veins consists of the metamorphic rocks, either pre-Cambrian or early Paleozoic, and many of the veins lie parallel to the schistosity. Young eruptive rocks are present in some districts, in others they are lacking and the mineralization appears to be related to deep seated rocks of probable Paleozoic age, as seems to be the case in the pampa ranges of San Luis and Córdoba. Auriferous quartz is the principal filling of the veins with which is associated more or less auriferous pyrite. Sulphides of copper, lead, and zinc are present in smaller amounts. The wall rock is often impregnated with auriferous pyrite. Most of the mining has been confined to the enriched oxidation zone in which the gold occurs chiefly in the native state. On reaching the leaner primary ores, operations have usually been suspended. On the whole, the veins seem to yield rather low grade ores.

Los Andes.—Along the eastern edge of the *puna de Atacama* (13, p. 40)[1] is a belt of quartz veins in quartzites, slates, and schists, carrying native gold, which have also given rise to numerous placers, extending from Rosario to Incahuasi.

Jujuy.—Another region of numerous veins and placers, is in northern Jujuy. The veins have a north-south strike, almost perpendicular dip, range from a few centimeters to 2 meters in width, and can be traced in some instances for several kilometers. The filling is quartz with visible free gold, a little pyrite, and rarely some sphalerite. Large quartz veins carry little gold, but pockets and veinlets carry high values. They are bedded veins in slates and graywackes and the wall rock is often impregnated with auriferous pyrite. Rinconada and Santa Catalina have been the principal districts. Placers are worked by the Indians in the rainy season, but a dredge installed on the Orosmayo River, southeast of Santa Catalina, some years ago proved a failure. The placer gold is finely divided and associated with much magnetite. Notable in these placers is the occurrence of native lead in particles similar to the gold up to 2 mm. in thickness.

La Rioja.—Gold ores in the Famatina district, are described on pages 58 and 59.

San Juan.—The principal gold districts of San Juan are Morado or Valle Fertil, Guachi or Jachal, Gualilan, and Castaño Nuevo. Valle Fertil lies on the west slope of the Sierra La Huerta, which consists of metamorphic rocks with a granite core. The ores occur in narrow veins in the schists and consist of quartz with pyrite, marcasite, galena, and chrysocolla. The Jachal mines are situated on the upper slopes of the Cerro de Gauchi, which reaches an elevation of 12,000 feet and consists of gneisses and granite cut by andesite and diabase porphyry. Veins are numerous but small and contain pyrite and arsenopyrite, ranging from ½ oz. to 1 oz. gold per ton. The Gualilan district lies on the west flank of the Tontal range, made up of

[1] Numbers in parentheses refer to articles in bibliography at close of chapter.

Paleozoic limestones dipping 45° west and cut by coarse-grained quartz porphyry. At the contact of porphyry and limestone, the latter rock is replaced for a width of 13 feet by ore consisting of quartz, auriferous pyrite, and sphalerite. Vertical stringers of black shale cross the ore body at intervals and the gold is largely concentrated in the vicinity. The grade of the ore is given at $3.00 to $16.00 per ton. The deposit has been worked to a depth of 300 feet. Another ore body (41, p. 111) running parallel to the limestone for 10,000 feet with a width of 30 feet, contains gold and silver-bearing sulphides of copper and lead and their oxidation products near the surface. This has been worked extensively by open cuts and underground. At Castaño Nuevo, are auriferous pyritic quartz veins, 2 to 3 feet in width in a region of decomposed granite (?) cut by andesite. Much of the gold is said to occur as tellurides. The primary ore averages ½ oz. gold, but ore shoots run as high as 1½ oz. The cementation ores carry still higher values.

Neuquén.—At Milla Michi-Có and Malal Caballo (76), on the left bank of the Neuquén River, is a network of veins and stringers grouped in zones several meters wide of which the more important have a northeasterly to easterly strike in a rock consisting of kaolinized feldspar with quartz and hornblende. The ore contains quartz, pyrite, and small amounts of sulphides of copper, lead, and zinc, and is also argentiferous. Placers derived from these deposits carry fairly coarse-grained gold and have yielded nuggets weighing several grams.

Chubut.—Gold is found at numerous localities in Chubut, but chiefly in placers, the best known localities being the upper courses of the Tecka and Corcovado rivers, and lakes Corcovado and Fontana. Gold quartz veins have been discovered in the Tecka River area.

Santa Cruz.—Placers occur along the streams of the Andes and along the beach of the southeast coast. The principal gold washings were located in the vicinity of Cabo Virgenes, where the gold occurs in the black beach sands.

Tierra del Fuego.—Most of the productive localities lie in Chilean territory, but the beach at Paramo was an important center about fifteen years ago.

San Luis.—In San Luis, placers have been more productive than lode deposits, but efforts to work them on a large scale have failed. The best known locality is Cañada Honda, where the detrital material has a thickness of about 7 to 8 m., and consists from top to bottom of 4 to 5 m. of turfy earth, 1 to 2 m. of sandy to loess-like loam, and 1 to 1½ m. of pebbles of crystalline and igneous rocks on a basement of gneiss. Gold nuggets as heavy as 5 oz. are found. The Rio de la Carpa, 3 miles east of, and Cerritos Blancos north of Cañada Hondo are other placer localities. An important lode district is the Carolina, on the west slope of the Cerro de Tomalasta. The deposits consist of a principal vein with a north-south strike and dip of 50° to 80° east and several parallel veins in the footwall, enclosed in black and gray slates extensively impregnated with pyrite. The width of the mineralized zone is 125 to 150 m. Impregnation appears to have been as important as fissure filling. The ores are auriferous pyrite irregularly distributed in zones in quartz; the gold content rapidly diminishes in depth. Small quantities of chalcopyrite, galena, and sphalerite occur.

Córdoba.—Gold ores are found at a number of localities in the Sierra de Córdoba, but most abundantly on the northern slopes of the Sierra Central between the rivers Soto and Candelaria, north and west of the town of Candelaria. The country rock consists of gneiss cut by dikes of pegmatite and aplite and nearby is a large granite massif. The veins strike north to northeast and dip 45° to 65° E. and have a width of 25 cm. to 140 cm. The filling consists of quartz which ranges in color from white to bluish or dark and is often cavernous and ferruginous, thoroughly decomposed fragments of gneiss, calcite, pyrite, a little arsenopyrite, and rarely galena and sphalerite. The gold content ranges from 1½ to 5 oz. and is highest in the cavernous quartz and ferruginous clays. Native gold is readily visible only in the oxidized ores.

SILVER

The silver production of Argentina has been derived chiefly from argentiferous copper and lead ores, and there are no important occurrences of silver ores in which both of these metals are not abundant constituents. Consequently, the silver-producing districts are described under either copper or lead. Well-known localities at which silver sulphides and sulphantimonides occur as important constituents of the ore are San Antonio de Los Cobres, in Los Andes; Hoyada in Catamarca; some of the veins of the Famatina district in La Rioja, where the base metal sulphides are chiefly of copper; and the Iglesia district in San Juan where galena is more abundant.

COPPER

Copper deposits of economic importance are restricted to the western part of Argentina, north of latitude 35° S., but are there very numerous and widely distributed. All of the important deposits consist of veins. Copper veins are found in the older Paleozoic and pre-Cambrian crystallines, occasionally in the later sediments, and in the volcanic rocks; but practically all of the occurrences, whether in those rocks or not, are closely associated with the young volcanic rocks and are doubtless genetically related to them. The ores are auriferous and argentiferous but there is a wide range in the precious metal content of the different districts. Famatina in La Rioja and Capillitas in Catamarca, the two most important and extensively developed mining districts in Argentina, are of this type, and the greater part of the production of metallic ores has come from the copper lode deposits.

Los Andes.—At San Antonio de Los Cobres are veins ranging from a few centimeters to 2 meters in width which according to Caplain (31) occur in conglomerates made up of coarse blocks of quartzite, feldspar, and eruptive rocks in an argillaceous and siliceous matrix with frequent outcrops of andesites. Barnabé (13) describes the country rock as trachytic and rhyolitic tuffs and agglomerates. The ore of the Concordia mine consists of tetrahedrite, chalcopyrite, galena, sphalerite, and pyrite. The crude ore carries 30 to 70 oz. Ag, 2 to 4 per cent Cu, and 6 per cent to 7 per cent Pb, and the hand-sorted 100 to 300 oz. Ag, 4 per cent to 12 per cent Cu, and 20 per cent to 45 per cent Pb. In some veins the copper content is subordinate and the ores are really argentiferous lead ores.

Salta.—The ores of the Acay district in western Salta also run high in silver, about 6 oz. to each per cent of copper. The veins are found mainly in the southern spurs of the Cerro Nevado de Acay, in country rock of granite and trachyte or andesite. They range from 2.5 to 6 feet in width and contain chalcopyrite and other copper sulphides and galena. In the Acay Chico, or Cerro de Minas, a western outlier of the main mountain on the east side of the Calchaquí valley, are highly ferruginous outcrops in metamorphosed conglomerates and argillaceous schists resulting from the decomposition of pyrite deposits that carry very little gold, silver, or copper.

Catamarca.—In Catamarca are three important copper districts, Capillitas and Atajo in the Sierra de Aconquija and Hoyada in the northwestern corner. The veins of the Capillitas district run in an east-west direction across a north-south contact with porphyry on the east and gneiss on the west. The best mines are in the porphyry. There are three groups of veins. The Restauradora mine, the most important of the district, is in the northern group; it has been tapped by an adit 800 feet below the outcrop and has 3 miles of workings on the vein, which ranges from 1½ to 6 feet in width. The ore occurs irregularly in shoots, and consists of pyrite, chalcopyrite, considerable chalcocite, and bornite. The Carmelita, the most important vein of the middle system, has a width of 20 to 120 cm., and a filling consisting of tetrahedrite, chalcopyrite, pyrite, galena, and occasionally sphalerite. The ores of the Grande mine, to a depth of 140 feet, consisted of red and black oxide of copper, mixed with blue and green carbonate, with some tetrahedrite and chalcopyrite in the central part of the vein. At greater depth the oxidized minerals disappeared. The width of the vein is 31 inches, but the richest ore is not over 22 inches wide. The ores of the district are auriferous and argentiferous and usually carry more or less galena; quartz is the principal gangue mineral, with rhodochrosite in subordinate amount. According to the smelter returns they average 7 oz. Au, 8 oz. Ag, 7 per cent Cu. It is estimated that the Capillitas and Atajo districts have produced $2,000,000 of metals under the primitive methods of the past. Both districts have been controlled for a number of years by English capital and the mines are now owned by the Capillitas Consolidated Mines, Ltd. The nearest railroad station, Chumbicha, is over 100 miles distant. In 1907, the company started the construction of an aerial tram 22 miles long to cover part of the distance. The Atajo, or Abajo, district is located in an east-west spur on the west side of the Sierra de Aconquija, and the ore deposits form a network of veins in an intrusion of porphyry or rhyolite. The ores consist of quartz with auriferous chalcopyrite, chalcocite, tetrahedrite, pyrite, and a little galena. The principal veins range from 2 to 4 feet in width. The Hoyada district is an area of eruptive rocks consisting of blue to gray phonolites and trachytes and agglomerates. The veins are narrow but characterized by a high silver content. Associated with sulphides of the common base metals in quartz gangue are rich silver minerals as polybasite.

La Rioja.—The Famatina district is the best known and doubtless most important mining district in Argentina. The ores are chiefly of copper, but gold and silver ores also occur. The district is more fully described on pages 55 to 59.

The Valle Hermoso district lies at an elevation of about 11,000 feet in a valley between the main Cordillera and the pre-Cordillera (59, pp. 30–81). It is an area of upper Jurassic sediments consisting from the base to the top of black compact fossiliferous limestone, a bed of whitish to gray gypsum 30 m. thick, variegated sandstone becoming gray toward the top, greenish-gray conglomerate, and fossiliferous limestone. The rocks have been considerably folded and faulted. Massive sills of melaphyre are interstratified in the sandstone, and thick cappings of basalt top most of the mountains. Dikes of andesite and trachyte as well as the melaphyre are cut by numerous dacite dikes. Two types of deposits occur in the district represented respectively by the Las Choicas and Burrero occurrences. The Las Choicas type occurs only in the lower limestone accompanied by andesite dikes. The ore is a mixture of chalcopyrite, bornite, and chalcocite in a gangue of barite and calcite. Bornite and calcite are more abundant in the lower levels than in the upper. The ore carries little gold and silver and 7 per cent to 8 per cent copper. A section across one of the veins from west to east shows the following sequence: trachyte dike; 5 m., somewhat mineralized white rock (probably the dacite); 8 m., highly altered and crushed limestone; 7 to 8 m., vein; andesite dike. The Burrero type consists of stockworks of narrow veins in the melaphyre rarely over 2 m. in width in which chalcocite is the only ore mineral and the not abundant gangue consists of quartz, prehnite, scolecite, and rarely calcite. There is no precious metal content. Loose boulders of native copper with prehnite gangue weighing several kilograms are encountered, but the nearest approach to such material found in place are small particles of native copper in cavities in the melaphyre.

Other Copper Deposits.—Copper ores as fillings of amygdules in melaphyres are reported from Corrientes and Misiones. In the Sierra de San Luis are fahlbands in gneiss impregnated with pyrite and chalcopyrite which are frequently auriferous.

In the Sierra de Córdoba are two parallel belts of copper deposits, the one in the Sierra Chica which is the easternmost ridge of the range and the other on the eastern slope of the Sierra Central. The strike of the deposits is parallel to that of the crystalline rocks and they occur in amphibolic slates and dioritic rocks that are intercalated in the schists. The ores consist of magnetite which is in part titaniferous, chalcopyrite, and pyrite, with a gangue of quartz and epidote. On the outcrop, the blue and green colors of malachite, azurite, and chrysocolla are prominent. The deposits may represent magmatic segregations in dioritic rocks that have been subjected to regional metamorphism during which there has been more or less solution and re-deposition of the ores. The Calamuchita ores are of this type.

LEAD

The region in which lead deposits occur is coincident with that of the copper deposits with the exception of the Mahuida district in Neuquén. The deposits have been worked primarily for their silver content and all are lode deposits. Though found in rocks ranging in age from pre-Cambrian to the Tertiary volcanics, in nearly all cases there is evidence of their genetic relationship to the volcanics. In reality no sharp line of demarcation exists between the copper deposits and the lead deposits as many of the occurrences contain both copper and lead sulphides and are to be classed with the one group or the other merely on the basis of the predominant metal.

Jujuy.—The lead ores of Jujuy are low in silver with the exception of a few narrow veins and have been little developed.

Salta.—Veins of argentiferous galena with cerussite in the zone of oxidation are abundant in Salta, but have received scant attention.

Catamarca.—Mineralization in Catamarca seems to have resulted chiefly in the formation of copper deposits.

La Rioja.—In the Guandacol district, La Rioja, the Urcushum deposits are veins of argentiferous galena in limestone, the oxidized zone of which consists of enriched cerussite and anglesite carrying 13 oz. Ag, and 25 per cent to 30 per cent Pb. Other veins of the district occur in Paleozoic schists associated with andesites.

San Juan.—In the province of San Juan, argentiferous lead ores have received more attention. In the Fierro district are quartz veins in Paleozoic schists and granite which carry native silver, argentite, tetrahedrite, galena, and, in the oxidized zone, cerussite and anglesite. The ores of the Salado or Iglesia district grade from highly argentiferous lead ores into dry silver ores. The vein filling consists of quartz, barite, and decomposed wall-rock, in which the ore minerals are fine-grained galena, polysulphides of silver, and some wire silver. The Desengaña vein which has a width of 3 to 4 feet, has a dike of fine-grained trap on one wall and porphyry followed in a few feet by granite on the other. The ores carry from 6 to 120 oz. Ag. The veins of the Castaño Viejo district range from a few inches to 5 feet in width and can be traced for 2,000 or 3,000 feet. The ores occur in shoots of galena and pyrite carrying 45 to 180 oz. Ag. Considerable sphalerite appears with depth. The country rock of the Huerta district, on the east side of the Sierra La Huerta, is granite, gneiss, and schist. The Santo Domingo is a vertical iron-stained quartz vein containing gypsum with a selvage on one wall. The pay ore occurred in three vertical shoots 200 to 300 feet apart, 3 to 22 feet long, which contained streaks of argentiferous galena 2 to 12 inches wide with which were mingled cerargyrite, argentite, and ruby silver so that the silver tenor amounted to 300 to 450 oz. per ton. Other low-grade veins containing 30 to 60 oz. Ag carried in addition to the galena, pyrite and sphalerite.

Mendoza.—The Uspallata district (11, p. 587) in Mendoza contained veins of siderite, quartz, and accessory calcite and barite, with argentiferous tetrahedrite, galena, sphalerite, and pyrite. The silver was most closely associated with the tetrahedrite. The oxidized zone was characterized by the occurrence of cerargyrite and embolite. The district contains a great variety of igneous rocks intruding sediments of different ages, but the argentiferous lead veins are principally in dikes and sheets of olivine diabase which intrude variegated conglomerates and sandstones of Triassic age. The Sierra Piedras de Afilar is a range of Paleozoic rocks on the west flank of the Sierra Pintada, which consists chiefly of upper Triassic variegated sandstones and conglomerates. Three groups of deposits extend for a distance of 15 km. south of the Diamante River in the Piedras de Afilar district. All of the veins are characterized by well-defined walls, uniform width and mineralization, and a filling of quartz with galena and smaller quantities of arsenopyrite, chalcopyrite, and sphalerite. In the southern part of the district, the country rock is micrograinite and in the rest schist. The veins average ½ to 1 m. in width.

Neuquén.—The Mahuida district has a series of east-west veins in Jurassic sandstone and andesite dikes cutting it in a direction parallel to the veins. In the andesite the veins have well-defined walls with a width of about 1 m., and the gangue consists of quartz, silicified wallrock, and clay; in the sandstone, they occur as lodes about 3 m. wide, and the filling is chiefly coarsely crystalline barite. The structure of the ore is banded. The principal ore mineral is coarse-grained galena but in the oxidized zone cerussite and pyromorphite occur. The average grade of the ore is about 45 oz. Ag and 24 per cent Pb.

Córdoba.—Veins of galena and sphalerite are widely distributed in the southern and western portion of the Sierra de Córdoba, but the most important occurrences are on the high plateau between the Guasapampa and San Carlos rivers, where are located the two neighboring districts of Guaico and Argentina. Common characteristics of these veins are a country rock of gneiss, preferably granitic, occurrences of pegmatites in their vicinity, northeast strike and steep westerly dip, average width of 50 cm. and rarely reaching 1 m., and a filling of quartz gangue with coarse- and fine-grained galena, dark colored sphalerite, pyrite, and arsenopyrite. The upper portion of the veins shows marked enrichment in silver, and sphalerite and pyrite become more abundant with depth. The veins have not been worked deeper than 50 m. and the silver content averaged 70 to 90 oz. Recent eruptive rocks occur in the vicinity. A series of east-west veins at the north edge of the Guaico district differ mineralogically from those just described only in the presence in the oxidized zone of the vanadates descloizite, vanadinite, and brackebuschite. A similar vein in the Sierra de San Luis carries also the molybdate, wulfenite.

ZINC

No zinc deposits have been described in Argentina, but sphalerite occurs in many of the lead and copper deposits in greater or less amount.

IRON AND MANGANESE

No important deposits of iron ore have been discovered in Argentina. In Los Andes, on the *puna* of Atacama, large magnetite deposits are reported to the east of Cerro Lacco. In the Sierra de los Altos, Catamarca, are narrow bodies of titaniferous magnetite in diorite which contain 17 per cent to 18 per cent TiO_2, in what is known as the Romay district. A company called the Sud Americana planned to smelt these ores but no progress was made with the enterprise. Lenticular intercalations of magnetite occur in slates between the Llareta and Santo Domingo rivers and on the Portezuelo de San Andres River. In the vicinity of Jachal and Valle Fertil, San Juan, large deposits of magnetite are said to exist. Iron-ore veins are abundant in the vicinity of the Puente del Inca on the trans-andine railroad in Mendoza. In the Paganzo beds at Paganzo, La Rioja, are oölitic iron ores; and large deposits of red hematite are said to have been discovered in the territory of Misiones.

At Piedra Parada Grande, near San Luis, is a small deposit of manganese ore from which a shipment of about 100 tons was made at one time. Other deposits are reported in the vicinity. They appear to be superficial deposits on gneiss and the ore is mixed with quartz and other gangue substances.

COBALT

Two cobalt deposits have been prospected. On the western slope of the Sierra de Famatina at Valle Hermoso, La Rioja, in an area of talcose schists near their contact with an acidic igneous rock of which the main range consists, are several quartz veins containing cobaltite and arsenopyrite, which average 90 to 120 cm. in width. First class hand-sorted ore assayed ¾ to 1 oz. Au, 5 to 10 oz. Ag, 6 per cent to 7 per cent Cu, 0.5 to 2.5 per cent Ni. Similar veins, except that pyrite and chalcopyrite instead of arsenopyrite are associated with cobaltite, are described at Eli Salto Quebrada in Catamarca, a locality not far from Valle Hermoso.

TUNGSTEN AND TIN

Tungsten and tin deposits occur in the pampa ranges. Tungsten deposits are most abundant in San Luis and Córdoba, but are also found in La Rioja. Tin is found only in La Rioja. The deposits occur in pre-Cambrian and early Paleozoic metamorphic rocks intimately related to the pegmatites of the younger granites of these ranges. They are described more fully on pages 59 to 63.

COAL

Argentina appears to be devoid of high-grade coal deposits. Along the eastern edge of the Andes is a coal-bearing horizon in the Rhaetic that extends from Neuquén to Jujuy; but wherever prospected the coal is too slaty to be of value. At Salagasta, northwest of Mendoza, it was opened by a tunnel 105 m. below the surface and cut by a boring at 606 m. The bed is believed to be 3.5 m. to 5 m. thick, and three samples ranged from 5,500 to 7,000 B.t.u., 6 per cent to 14 per cent ash, and 21 per cent to 33 per cent volatile matter (44, p. 579). Fifteen miles west of Retamito, San Juan, in a horizon of black slates of Culm age is a bed of slaty coal 50 to 60 cm. thick.

Lignite has been found in the Miocene of Patagonia and Tierra del Fuego and is worked intermittently at some localities. As a rule, it is too clayey, however, to be of value. Cabo Watchman, Cabo Donoso, and Bajo Grande, in Santa Cruz, are among the localities mentioned.

PETROLEUM AND ASPHALT (10, 46)

Arnold estimates the petroliferous area of Argentina at 8,000 square miles, of which 400 sq. mi. gives superficial evidence of petroleum and not over 2 sq. mi. has been proved. Petroleum is found in upper Triassic, Jurassic, Cretaceous, and Eocene strata and predominantly in sandstones, limestones, and dolomites. The oil has accumulated in anticlines and in practically structureless areas. It is asphaltic in character and ranges from 11° to 24° Baumé. The wells thus far drilled range in depth from 200 to 4,000 feet and are small producers, averaging less than 100 barrels daily. There are three principal petroliferous areas, Comodoro Rivadavia, Salta-Jujuy, and Mendoza. A fourth district is the Cacheuta in Mendoza. The Comodoro Rivadavia has been the only important producer and its output has been steadily increasing since its discovery in 1907, and in 1917 amounted to nearly 1,000,000 barrels.

Comodoro Rivadavia District.—The Comodoro Rivadavia district is in the southeast corner of the territory of Chubut on the Gulf of St. George. The oil comes from a coarse pebbly Cretaceous sandstone lying on schist and granite, and is unconformably overlain by Eocene and later Tertiary tuffaceous and fossiliferous beds. The oil appears to occur in a series of lenses produced by a change in facies of the petroliferous beds in a horizontal direction. The beds dip 12 feet to the mile in a broad syncline. The petroliferous horizons begin at a depth of 435 m. below sea level and continue to 620 m., the maximum depth that has been attained by drilling. Some wells have had an initial flow of 1,000 barrels, but the average daily yield is 50 to 100 barrels. The oil ranges from 21½° to 24° Baumé. The larger part of the operations are in control of the government and the oil is consumed for fuel on the national railways. The district was accidentally discovered in 1907 as a result of borings for water.

Salta-Jujuy Region.—The Salta-Jujuy region is the southern extension of the Bolivian petroliferous region. The region is one of well-defined long narrow anticlines in a series of sandstones, arkoses, gypsiferous beds, limestones, and dolomites, which are of Jurassic or possibly Cretaceous age. The most prominent anticline is that of the Sierra Agüaragüe which extends over into Bolivia. Production from wells thus far drilled has been very small and consisted of a black asphaltic oil ranging from 11° to 14° Baumé. The well-defined anticlines and good seepages are encouraging features in spite of the indifferent results of past explorations.

Mendoza-Neuquén Region.—The Mendoza-Neuquén region extends as a narrow belt along the eastern edge of the Andes, between latitudes 34° S. and 40° S. The oil occurs in the upper Jurassic at some localities as at Cerro Lotena in Neuquén, but more commonly in the Cretaceous deposits at the eastern edge of the Andine geosyncline where the Tertiary folding is gentlest. The oil-bearing horizons are sandstones and marls, which have yielded a product of about 20° Baumé. Wells thus far drilled have been small producers and short lived. Cerro Lotena and Covunco in Neuquén and Los Buitres in Mendoza are among the localities that have been prospected.

Cacheuta District.—The Cacheuta district in Mendoza differs from other Argentine petroliferous areas in that the oil occurs in Rhaetic beds. Discovered in 1886, the district has yielded small quantities of oil which were conveyed by a 45 km. pipe line to the city of Mendoza. The oil contains 4 per cent light oils, 23 per cent illuminating oils, and 73 per cent heavy oils with much paraffine. Hermitte thinks it may have resulted from the distillation through igneous intrusion of black slates containing *Estheria magellensis.*

Rafaelite Deposits.—The petroliferous region of Mendoza and Neuquén is characterized by the occurrence of deposits of asphalt, or rafaelite, in the lower and upper Cretaceous sediments, of which the best known and most important seems to be that of Auca Mahuida in Neuquén, and which are also abundant in the Los Buitres district. A notable feature of the rafaelite is the high vanadium content in the small amount of ash that it yields. The Auca Mahuida (79, 77) deposit is a vein with west-northwesterly strike which varies from a little over one meter to three meters in width and which can be traced somewhat discontinuously for 8 km., cutting upper Cretaceous sandstone and arenaceous marls. The wallrock is bleached and there is a narrow selvage of a copper-bearing substance containing 2.7 per cent Cu. Between this and the rafaelite there is also in places a band of gypsum. The rafaelite is a hard resinous material with a distinct asphaltic odor when hot, is black with a slightly reddish reflection, melts at 130°C., and contains 57 to 66 per cent volatile matter, 34 to 43 per cent fixed carbon, 0.3 to 0.6 per cent ash, 3 to 5 per cent sulphur, 1 to 1.2 per cent nitrogen, 9,000 to 10,000 B.t.u. The ash consists almost entirely of vanadium salts. At Los Buitres, the asphalt occurs along the contact of mica diorite and variegated argillaceous sandstones and in fractures in the mica diorite close to the contact.

BORATES (31, 47)

Deposits of borates are found in Los Andes and the immediately adjacent portions of Jujuy, Salta, and Catamarca in large saline lakes and *salares*. The salt usually occurs as sodium-calcium borate mixed with sodium and calcium sulphate, sodium and magnesium chloride, oxide of iron, and more or less sand and clay. The thickness of the borate layers ranges from tens of centimeters to one or two meters. Sometimes they outcrop, or they may be covered with a layer of salt or with a layer of dirt up to a meter or more in thickness. The borate occurs either in solid layers of massive material, or in the form of pebbles and concretions; the latter type carries a higher percentage of boric acid than the former. The commercial deposits range from 25 to 40 per cent boric acid. The source of the boric acid is ascribed to geyser and hot spring action that followed the intense volcanic activity to which the region has been subjected. Presumably the boric acid was first deposited around the outlets of the thermal waters on the slopes of the hills surrounding the undrained basins and depressions, and was subsequently carried down into the *salares* by rain waters, largely through the underlying alluvial sands. Preparation of the borate for market usually consists simply in drying the lumps, screening from them adhering sand and dirt, and sacking for shipment. Dessicated material contains 45 to 50 per cent boric anhydride.

Borate deposits are most numerous along the eastern part of the *puna* of Atacama where they lie at elevations of 12,000 to 13,000 feet. The more important occurrences from north to south are the Salar de Cauchari, which is 53 km. long and 3 to 8 km. wide, and contains borate layers in the form of agglomerated concretions from 10 cm. to 2 m. thick; the Salar de Rincón, which is almost entirely saline but along its southeast bank contains a layer of borate 50 cm. thick; the Salar de Pastos Grandes; the Salar de Diablillos; and the Salar de Hombre Muerto, in which the borate occurs both in massive layers and as concretions in beds with a maximum thickness of 60 cm. The most important operations in Los Andes have been those at Porvenir at the south end of the Salar de Cauchari.

More favorably located is the Salar de Salinas Grandes on the boundary of Salta and Jujuy. At Tres Morros, on the eastern edge, is a layer of concretions 80 to 100 cm. thick that contains 37 per cent boric anhydride. At other points the borate occurs massive and mingled with more sodium chloride. The Tres Morros is the most actively worked deposit in Argentina.

Nearly all of the borate deposits are under the control of the International Borax Company, and as they are more inaccessibly located than deposits in Peru and Chile owned by the same company, they are not actively worked at present. The total annual production is about 650 tons for domestic consumption and about the same quantity for export.

OTHER NON-METALLIC PRODUCTS

Sulphur.—Many of the volcanoes of Los Andes contain deposits of sulphur, but they lie at such high altitudes and in such remote localities that they are hardly profitable to work. They are analogous in their mode of occurrence to the economically more important deposits of Chile. Among the peaks containing sulphur deposits are the Cerro Azufre de Pastos Grandes, Cerro Lacco, and further southwest toward the Chilian border Cerro Estrella and Cerro Sin Nombre.

Alum and Soda.—Likewise closely associated with extinct volcanoes, in Los Andes, are deposits of alum and soda. In and around the edges of two old craters known as the Cerro Alumbrera are large quantities of alum. The lava has been greatly decomposed, probably through the action of sulphuric acid, and there occur clean white compact masses of mixtures of aluminium and magnesium sulphates, containing about 20 per cent aluminium sulphate. The sodium carbonate occurs nearby at Antofagasta de la Sierra. It is worked only for local use and is known as *coipa.* The main deposit consists of an area of about 1,500 sq. m. covered by 30 to 50 cm. of sodium carbonate, sodium sulphate, and sodium chloride, which contains 25 per cent to 35 per cent sodium carbonate. Much of the material is carried away by the winds but the supply is continually augmented. Numerous other deposits occur and tuffs to the south are covered with a coating of *coipa.*

Mica.—Some of the pegmatites of the Sierra de San Luis and the Sierra de Córdoba contain mica of commercial quality and many attempts have been made to work them but no important occurrences have been discovered. Several mines near Calamuchita, Córdoba, have shipped small sizes of light brown muscovite to Europe; and the Realidad mine, 12 km. northwest of La Toma, on the eastern slopes of the Cerros del Rosario, San Luis, has been a producer. At the Realidad mine the largest sheets of mica occur close to and perpendicular to the wallrock schists.

Fluorite.—At San Roque in Córdoba, are veins of fluorite in biotite gneiss east of the contact of the gneisses with the main range granite massif and in association with numerous pegmatites. The veins have a northwesterly strike, can be traced for several hundred meters, and range from fissure veins 20 to 30 cm. wide to lodes several meters in width. The fluorspar occurs in bands of different colors, colorless, light green, yellow, violet, blue, and almost black. Pyrite is the only metallic mineral in the veins, and there is some chalcedony which is white in color with a light violet tinge due to the inclusion of microscopic fluorite.

Onyx.—El Pantano, on the west side of the Cerros del Rosario, in San Luis, is famous for its deposits of banded aragonite of various colors that is used for decorative purposes under the name "onyx," or "marmol verde." At the base is a layer of travertine with inclusions of quartz, gneiss, and granite, and this is overlain by the so-called "onyx" which consists of layers of granular aragonite, prevailingly green in color but also gray, red, and yellow, separated by layers with fibrous structure of a white to gray color. The deposits are of thermal spring origin, and the desirable green material has a maximum thickness of 9 m. and a limited horizontal extent. On the north side of the Diamante river, near San Rafael, Mendoza, similar deposits are worked.

Salt.—The prevailingly arid climate of so much of Argentina and the numerous depressions without outlets result in the presence of many saline lakes which serve as the sources of the local salt supply. In the southern part of the province of Buenos Aires is a saline lake, the water of which is transported by the South American Salt and Chemical Production Company, Ltd., in a 4-inch pipe line to works on the Bay of San Blas, where it is evaporated and yields a salt containing 97 per cent sodium chloride. On the peninsula of Valdez in Chubut, are two saline lakes which, through the evaporation of the waters in the dry season, contain large quantities of high-grade salt along their margins. A railway has been built to the coast to facilitate shipments. Considerable salt for local use is also produced by solar evaporation of the waters of Lake Bebedero near the city of San Luis.

DESCRIPTIONS OF IMPORTANT DEPOSITS

The Famatina District

The Sierra de Famatina in La Rioja is a range with a general north-south trend separated on the east from the Sierra de Velasco by the Famatina valley in which the towns of Famatina, Chilecito, and Nonagasta are located, which are supply points for the mines and centers for the treatment of the ores of the Famatina district, and on the west by the Valle Hermoso from the more irregular outliers of the Cordillera. The range is one of great elevation and culminates in the Nevado de Famatina at an elevation of nearly 20,000 feet. The ore deposits of the district are located on the eastern slopes of the range in the vicinity of the peak. (Map, figure 3.)

The geology of the district is quite complex (78). The most abundant rocks are a thick series of Paleozoic slates with some limestone intercalations, the exact age of which is not known but which are probably between Cambrian and Devonian. These slates have been so metamorphosed by igneous intrusions, that at many places stratification is no longer recognizable. More recent sediments are not widely distributed and, as the deposits are confined to the Paleozoic and igneous rocks, need

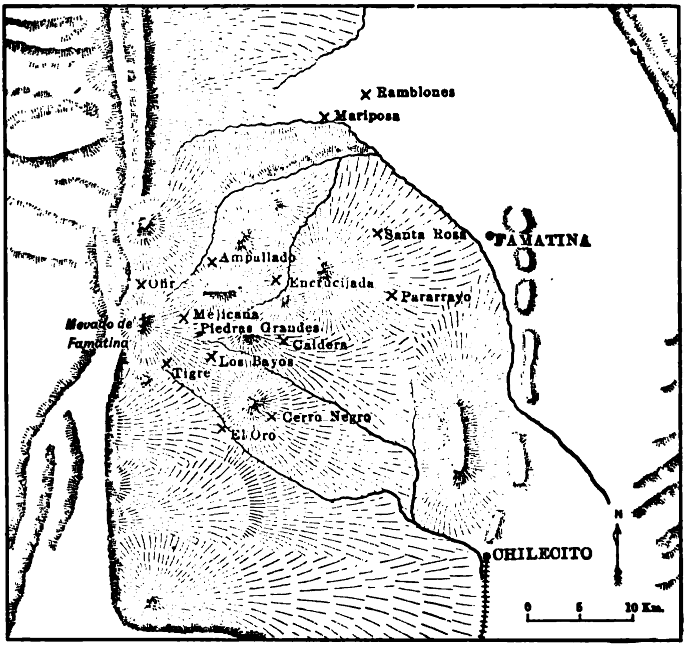

FIG. 3 —Sketch map of Famatina District, Argentina.

not be considered. The igneous rocks show a wide range in composition and have cut through and flowed out over slates at many points. Among the varieties mentioned are granite and pegmatite at the acidic end, and greenstone at the basic, but diorites and particularly dacites appear to be most common. The Paleozoics are with few exceptions the wallrocks of the veins.

The district consists of a number of sub-districts characterized by the predominance of ores of copper, silver, or gold. The copper deposits are Mejicana, Ofir, Ampallado, Los Bayos, Encrucijada, Santa Rosa, and Pararrayo; the silver deposits are Tigre, Cerro Negro, and Caldera; and the gold deposits El Oro, Piedras Grandes, Mariposa, and Ramblones.

The Copper Deposits.—The most important deposits of the district are the Mejicana. The veins occur in two ridges near the foot of the Nevado de Famatina called the Mejicana and Atacama respectively, separated by Mejicana gulch in which the principal mine workings are located. The most important mines on the Mejicana ridge are the San Pedro and Upulongos, and on the Atacama the Forastera and Atacama, and they lie at elevations of 15,000 to 16,000 feet. All the veins have slate as their wallrock. The gangue is primarily quartz with some calcite and barite. The important ore minerals are enargite, famatinite, tetrahedrite, and chalcopyrite, the mineral famatinite receiving its name from this occurrence. Pyrite, galena, and sphalerite are also abundant. The copper content seems to show appreciable diminution in depth and the rich ores occur in shoots. The San Pedro vein strikes east-west, dips to the south and has a width of 30 to 70 cm. The ore shoot in this vein is about 600 feet long, and the ore averages 0.3 oz. Au, 2.6 oz. Ag, 11.5 per cent Cu. The Upulongos vein lies about 1,000 feet from the San Pedro, parallels it in strike but dips to the north, is 60 to 110 cm. wide and has been developed over a vertical range of 200 m. The ore shoot is 1,200 feet long, and the ore ranges from 0.2 to 1.2 oz. Au, 6 to 14.5 oz. Ag, and 2.9 to 3.3 per cent Cu.

The Ofir mines lie 2 km. to the northwest of Mejicana, at about the same elevation. The veins are well-defined fissures and lodes in slates at and near their contact with a granite porphyry massif. The filling is principally quartz with pyrite and chalcopyrite. Some of the narrow veinlets carry high gold values. The Ampallado veins, situated near Ofir, are in slates cut by porphyry intrusions and are characterized by large amounts of galena and sphalerite in the ore.

A second group of copper deposits in the northeastern part of the Cerro de Famatina are not as well known as the preceding, though they lie at much lower elevations. They are the Encrucijada, the Santa Rosa, and the Pararrayo, which consist of veins of chalcopyrite in slates cut by igneous intrusions and especially green magnesian rocks containing pyrite inclusions that seem to be connected with the mineralization. The Santa Rosa ores carry no precious metals; the Encrucijada consisting of chalcopyrite, bornite, covellite, and chalcocite, contain silver only; and the Pararrayo ores are low in gold and silver tenor.

The Los Bayos deposits at an elevation of about 14,000 feet are similar to the Mejicana mineralogically but differ from the other copper deposits in their mode of occurrence. Cooling fractures in dacite were enlarged by circulating waters which at the same time decomposed the rock. The ores were deposited in the form of pockets in the cavities thus produced in the dacite. The average grade of the ore is 10 oz. Ag and 2.75 per cent Cu. Hand-sorted ore carries as much as 7 per cent Cu.

The Silver Deposits.—The silver-bearing veins are much alike and the division of the deposits is on a topographic basis. They consist of quartz veins with a little barite and calcite containing the silver haloid ores, cerargyrite and bromyrite, in the oxidation zone, followed below by native silver, argentite, pyrargyrite, proustite, and considerable argentiferous galena. Sphalerite is also abundant, and there are smaller quantities of pyrite and chalcopyrite. The width of the veins is irregular and varies from zero to one meter. The country rock is slate cut by dikes of granite, porphyry, and dacite. In the Cerro Negro district there are two vein systems with east-west and northwest strike respectively. La Peregrina, the most important mine, was worked to a depth of over 300 meters. The deposits lie at elevations of 10,000 to 13,000 feet. The Tigre district lies at a little lower elevation. The San Miguel mine in this district yielded 1,500,000 oz. silver. In the Cerro Negro and Caldera districts the igneous rocks are granite and porphyry, in the Tigre district dacites.

The Gold Deposits.—Gold veins occur in the El Oro and Piedras Grandes districts. The veins of the El Oro district are found on both sides of the Rio del Oro, at the foot of the Cerro Negro, in granite which encloses many large masses of slate. They are narrow veins with a north or northwest strike, carrying quartz and pyrite with a little barite and chalcopyrite. The gold content is given at $\frac{1}{3}$ to 1.7 oz. and the silver about the same. The Piedras Grandes deposits are geologically part of the Mejicana district, occurring on the Atacama ridge of that district. There are two well-defined fractures filled from above with a breccia of slate and a younger conglomerate. In depth are great caverns that have not been filled by the débris, and still deeper veins of pyrite. The breccia contains a yellow or gray auriferous clay that carries about ½ oz. Au.

Gold placers occur at Mariposa and Ramblones at the base of the northeast slope of the Cerro de Famatina. A dredge on the left bank of the Aschavel River installed in September 1907 and operated until February 1908, yielded 5 kg. gold from gravel 8 m. deep.

Operations.—The deposits of the Famatina district have attracted more attention and have been more extensively developed than any other ore deposits in Argentina. A location remote from transportation and at unusually high altitudes has been a serious impediment to their exploitation. They were regarded of such promise, however, that in 1907 the Argentine government constructed an aerial tram from the terminus of the railroad at Chilecito to Mejicana, a distance of 21.5 miles, with a difference in altitude between the terminals of 11,526 feet. Its capacity is 400 tons in 10 hours. In spite of these facilities the district has not come up to expectations. The Upulongos, San Pedro, and other important mines have been worked intermittently by several English companies, all of which have met with failure and have been compelled to liquidate. The yield of about 56,000 tons of ore in 1910 to 1912 averaged 0.4 oz. Au, 6 oz. Ag, and 3 per cent Cu.

THE TUNGSTEN AND TIN DEPOSITS

The tungsten and tin deposits of Argentina with a single exception are confined to the pampa ranges in which the tungsten deposits have a wide distribution, though they are most abundant in San Luis and Córdoba, whereas tin has been found at only two localities in La Rioja. The boundaries of the pampa ranges and the principal ore occurrences are shown on the map, figure 4. Tungsten was first discovered in the Sierra de Córdoba where the ores were worked 25 years ago, but the most important mine is now the Los Condores, near Concoran, in the Sierra de San Luis.

The deposits present a number of common geologic features. They occur in regions of crystalline schists and metamorphosed Paleozoic sediments that have been intruded by granites and granodiorites of different ages, pre-Cambrian to post-Silurian. The post-Silurian granites are accompanied by numerous pegmatites with which the veins are genetically associated. Though the veins themselves are usually in the schists and only occasionally in the granite, their genetic dependence on neighboring granites is established in nearly every instance. The most abundant filling of the veins is quartz and mica. Beder (16) classifies the veins on a mineralogical basis into the following groups:

A. Wolframite in pegmatites (veins of quartz and mica with feldspar).

B. Wolframite in veins of quartz and mica.

(*a*) Without cassiterite { (1) Without tourmaline. (2) With tourmaline.

(*b*) With cassiterite.

Pegmatites.—The wolframite-bearing pegmatites are of no economic importance and are not numerous, but are interesting and important in linking the veins unmistakably with the granites.

Veins Without Tourmaline.—Veins of quartz and mica without cassiterite or tourmaline are found at a number of localities in San Luis and Córdoba, of which the principal ones in San Luis are Loma Blanca and El Aguila, and in Córdoba, San Virgilio and the neighboring deposits of Fischer, Santa Barbara, and Santo Tomás, and San Ignacio and La Brillante. The Loma Blanca deposits are on the western slope of the Cerro del Morro, and consist of a group of anastamosing veins with east-west to northwest strikes, nearly vertical dip, and widths of a few centimeters to 1.5 meters, but averaging 70 to 80 cm. To the south of the veins is an area of coarse-grained biotite granite characterized by phenocrysts of alkali feldspar, the periphery of which and the adjoining schists are cut by dikes of pegmatite and veins of quartz as well as by aplitic and lamprophyric dikes. The wolframite-bearing veins grade into the pure quartz veins. The most abundant filling is quartz ranging in color through white, gray, yellow, and dark shades. Sheets of muscovite mica are scattered throughout the quartz, and the mineral frequently forms a band several centimeters wide on the walls of the vein with the sheets inclined at right angles to them. A flexible talcose mineral occurring in minute scales which is a common accompaniment of the wolframite in most of the tungsten veins and which is characterized by a boron content is believed to be a chlorite or sericite rather than a true mica. The Loma Blanca veins contain considerable fluorite, elsewhere scarce or completely

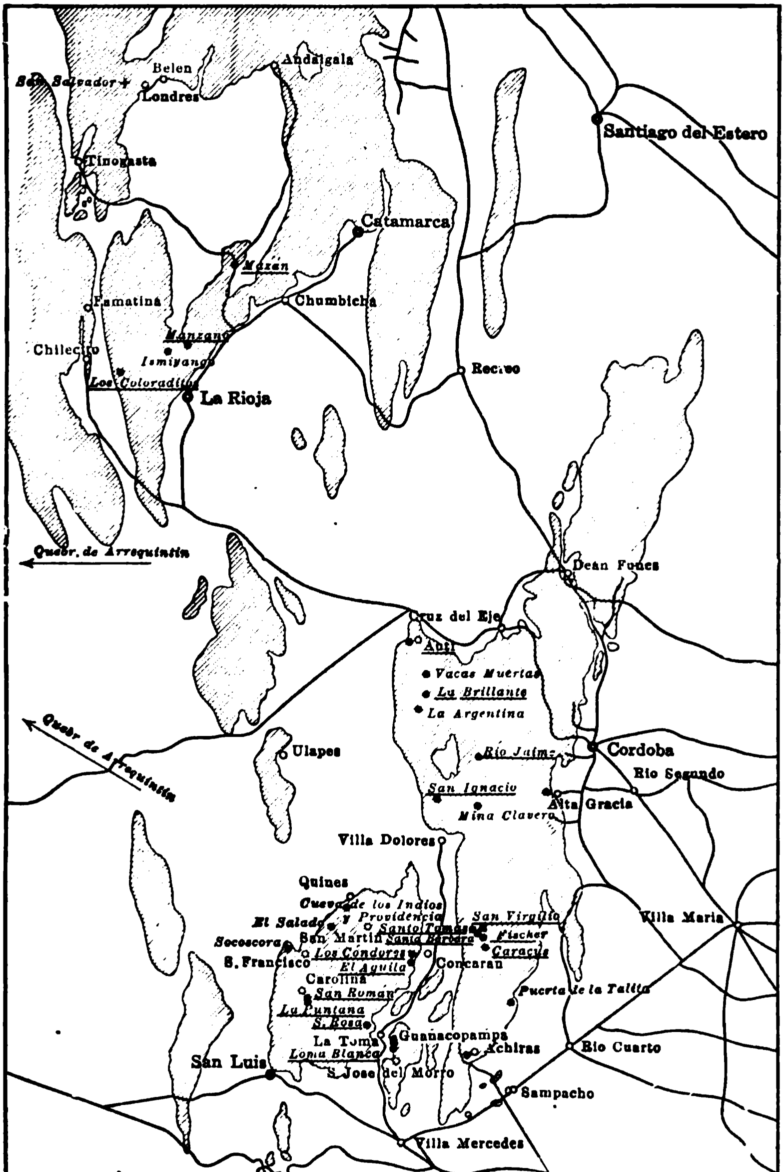

Figure 4

MAP OF PORTION OF ARGENTINA SHOWING DISTRIBUTION OF TIN AND TUNGSTEN DEPOSITS. (After Beder)

Lined areas indicate the pampa ranges. Black dots indicate deposits. Underscored names indicate the important ones.

0 20 40 60 80 100 Km.

FIG. 4.

lacking in the tungsten veins; on the other hand, apatite, which is abundant elsewhere, occurs but sparingly here. The fluorite comes in turbid, poorly-developed crystals several centimeters in diameter, either gray or rarely violet in color; the apatite in grayish-blue groups of prisms. A little pyrite, chalcopyrite, and magnetite occur. Wolframite occurs either in small groups of crystals or in larger masses showing only cleavage; its distribution is very irregular but is more abundant toward the center of the veins. A crystal of scheelite has been noted and a little yellow tungsten ochre. The richer parts of the veins do not carry more than 1 to 1¼ per cent of wolframite.

At San Virgilio and vicinity in the Sierra de Comechingones, a southwest branch of the Sierra de Córdoba, the geologic position of the veins differs from that at Loma Blanca in that they are in part in granite, and they grade from typical pegmatitic to distinctly hydrothermal veins in which sulphides are more abundant than usual, as represented by the San Virgilio itself. The San Virgilio veins, with an average width of 50 cm. and 50° or more dip, commencing in granite, run in a northerly direction into gneiss with a total length of 1,500 m. The hanging wall is regular and has a band of mica; the footwall is a brecciated zone cemented by quartz. The two types of micaceous minerals are present, also abundant apatite, but little fluorspar. Sulphides are relatively abundant, of which chalcopyrite is most important, covellite rarer. It is the only locality in which molybdenite has been found. A crystal of topaz and of scheelite have been noted. The wolframite is usually enclosed in quartz, but is also found at the contact with the gneiss and in association with the other minerals. The San Ignacio mine is worthy of mention as the original locality at which wolframite was found.

The veins in the Quebrada de Arrequintín in San Juan, the only known occurrence of wolframite in Argentina outside of the pampa ranges, belong to the group of veins without tourmaline and cassiterite. They are similar to the deposits of La Brillante in Córdoba in consisting of nearly horizontal intercalations of quartz in gneiss.

Veins With Tourmaline.—The tourmaline-bearing tungsten veins include Los Condores, the only important producing deposit, San Roman, and La Puntana in San Luis, Rio Jaimé and Auti in Córdoba, and Los Coloraditos and Manzano in La Rioja. The Los Condores veins, on the eastern slope of the Sierra de San Luis, have been worked for about 15 years by the Sociedad Hansa and yield wolframite with small quantities of scheelite. Phyllites enclosing veinlets of quartz and feldspar, metamorphosed near the veins with the formation of rutile and tourmaline constitute the country rock. The veins have an east-west strike, and are nearly perpendicular in dip. The principal vein is 600 m. long and has an average width of 80 to 100 cm. and a maximum of 200 cm. Characteristic of this locality is the zonal arrangement of the ore. A zone of mica at the walls, is succeeded by a zone of mica and wolframite, and this toward the center by wolframite and quartz. The quartz is commonly compact and druses are rare. Tourmaline is not abundant and occurs as needles projecting from the mica zone toward the center of the vein. Pyrite and chalcopyrite are fairly abundant and there is a little sphalerite in the ore. Wolframite rarely occurs in single crystals but in aggregates up to tons in weight, the largest mass encountered having weighed 13 tons. The tungstic acid content of these ores as well as those of San Roman and La Puntana, which also belong to the Hansa Sociedad, is unusually high, ranging from 1 to 4 per cent.

In the Sierra de Córdoba, the Rio Jaimé vein is likewise characterized by tourmalinization of the wallrock and the presence of abundant scheelite. The country rock is granite, the veins strike east-west and dip 45° north; and the wolframite occurs most abundantly along the walls associated with black tourmaline. At Auti, the veins cut both granite and gneiss, and have a border of mica in the granite and calcite or calcite and mica in the gneiss. The calcite is presumably a secondary infiltration. The ore minerals are distributed principally along the walls and tourmaline is abundantly associated with scheelite. The La Argentina mine presents a vein with tourmaline and wolframite along the walls and argentiferous galena in the center, the only example of the kind. A tungsten vein was doubtless reopened and subjected to the later sulphide mineralization in this instance.

In La Rioja, at Los Coloraditos, in a southwesterly spur of the Sierra de Velasco extending into the Famatina valley, is a group of quartz veins averaging 40 cm. in width with a prevailing north-south strike and steep easterly dip which in addition to considerable tourmaline carry wolframite and smaller quantities of magnetite, pyrite, chalcopyrite, molybdenite, bismuthinite, and their oxidation products. The veins occur in the marginal facies of a muscovite biotite granite at its contact with biotite gneiss which is cut by numerous pegmatites with large tourmaline crystals. Near the contact the granite is lighter in color, has an aplitic structure, and is impregnated with much tourmaline.

Veins With Cassiterite.—Mazán (54) in La Rioja is the only example of the occurrence of cassiterite and wolframite in the same deposit. The country rock is a reddish, coarse- to medium-grained, porphyritic older granite with basic segregations consisting chiefly of biotite and a red to yellowish-gray younger granite in which the mica is almost entirely muscovite and which is characterized by acidic segregations of quartz and tourmaline. Pegmatites and aplites are frequent accompaniments of the younger granite. The veins are genetically related to the latter, but occur in both granites, and are distinguished by an intense greisenization of the wallrock. Near the veins the feldspars are changed to unctuous kaolin, nacrite, or lithomarge, and in the vein walls they have been replaced completely by gray to bluish-gray quartz, and white mica replaces biotite. The filling consists primarily of quartz with a border of mica. Tourmaline and fluorite are relatively rare, and scheelite is lacking. Arsenopyrite is associated with the cassiterite. Both cassiterite and wolframite are irregularly distributed in the veins in pockets, one of which in the Yanacoya mine contained 7 tons of ore. Attempts to work the deposits have failed on account of the low grade of the ore which averages only ¼ per cent.

San Salvador in Catamarca is a typical tin deposit and is regarded by Beder as representing an earlier stage of mineralization than represented by the wolframite veins. Tourmaline is absent, but fluorite and topaz occur. Mineralization commenced during the solidification of the granite so that cassiterite is enclosed within granite as well as filling fractures in it. Greisenization was more intense and more typically developed than at Mazán and in addition there was a formation of *zwitter*. The deposit is credited with a small production in 1914.

CONDITIONS GOVERNING AND AFFECTING THE MINING INDUSTRY

The ore deposits of Argentina are located in the farthest corner of the republic and are hence most inaccessibly located with respect to transportation; and even after the mineral products are with much difficulty and at considerable expense brought to the railroad, they are further burdened with the expense of a long haul to the coast. Scarcity of water, lack of fuel, and high altitude are other drawbacks. The efficiency of operations is consequently comparatively low, and operating expenses are high. The miners are chiefly Indians and come largely from neighboring sections of Chile and Bolivia, so that labor conditions are essentially the same as prevail in other Andean mining regions. The obstacles to successful mining operations are the same, therefore, as those encountered in the West Coast countries with the added disadvantage that the mining districts are more remote from the coast.

Various reasons have been advanced to account for the lack of progress shown by the Argentine mining industry. Unstable political conditions have not existed for many years. Disastrous failures of a number of ill-advised and incompetently managed enterprises are assumed to have discredited Argentine mining projects, but it does not appear that the country has suffered markedly more in this respect than other countries in which the mining industry has progressed in spite of such handicaps. On the other hand, it is true that there is not a single successful large mining venture that can be used as an example of the rewards of rightly conducted efforts. Though the backwardness of the mining industry may in part be due to psychologic reasons, other more tangible factors have undoubtedly played a part. The Argentines have had abundant opportunities in the development of the more certain agricultural possibilities of the easily accessible portions of their country and have had little incentive to try for the less certain rewards of mining. The more remote location of the Argentine ore deposits on the east side of the Cordillera has made them less attractive to foreign capital than the ore deposits of the Pacific Coast countries. There remains the question of whether the deposits themselves are as valuable as the latter, to which no conclusive answer can yet be given. It seems reasonable to assume, however, that in a mineralized area so extensive as that of Argentina there must be points at which the mineralization was sufficiently intensive to have produced large and valuable deposits, and that the future will see a much greater development of the mining industry in Argentina.

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CHAPTER III

BOLIVIA

RÉSUMÉ OF MINERAL PRODUCTION

That Bolivia is distinctly a mining country is attested by the fact that three-fourths of her revenue from export duties is obtained from those levied on her mineral products. In the colonial days it was a treasure house from which the Spaniards drew inexhaustible supplies of silver. During the early history of the republic, political disturbances interfered greatly with the progress of the industry, but a considerable silver production was maintained until the depreciation in the value of the metal a quarter century ago made it impossible for most of the Bolivian silver mines to continue operations, and silver mining lost its importance. About this time attention was attracted to the tin deposits; and with the increasing industrial importance of that metal and improving transportation facilities in Bolivia through the construction of railroads, tin mining became the most important branch of the country's mining industry, and compensated for the decadence in silver mining. During the same period there has been a slow but steady increase in copper production. In recent years, under normal conditions, tin accounted for 83 per cent of the mineral production, silver 6 per cent and copper nearly 5 per cent. There is also an important production of bismuth averaging nearly 3½ per cent of the total. The remainder consists of smaller quantities of gold, lead, zinc, antimony, and tungsten. There is practically no production of mineral fuels and nonmetallic products. The average annual mineral production during the five years 1910 to 1914 was $24,000,000, with a maximum of $31,000,000 in 1913. The war has resulted in abnormal conditions of production.

The gold production of Bolivia has for many years been small, though considerable quantities are believed to have been produced in colonial days. In 1914 the production reached 5,790 oz., but the average for the five-year period closing with 1914 was

3,362 oz. The silver production has been slowly declining and shows an average of 3,526,952 oz. for the same period and 2,475,-884 oz. in 1915.

Copper is the only one of the common base metals produced in important quantity. The average output during the years 1910 to 1914 was 3,753 tons, and the 1916 output was slightly greater. The lead production increased from 30 tons in 1910 to 2,208 tons in 1915. Zinc production, on the other hand, has rapidly declined from 11,897 tons in 1910 to 104 tons in 1915.

Tin production undergoes considerable fluctuations, but has averaged nearly 40,000 tons and in 1913 reached a maximum of 44,595 tons. The tungsten production had been averaging about 300 tons annually, but under the stimulation of war conditions, increased to 793 tons in 1915 and 920 in 1916. The tungsten boom collapsed early in 1916 and the subsequent production has been small. The bismuth output increased from 311 tons in 1910 to 568 in 1915. The antimony yield from 1910 to 1914 averaged 235 tons, but in 1915 showed a phenomenal increase to 13,085 tons, valued at $4,216,050, equivalent to nearly one-seventh of the total value of the mineral production of that year.

TOPOGRAPHIC AND GEOLOGIC FEATURES

The Andes enter Bolivia from the north as two distinct chains, known respectively as the Cordillera Real, or eastern range, and the Cordillera Occidental, or western range, which are separated by an immense high plateau, the *altiplanicie.* They have a southeasterly trend until reaching latitude 18° south, and then turn to the south. The western range lies principally in Chile and Peru, but its eastern slopes fall within Bolivian territory, so that the range marks approximately the western boundary of Bolivia. The eastern range rises abruptly above the eastern edge of the *altiplanicie*, and then slopes off gradually on the east until it fades away at about the meridian of Santa Cruz into a vast plain that extends far away to the eastern boundary of the country.

The western range is a relatively well-defined ridge with average elevation of 15,000 feet, projecting above which are numerous isolated peaks or groups of peaks approaching 20,000 feet. The *altiplanicie* is a high table land nearly 500 miles long and over 100 miles wide and about 12,500 feet high. At its northern end, on the boundary between Bolivia and Peru, is Lake Titicaca, the highest body of navigable water in the world, which has a length of 125 miles. The surface of the plateau is broken by numerous isolated groups of mountains and hills.

The eastern range rises with steep slopes above the high plateau to an average elevation of 15,500 feet. In the north is a great series of ridges and peaks forming the mountain masses of Illimani and Illampu, which reach elevations of 22,000 feet and a number of peaks further south approach 20,000 feet in height. East of this series of ridges are numerous lower ranges running parallel to it, separated from each other by deep valleys; and further east spurs extend out at right angles to the general trend of the mountains. At the eastern base of the range, there extends eastward the great plain of the Chaco with an elevation of less than 1,500 feet.

The Cordillera Occidental is made up essentially of volcanic rocks, representing vast accumulations of lavas of rhyolitic, trachytic, and andesitic composition. The peaks are largely dormant and extinct volcanoes. Douglas[1] resolves the rocks into three groups, on the basis of their femic constituents, which represent increasing basicity with decreasing age: acid rhyolites and rhyolitic tuffs with biotite, trachytes or trachyandesites with hornblende, and andesites or basalts with pyroxene.

Greatly folded Paleozoic sediments ranging in age from Cambrian to Devonian make up the greater part of the Cordillera Real. They are typically shales or slates, sandstones or quartzites, and graywackes. These sedimentaries rest on a granitic core which is particularly prominent in the Illimani and Illampu massifs. The age of the granite is somewhat uncertain, but appears to be Devonian or later, and probably an accompaniment or cause of the folding and uplift which the range experienced in Devonian time. A portion of the area now embraced by the range was under water in later times as Cretaceous sediments are widespread on the eastern slopes, consisting of sandstone, variegated marls, gypsum, limestone, and dolomite. An extensive emergence followed in Tertiary time together with another period of igneous activity manifested in intrusions and, on a smaller scale than in the western range, extrusions. Marine brachiopods of late Tertiary age now resting at an elevation of 13,500 feet on the slopes of Potosi mountain and plants of the

[1] James Douglas: Geological sections through the Andes of Peru and Bolivia. *Quarterly Jour. Geol. Soc.*, Vol. 70, p. 19, London, 1914.

same age in the Potosi tuffs indicate that part at least of the Tertiary uplift and igneous activity took place in Miocene or Pliocene time.[1]

The Devonian uplift of the backbone of the eastern range did not affect the region of the *altiplanicie*, as Paleozoic sedimentation continued into the Permo-Carboniferous. These, however, are the latest marine sediments known in that region. They are transgressed by a great series of terrestrial sediments consisting of prevailingly red, gypsiferous, and ferruginous shales, sandstones, and conglomerates, which may represent the entire time interval from Triassic to late Tertiary. Toward the close of their period of deposition, this region also was characterized by igneous activity. In the western part of the *altiplanicie* is the post-Miocene Mauri volcanic series consisting of rhyolitic tuffs and ashes of subaqueous deposition, and at Corocoro Miocene or Pliocene plant-bearing tuffs[2] are interstratified in the red bed series. Extending longitudinally across the high plateau is a belt of diorites or hornblende andesites which are probably of the same age. Pleistocene and recent deposits cover a large portion of the earlier formations.

The boundary between Bolivia and Chile on the map, figure 5, lies a little west and approximately parallel to the western edge of the *altiplanicie*. The line of the railroad from La Paz to Uyuni follows a little west of the foot of the eastern range, and a line roughly parallel to it passing through Santa Cruz would mark the foot of the eastern slope of the range. The map does not include the eastern part of the great plain of the Chaco.

DISTRIBUTION OF THE MINERAL DEPOSITS

The locations of the best known Bolivian mining districts are shown on the map, figure 5. The mineral deposits are found principally in the eastern range of the Andes from Lake Titicaca to the Argentine border, a belt having a length of about 500 miles. There are also isolated groups of hills on the *altiplanicie*, geologically a part of the range, that are mineralized, as for example, the Oruro hills and a number in the southwestern part of the department of Potosi. The western range, which lies principally

[1] Edward W. Berry: Fossil plants from Bolivia and their bearing upon the age of uplift of the eastern Andes. *Proc.* U. S. National Museum, Vol. 54, pp. 103–164, 1917.

[2] Edward W. Berry: op. cit.

in Chile, characterized by recent volcanic activity, has not been so generally mineralized. Its most important deposits are the non-metallic deposits of sulphur and borax that lie chiefly across

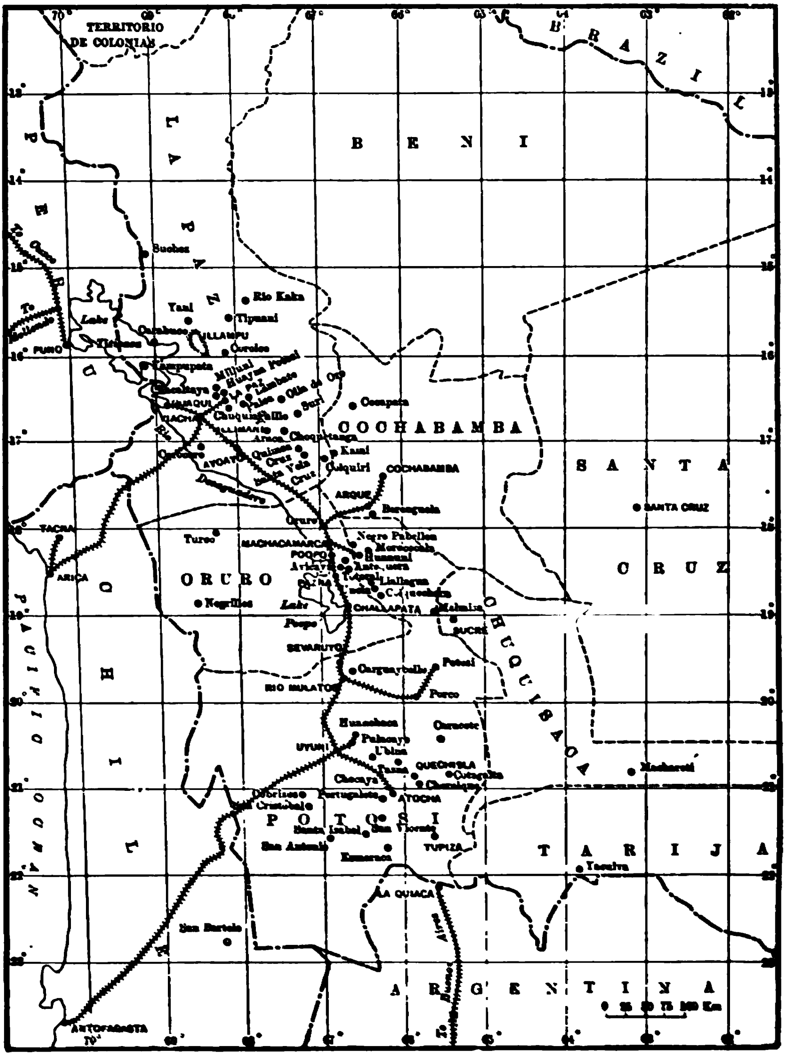

FIG. 5.—Map of Bolivia showing location of mining districts. (Not including extreme northern and eastern unmineralized parts.) Mining localities with initial capitals, other localities all capitals.

the boundary line. Extending longitudinally across the *altiplanicie* is a belt of copper deposits in which Corocoro and Cobrizos lie. With this exception, most of the mining districts of Bolivia are found within a belt about 100 miles wide on the east side of the railroad which traverses the *altiplanicie* from Guaqui to the Chilean boundary. Though deposits of all the metals found in this belt are nearly coextensive with it in their distribution, those of greatest economic importance seem to be grouped about more or less well-defined centers.

The relation between ore deposition and igneous intrusion is striking. The principal gold deposits are grouped around the granite massifs of the Illampu-Illimani range in the department of La Paz. The silver, tin, bismuth, tungsten, and antimony deposits show intimate relationship with the Tertiary intrusives of the eastern range. A genetic connection is also probable between the belt of copper deposits and the line of dioritic intrusions that so nearly coincides with it on the high plateau. Late Tertiary time was consequently the period of greatest mineralization in Bolivia. The gold deposits, however, appear to be of Paleozoic age, probably Devonian. It should be said that the data on which the granites of the northern part of the eastern range are assigned to the Paleozoic are not absolute, and some have regarded them also of Tertiary age. Such a view places the whole of the mineralization in the Tertiary.

GOLD

Armas credits Bolivia with a total gold production of $200,000-000, which has come chiefly from placers on the eastern slopes of the Andes north and east of La Paz. The two lode gold mines now active are in the same area. Commencing a short distance south of Illimani and extending to beyond Illampu, the main ridges of the mountain range are made up of metamorphosed sediments ranging in age up to lower Devonian and consisting of slates, quartzites, and graywackes, into which granite masses have been intruded and which now form the upper parts of the highest peaks. The rocks throughout this area are traversed by innumerable veinlets of auriferous quartz. Commonly they are small lenticular intercalations in the slates, rarely large enough to be worked. In addition to free gold in the quartz, which is often visible to the naked eye, small quantities of auriferous pyrite, arsenopyrite, stibnite, and pyrrhotite are scattered through the ore. Disintegration of these auriferous veinlets, has provided the gold which has been found in greater or less amount in all the streams draining this mountain mass and particularly in those on the east side where the stream courses are longer.

Placers in Illimani-Illampu Region.—Most famous of the placer deposits is Tipuani. The Tipuani River has a length of 40 miles, of which the lower 10 miles is rich in gold. The accumulations of metal occur chiefly in basin-shaped enlargements in the swift tortuous river course. The river bed at such points is covered with 20 to 60 feet of alluvial material. Much of the gold is concentrated at bed rock and particularly in depressions so that its distribution is quite irregular. Higher up are often false bed-rock layers known as *cangalli*, on which gold has accumulated. *Cangalli* is usually nothing more than hard conglomerate cemented with iron oxide. The gold occurs as coarse flat scales, thin lenses, leaves, angular plates, grains, and dust associated with magnetite and ilmenite sand. Nuggets are rare. Coroico occupies a position on its stream course analogous to that of Tipuani. Below the junction of the Tipuani River with the Kaka an unsuccessful attempt was made to dredge the auriferous sands a few years ago by the Incahuara Gold Dredging Company. The project was based on a reported tenor of 75 cents per cubic yard. The richest patches are associated with red garnet sands. Further up the stream courses than the localities above mentioned, the materials are coarser and contain numerous boulders, many of huge size, which interfere with large scale operations. An attempt to work the deposits at Yani by hydraulicking some years ago failed on this account. Another locality on the east side of the mountains is Suchez, where work was carried on by the Incas and the Spaniards and again in later years. Glacial and alluvial gravels, reported to run 16 cents to 33 cents per cubic yard in gold, filling a wide valley at 15,000 feet elevation, were washed into Suchez Lake with a hydraulic giant. Some work has been done in recent years at Chungamayo near Lambate, and at the Amy placers of the Incaoro mines. The best known locality on the western slopes is at Chuquiaguillo on a branch of the La Paz River near La Paz; the deposit was worked successfully for a number of years, but has recently been the scene only of desultory operations. Large boulders interfered with successful hydraulicking. The coarseness of the material is indicated by the occurrence of large nuggets, some reported to weigh several pounds.

Lodes in Illimani-Illampu Region.—In this same region lode deposits are being worked at Pallaya near Yani, and at Olla de Oro. At Pallaya, the Incaoro Mines Company is working bedded veins in black Silurian slates. Nearby are fine-grained quartzites, and over a mile distant andesite dikes. The veins have been folded with the enclosing slates whereby they have been enlarged and squeezed, but as a rule without destroying their continuity. Lincoln (58, p. 561)[1] suggests they may in part at least represent quartzite strata that have been more or less completely replaced by vein quartz. The ore consists of quartz accompanied by some white mica and subordinate amounts of arsenopyrite, pyrrhotite, and pyrite. Gold occurs principally native in the quartz, but also associated with the sulphides. Old fillings and pillars yield $5 per ton by amalgamation. The Olla de Oro veins are also bedded deposits in slates and of the saddle reef type. The saddles are generally faulted near their crest, leaving only half of the ore body for exploitation. The character of the ore is similar to that at Pallaya. Further south, across the La Paz river, in the northern end of the Tres Cruces range, gold veins were extensively worked by the Spaniards, but the grade of the ore seems to be too low for successful results at present. Indeed, the gold lodes of the entire region are characterized by low-grade ores and are of moderate to small size. On account of their abundance, they have been important as sources of gold for the more valuable placers resulting from their disintegration.

Southern Bolivia.—Gold-bearing ores are found further to the south, but the deposits are not as abundant and of little economic value. At Caracote, auriferous veins consisting of quartz and stibnite, roughly parallel to the stratification of the country-rock, which is shale, carry 0.7 oz. to 1.2 oz. gold. Placer deposits are found here and there through the mountains to the south, but are not of importance until the Argentine boundary is approached in the department of Potosi, where the placers represent an extension of a larger gold-bearing area in Argentina. There is very little activity here, however.

SILVER

Whereas the principal gold deposits of Bolivia lie in the part of the eastern range northwest of Araca, the silver deposits are most

[1] Numbers in parentheses refer to articles in bibliography at close of chapter.

widely distributed over that range south of Araca. The silver production from 1553 to 1910 is estimated at 48,800,000 kg., of which 30,000,000 kg. are credited to Potosi which has the distinction of being the world's greatest silver producer. Other famous producers have been Colquiri, Oruro, Colquechaca, and Pulacayo; and a host of other deposits have yielded large amounts of silver. The oxidized zone of most of these deposits was unusually rich in the horn silver ores, and many of the smaller occurrences have never been attacked below that zone. In some instances the zone of enriched sulphides carried large quantities of the high-grade silver minerals as argentite and ruby silver, Colquechaca having been especially famous in this respect. A number of these early silver producers are now producing more tin than silver, or are even solely tin producers at the present time. In others the occurrence of tin is not mentioned. This is particularly true of nearly all of the many occurrences lying south of latitude 21° S. As a number of these deposits have been idle since the development of tin mining in Bolivia, it is quite probable that tin ores are not as rare in this region as the lack of mention of their presence would indicate. On the other hand, the deposits lie at the south end of the Bolivian tin belt so that a marked decrease in the amount of tin in the ores is to be expected. There is an equally pronounced absence of tin in a few districts further north in the midst of the tin belt, as for example at Pulacayo and Colquechaca. There is in fact a complete gradation in the relative proportions of silver and tin in the veins from such as carry only tin to those that carry only silver. The silver and tin veins, together with some of the districts in which they are found, are more fully described in a subsequent section.

A few unimportant occurrences of silver ores are found far out toward the western edge of the *altiplanicie*, as at Negrillos, where a hill of quartz porphyry and porphyry contains two systems of veins, striking northeast and east respectively, dipping 68° to 85° north, ½ to 1 yard wide, with a filling of galena, quartz, and calcite.

COPPER

Copper deposits are not found in the eastern range, the copper production of which is limited to small amounts recovered through the treatment of the silver-tin ores of Oruro, Potosi, Pulacayo, and the Aramayo Francke Mines, Ltd., south of

Pulacayo. Nine-tenths of the Bolivian copper production comes from the Corocoro district, in the department of La Paz, which lies in a belt of copper deposits characterized by the occurrence of native copper in red sandstones, extending from a few miles north of Corocoro through Turco (49, p. 911) and Cobrizos and then swinging to the southwest of San Bartolo in Chile. All of the occurrences present features analogous to those of the Corocoro deposits which are described on pages 88 to 94.

LEAD AND ZINC

The lead production of Bolivia comes almost entirely from the southern part, in the region about La Quiaca, to which point the ores are packed on llamas and mules and exported via Argentina. Galena, as an accessory constituent of the ores of other metals, is widespread in occurrence. The zinc production which has shrunk to very small proportions has been derived principally from the Pulacayo mines. As with galena, sphalerite is widespread as an accessory constituent of other ores. At Milluni, are some sphalerite veins which have received a little attention. The scarcity of information concerning lead and zinc deposits is doubtless largely due to the fact that only under most favorable circumstances could one hope to work successfully such ores in Bolivia, and for that reason they have received little attention. It seems, however, that the common type of argentiferous lead and zinc ores is not abundantly represented in the mineralization of the country.

TIN

Tin deposits are widely distributed throughout the eastern range of the Andes from Lake Titicaca almost to the Argentine boundary. Though the occurrence of tin ores in Bolivia has been known for many years, it was not until the last decade of the last century that the importance of the deposits was appreciated and extensive operations inaugurated. Bolivia rapidly became the most important lode-tin producing country in the world, and by 1900, tin ores constituted 37 per cent of her mineral production, and in the five year period of 1910 to 1914 the average was 83 per cent. Tin mining is now the bulwark of the Bolivian mining industry. Though the number of deposits is very great and the number of mines in operation large, the great bulk of the production comes from a comparatively small number of districts. Eight important centers of production, accounting for seven-tenths of the output, are from north to south Oruro, Morococala, Huanuni, Pazña, Llallagua, Uncia, Potosi, and Chorolque. Other large producers are Milluni, Araca, Quimsa Cruz, Colquechaca, and Chocaya. Simon I. Patiño's mines at Uncia and Huanuni produce nearly 30 per cent of the total. The Uncia and Llallagua mines, which work different parts of the same group of veins in the same mountain, together produce two-fifths of the total; and Uncia alone contributes nearly one-fourth of the Bolivian tin output. Nearly three-fourths of the production comes from the department of Potosi.

The Bolivian tin veins are of more than usual interest aside from their economic importance, on account of their intimate association with silver ores. Their geologic and mineralogic features and individual districts are described in a subsequent section.

TUNGSTEN

Tungsten ores occur in Bolivia either in subordinate amounts in the tin veins or in separate veins in the same general region in which the tin veins occur. They represent a variant expression of the mineralization which produced the latter. Most of the tungsten deposits are of such low grade that they can not be worked in normal times, but they are numerous enough to be susceptible to a considerably expanded output under the stimulation of high prices. During the recent tungsten boom, the departments of La Paz, Cochabamba, Oruro, and Potosi contributed to the output. In the department of La Paz, Milluni, Araca, Yaco, Ichoca, and Quimsa Cruz were producers, the last mentioned the largest. Between Quimsa Cruz and Cochabamba, in the department of Cochabamba, Kami, Chicote, Solano, and Amutara were the most important localities. Patiño's mine at Kami became the largest tungsten producer in Bolivia. Oruro, Huanuni, and San Jorge were the most active producers in the department of Oruro. In the department of Potosi, the largest output came from Sala Sala at Chorolque, and other producers were Frias, Llallagua, and Uncia. The most common ore mineral is wolframite, but scheelite is also mentioned in the Potosi ores. The wolframite is mixed with quartz and frequently accompanied by arsenopyrite and rarely native bismuth. The mode of occurrence and geologic features of the tungsten deposits are identical with the corresponding features of the tin deposits.

BISMUTH

The bismuth ores are also associated with the tin ores, but are not so widely distributed. Important amounts of bismuthinite are found in certain of the Uncia veins, but the chief producing mines are those of the Aramayo Francke Company, Ltd., at Tasna and Chorolque and the Carmen mine at Huayna Potosi. The latter mine is particularly noteworthy for the abundant occurrence of native bismuth. Otherwise the prevailing bismuth mineral is the sulphide, bismuthinite. Bismuth ochre also occurs in oxidized ores. The bismuth-bearing veins are a complex local phase of the more widespread tin mineralization of which they are genetically a part. Associated with the bismuth minerals are cassiterite, wolframite, pyrite, pyrrhotite, chalcopyrite, and other copper minerals and silver minerals. The above-mentioned productive deposits are described in the section describing the tin deposits of those localities.

ANTIMONY

Though the antimony ores are found in the same general region in which the tin ores occur, any genetic relation that may exist between the two groups is more remote than that existing between the tin, tungsten, bismuth, and silver deposits. The antimony veins are distinct from the veins of the latter metals. They fill comparatively narrow fissures in the black Paleozoic shales that make up to such a large extent the eastern Andean range, and consist principally of stibnite with subordinate amounts of quartz as the most abundant gangue mineral. In some veins, the value of the ore is greatly depreciated through the presence of galena, in others it is enhanced by an appreciable gold content. The mines are chiefly small crudely worked properties in the hands of Indians whose operations are financed by the purchasers of the ores. The output consists of hand-sorted stibnite with which is associated a little antimony ochre and ranges from 50 to 55 per cent antimony. The principal producing centers during the recent boom were the Chuquiutu district and vicinity near Uncia, the country about Porco, and the region about and to the south of Atocha.

COAL

Coal has been reported from a number of localities on the *altiplanicie* and on the eastern slopes of the Cordillera Real, but there is no reliable information concerning any except the peninsula of Copacabana on Lake Titicaca. The coal seams on this peninsula are of Carboniferous age and occur as lenses and overlapping layers interleaved with argillaceous and sandy shales. The strata have a northwesterly strike and dip at high angles. Horizons of carbonaceous shales attain considerable thickness, but the true coal usually ranges from a few inches to more than 2 feet. According to Gregory (48), the indications are that no beds exceed 3 feet in thickness or 300 to 400 feet in length. In 1875, Yampupata was producing 30 tons of coal daily, but the deposits have lain idle for years. The geology of the country renders it unlikely that important coal deposits will ever be found in Bolivia.

PETROLEUM

There is no oil production in Bolivia, but a large area extending as a belt along the eastern base of the Andes from the Argentine boundary, and representing a prolongation of the Salta-Jujuy field of Argentina, through Jacuiva and Macharetá to Santa Cruz, is looked upon as favorable territory. Its inaccessible location has exerted a retarding influence on its development. A number of springs and seepages from lower Cretaceous dolomites are known and some exploratory work and shallow drilling has yielded oil of 35° to 47° Baumé (11). In the southern portion of the belt (93), the petroliferous formation consists of 3,000 feet of Cretaceous reddish-gray conglomerates and sandstones and dark variegated shales which are intensely folded and faulted. Dolomites rarely occur in the series in this part of the area, and the oil and asphalt are contained in the sandstones and conglomerates.

DESCRIPTION OF IMPORTANT DEPOSITS

The Corocoro Copper District

The Corocoro district (97) shares with the Lake Superior district of the United States the distinction of being one of the two commercially important copper districts in the world in which native copper is the principal ore mineral. The city is strung out along several small valleys and gulches at the foot of the north slope of the Cerro de Corocoro, which is one of a group of low hills near the western edge of the *altiplanicie*. The mines are located on the hills surrounding the town (figure 6). With a few unimportant exceptions, the mines have been consolidated under the ownership of two large companies, the Corocoro United Copper Mines, Limited, an Anglo-French company, and the Compañía Corocoro de Bolivia, a Chilean company.

Geology.—The country rock of the district consists of a thick series of prevailingly red, gypsum- and iron-bearing shales,

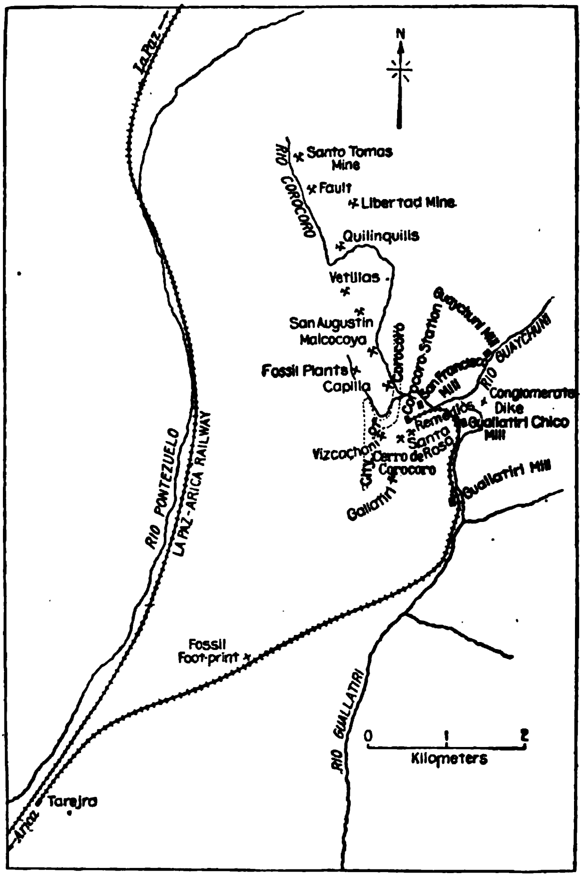

Fig. 6.—Map of Corocoro mining district, Bolivia.

sandstones, and conglomerates, the relative abundance of which ranges in the order named. The strike of the beds in the hill on the west side of the Corocoro valley, which extends northward from the town at the base of the Cerro de Corocoro, is about N 30° W, or parallel to the direction of the ridge and the valley, and their dip is from 50° to 70° W. The prominent characteristic of the series as exposed in this hill is an abundance of sandstone beds ranging in thickness from one to several meters. On the east side of the Corocoro valley is a less prominent ridge, or range of hills, in which the strata strike a little more northerly and have an easterly and flatter dip. In this series, sandstones are less prominent and shales more abundant. The valley itself is underlain by the easterly dipping series. About 2 miles north of Corocoro, a fault separating the two series is distinctly exposed. The fault plane is nearly parallel to, though a little steeper than,

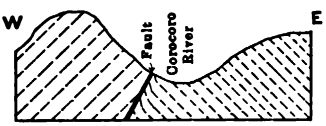

Fig. 7.

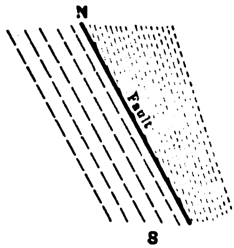

Fig. 8.

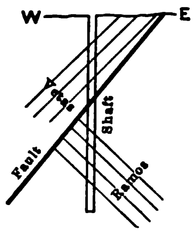

Fig. 9.

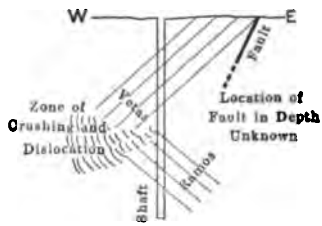

Fig. 10.

Sections showing relations of vetas, ramos, and fault plane.

the westerly dipping beds; and the easterly dipping beds show an upward drag that steepens their dip close to the fault plane, indicating a reverse fault (figure 7). As the strike of the fault is parallel to the westerly dipping series of beds, the strata of the eastward dipping series diverge from it toward the north and consequently successively lower beds emerge to the surface in that direction (figure 8).

Though the region has been one of considerable igneous activity, no igneous rocks have been encountered in the immediate vicinity of the mines. The nearest rocks of that character are found at Chukapaca, 10 miles to the west, and on the Cerro de

Comanche at Mirikiri, 15 miles to the north, the latter a hornblende andesite.

Ore Deposits.—As regards their position, three types of ore bodies are distinguished, *vetas*, *ramos*, and the *dorado*. The *dorado* is the name applied to an ore body that was found in the fault plane at the intersection of it and the *ramos* zone. It is now practically worked out. The important ore bodies have been and are the *vetas* and *ramos*. They are not as their names would imply, fissure fillings but are mineralized beds of sandstone in the shale-sandstone series. Those in the westward dipping rocks are termed *vetas*, those in the eastward dipping series *ramos*. Since the sandstone beds are thicker and more prominent in the former series, the *vetas* average thicker than the *ramos*. In both series mineralization has occurred at a number of closely spaced horizons, but at only a few to form important ore bodies. The thickness of the mineralized beds varies from a few inches up to as much as 10 to 12 feet.

Active mining operations are centered about the Cerro de Corocoro and the south end of the ridge on the west side of the Corocoro valley. Here the *vetas* outcrop, but the *ramos* are first encountered in depth. Shafts put down in the territory of the *vetas* encounter in depth a zone of disturbance and pass through it into the *ramos* ground, as shown in figure 9. The geologic structure along the fault plane, gives the zone of the *ramos* an upward pitch toward the north and the *ramos* emerge to the surface in the northern part of the district in the vicinity of the Libertad mine.

A different, but less probable interpretation, of the relations of the *vetas* and *ramos* is held by Fernando Dorian and Adrian Berton, general manager and chief engineer respectively, of the Corocoro United Copper Mines, Ltd. They believe that the *vetas* and *ramos* are identical and that both lie on the west side of the fault. The reverse dip they ascribe to a southward pitching zone of disturbance, as indicated in figure 10. The eastward dipping *ramos*, in the vicinity of the Libertad mine, on the east side of the fault, they regard as entirely distinct from the *vetas*, but that owing to the fact that where the *vetas* changed their dip to the east underground, the name *ramos* was applied to that portion of them, it was subsequently erroneously concluded that both sets of eastward dipping ore bodies were the same. A crosscut that is planned in the deeper levels of the Vizcachani shaft to run west from the *ramos* ground for the purpose of opening up deeper horizons of the *vetas* will when completed decide which of the two interpretations is correct. The surface geology is decidedly in favor of the interpretation first given and against the second one.

The mineralizing solutions that circulated through the ore beds have bleached them to a white or light green color, but the impervious shales between have not been affected by the solutions. Patches of red sandstone within the ore bodies that have been protected from the bleaching action of the mineralizers are barren of ore. The bleached rock has also been rendered soft and friable as a rule through the removal of much of its cementing material. There have been some transverse displacements and movements along the bedding planes, evidenced particularly by slickenslides in the shales between the ore beds, but the amount of movement has not been sufficient to greatly disturb the position of the ore bodies.

Description of Ore.—In the *ramos* the ore is entirely native copper, and occurs chiefly in the form of small particles disseminated through the sandstone. The ordinary rich ore is called *tacana;* if the particles of native metal are coarse it receives the name *chafra*. In very rich ore the sand grains are so knitted together by the copper that, although extremely soft, the ore is so tough as to be difficult to break. Plates and arborescent forms of copper, abundant as fillings of joints and cracks and openings along bedding planes, are called *charqui*.

Gypsum and, less abundantly, barite and celestite, occur as gangue minerals, but chiefly in association with *charqui*. Of great mineralogic interest are pseudomorphs of native copper after aragonite that are found in almost perfect crystals.

In the lower part of the *vetas*, the mineralization is identical with that just described in the *ramos*, but toward the surface it is chiefly chalcocite with which are associated domeykite, and other arsenic and sulphur compounds of copper in smaller quantity. Near the surface, the sulphides have undergone oxidation and there is an abundance of the green basic copper sulphate, considerable malachite and azurite, and also cuprite. The sulphides extend to a depth of 350 to 500 feet, below which only native copper is found. The cause of this difference in the mineralogic constitution of the ore which is a most unusual phenomenon is not at all clear.

Since the advent of the railroad about 5 years ago, it has been profitable to hand-sort the sulphide and oxidized ores and ship a product running from 18 to 20 per cent copper. Before that only the native copper ores were worked. The bulk of these range from 2½ to 4 per cent copper, but some of the richer ores contain as much as 15 per cent copper. Simple concentration with jigs and tables yields a native copper concentrate containing 85 to 95 per cent copper.

Age of Country Rock.—The age of the sediments in which the Corocoro deposits occur has been variously placed in periods ranging from Permian to Tertiary, but in the absence of paleontologic evidence, there has been no sound basis for any of the correlations. The recent discovery, therefore, of determinable fossil remains is a matter of considerable importance and scientific interest. The authors are indebted to Fernando Dorian, general manager of the Corocoro Copper Mines, Ltd., for having shown them a ledge of sandy tuff northwest of the city from which they obtained fossil leaves and also for a plaster cast of a fossil footprint found along the railroad between Tarejra and Corocoro (figure 6). Professor Edward W. Berry[1] has determined the age of the flora as Pliocene, and Professor Richard S. Lull (97, p. 173) regards the footprint as that of an upper Triassic amphibian. The stratigraphic relation between the two outcrops is unknown. The paleontologic evidence indicates that part of the series of red rocks is late Triassic and part late Tertiary. Whether such special conditions as gave rise to these strata existed continuously between the two periods or whether these red-colored rocks represent more than one series with breaks between is still undetermined. Of more immediate interest are the fossil plants, as they occur in the horizon of the *vetas*, and hence fix the age of their country rock and consequently of the mineralization also as late Tertiary.

Origin of the Deposits.—The close association of the mineralization in the *vetas* and the *ramos* with the fault plane would suggest some relation between it and the fault and argue against a syngenetic origin of the deposits. Attention has been called to the fact that, though igneous rocks are not exposed in the immediate vicinity of the mines, they do occur at no great distance and further that the district lies within a belt of dioritic rocks that Steinmann thinks are late Tertiary in age. Moreover,

[1] Op. cit.

the mineralization is not a local phenomenon but is coextensive with the belt of igneous rocks. Hence there would seem to be no objection to ascribing the mineralization to the same magmatic source from which the igneous rocks were derived, particularly in view of the harmony now established between the period of igneous intrusion and the period of mineralization.

The chemistry of the process of ore deposition is not so clear. L. Sundt believed the mineralizing solutions were introduced as sulphates and chlorides and that they reacted with calcium carbonate in the rock, giving rise to gypsum and copper carbonate. Decomposing organic matter reduced the ferric oxide, which gave the red rocks their color, and thus bleached them, and reduced the copper carbonate to native copper. Steinmann explains the chemistry of the process in an entirely different way. He believes the mineralizing solutions were analogous to those that formed the other copper deposits of the Andes; that is, characterized by the presence of sulphur and arsenic to the subordination of oxygen. On coming in contact with the ferric oxide of the red beds, they reduced it and bleached those strata, and the sulphur was oxidized to sulphuric acid. On account of the greater affinity of sulphuric acid for lime, magnesium, and iron, the sulphates of those metals were formed and copper was set free. Since the lime is the least soluble of the sulphates, it remained behind as gypsum.

THE TIN-SILVER (BISMUTH, TUNGSTEN) VEINS

A Metallogenic Province.—The intimate association of the tin, silver, bismuth, and tungsten ores of Bolivia has been remarked upon. Districts in which the ores of one or more of these metals occur stretch from Carabuco on Lake Titicaca, near the northern boundary of Bolivia, to Esmoraca, near the southern boundary. It curiously enough happens that only a very feeble development of this mineralization extends for a short distance into Peru, and the mineralization encountered across the line in Argentina is of an entirely different character. The Cordillera Real within the boundaries of Bolivia seems to constitute, therefore, a well-defined metallogenic province. Tin and silver ores enjoy the widest distribution and have been deposited in greatest abundance. Tungsten ores are less widely distributed and less abundantly. Bismuth is still more restricted in its occurrence and in quantity, but has been of greater economic importance than tungsten in the past on account of its relative abundance in a few deposits. The association of these ores is manifested at times by their occurrence in the same veins and then again by occurring in different veins but within the same restricted mineralized area. That all of the veins are the product of a common mineralization and that their varying mineralogic composition expresses but a different facies of it is very probable. In arriving at this conclusion unusual interest attaches to these deposits through the departure they form to the otherwise uniform mode of occurrence and mineralogic type of tin veins.[1]

Certain characteristics of the Bolivian silver-tin ores were first emphasized by Stelzner (105, 106) who regarded them as departures from the common type of tin veins as recognized from their occurrence in Saxony, Cornwall, and elsewhere. The difference was considered not alone mineralogic but also genetic: and whereas it was generally assumed that tin deposits the world over not only occur with similar geologic and mineralogic relations but also were always formed pneumatolytically, he believed the Bolivian deposits to represent deposits of hydrothermal origin, and constituted them a distinct vein type which he designated "typus Potosi" from their prominent development at Potosi. The characteristics emphasized by Stelzner are that the veins are associated with igneous rocks ranging in composition from dacites to quartz trachytes and not, as is usually the case, of granitic texture. The common pneumatolytic minerals, tourmaline, topaz, fluorspar, and apatite are absent; on the other hand, carbonate and barite gangue minerals are found. (He later became aware of a minute quantity of tourmaline and apatite at Chorolque and Tasna.) The tin occurs as both the oxide and the sulphide, that is, as cassiterite and stannite. As cassiterite it occurs massive, frequently in association with much pyrite, and in the form of microlites enclosed in sulphides. The veins are remarkably rich in silver, especially in the enriched zones, and the silver occurs chiefly in association with tetrahedrite. In the oxidized zone enormous masses of secondary cassiterite, called from its appearance "wood tin," occurred together with great masses of secondary silver ores. The latter, mined years ago, gave Bolivia its great renown as a silver producing country. Besides the tin and silver ores, lead, zinc, copper,

[1] Joseph T. Singewald, Jr.: Some genetic relations of tin deposits. *Econ. Geol.*, Vol. 7, pp. 263–279, 1912.

bismuth, and antimony ores are prominent in different parts of the region. Rare germanium minerals, as argyrodite and franckeite are found. The silver and tin minerals are so intimately intergrown, that it is impossible to separate them by hand-sorting, and the tin is obtained from the residue after the silver has been extracted by leaching, indicating that the two groups of minerals were deposited simultaneously, and that consequently the veins were formed under hydrothermal and not pneumatolytic conditions. The features just described seemed to Stelzner to sever completely the Bolivian tin veins from the tin veins hitherto known.

Stelzner's characterization of the Bolivian tin veins was based on the knowledge of them at the beginning of the era of tin mining in that country, when the known tin ores were confined largely to the veins which had produced silver ores in years gone by, those of Oruro, Potosi, Chorolque, Tasna, Chocaya, districts characterized by the more complex ores. With the development of tin mining, new deposits were discovered in new areas which more closely resembled the normal tin vein type. Steinmann (102) in 1907 called attention to deposits lying to the north and east of the districts mentioned, extending from Araca to Arque, which show a simpler mineralogic composition—quartz with cassiterite and pyrite, and absence of the complex silver ores, which he called "typus Araca." He also stated that the dacites and liparites which are usually associated with the silver-tin veins are lacking in this region, but he considered the veins to be genetically related to the same magma or magmas, and to be the result of a differentiation in the mineralizing solutions whereby the "typus Araca" represents a facies more remote from the magmatic source than the "typus Potosi." This interpretation of the genetic relation of the two types is rather improbable as it is not likely that solutions forming deposits analogous to the normal tin vein type represent a greater departure from the common magmatic source than do those forming deposits of the "typus Potosi;" but Steinmann is doubtless correct in assigning a common source to the mineralizing solutions.

In the same year, 1907, Spencer (100½, p. 336) described the presence of abundant tourmaline in the tin and bismuth ores of Tasna.

De Romaña in 1908 (89) also described features of the Bolivian tin deposits which impair somewhat the sharp separation from the normal tin vein type established by Stelzner. Microscopic examination showed that the igneous rocks with which the tin veins are related are of the type of rhyolites and contain bipyramidal quartz phenocrysts, abundant muscovite, and large crystals of feldspar which are often completely decomposed and transformed into muscovite and tourmaline. As secondary minerals, crystals of apatite are occasionally encountered. At Avicaya is a true schorl rock consisting of quartz and tourmaline.

In the following year, Rumbold (90) insisted on the essential similarity of these tin deposits with tin veins in general, basing his evidence in part also on microscopic data. He emphasized the widespread occurrence of tourmaline in the deposits from Araca to Uncia, and that among the number of metals found in the Bolivian veins, silver is really the only one not commonly found in tin veins. He disagrees with Stelzner in considering the deposits hydrothermal. It should be noted that just as Stelzner's conclusions are based wholly on a study of those deposits characterized by abundant silver ores, those of Rumbold are based on a study of deposits characterized by a minimum amount of silver ores.

Another attempt to establish a pneumatolytic mode of deposition and to bring these deposits in thorough accord with the established views concerning the geologic and genetic features of normal tin veins was made in 1911 by Armas (10). He recognizes two zones of tin deposits in Bolivia having a southeasterly trend and lying about 35 miles apart. The southwesterly zone includes the most important deposits, Oruro, Potosi, Chorolque, etc., and is associated with young eruptives. The northeasterly zone, within which Araca is situated, lies in great part in slates and quartzites. The mineralizers for all the veins are considered as having been derived from the same source, that is, from a deep-lying acid magma of great extent with apophyses which show here and there in the mineralized region as dikes and intrusive masses. To substantiate his views Armas describes in detail many of the deposits, but principally those of the northeastern zone with which he was better acquainted. In this belt he describes stanniferous pegmatite dikes and veins closely associated with pegmatite dikes carrying pneumatolytic minerals. The description of the southwesterly zone, in which the principal silver-bearing veins occur is very brief; but he regards the introduction of the ores, other than the tin, subsequent to the deposition of the ores, and as a result of a reopening of the veins. The tin mineralization he maintains was pneumatolytic, the later mineralization hydrothermal. This position with respect to the paragenesis of the ore minerals is untenable; the relation of the two groups is too intimate to be explained in that way.

Though information concerning many of the silver and tin deposits of Bolivia is not as reliable and in no case as thorough as one might wish, the nature of the deposits is now sufficiently well established to show that neither of the two extreme interpretations described above is the correct one. It is futile to attempt to establish an exact correspondence between these veins and tin veins of the type represented by those of Saxony and Cornwall; it is equally futile to attempt a sharp and complete differentiation between the two types. In the first place, the Bolivian tin deposits do not occur in two distinct zones, one characterized by typical tin mineralization and the other silver-tin mineralization. It is true that a belt extending from Araca through Berenguela to Uncia is marked by a predominance of the ores carrying little or no silver. But Colquiri which lies in the very heart of the belt has a typical silver-tin mineralization. The northwestward extension of the belt at Huayna Potosi is an important producer of bismuth and received its name from the abundance of silver which it yielded in the past. Colquechaca, one of the most productive of the old silver districts, lies only a short distance beyond Uncia in the southeastward extension of the belt. The area of occurrence of the "typus Araca" grades, therefore, into that of the "typus Potosi," and the latter is more pronouncedly developed toward the south. As the southern end of the department of Potosi is approached, the "typus Potosi" seems to grade into a third type characterized by the presence of the silver ores to the exclusion of the tin. The line of demarcation is roughly latitude 21° S. But tin minerals are mentioned among the ore minerals of some of these districts, and there is a small tin production from as far south as Esmoraca. Moreover, it should be remembered that these districts have lain almost idle since tin mining commenced in Bolivia and the meagre knowledge concerning them largely antedates its commencement, so that it is quite likely that tin ores may occur more abundantly in them than the scant literature indicates. On the other hand, it is equally probable that the relative quantity of tin ore is less in these districts than in the districts further north. The distribution of the metals broadly considered is consequently, a gradual relative decrease in tin and increase in silver from north to south, with some notable exceptions to this tendency. Tungsten appears to be distributed throughout the region, more abundant here and there, but apparently showing no regular geographic variation. Bismuth minerals are encountered in a number of deposits, but appear in abundance at only two localities at nearly opposite ends of the region, at Huayna Potosi in the north and Chorolque and Tasna in the south.

A Metallogenic Epoch.—Not only do the silver-tin deposits of the Bolivian Cordillera Real constitute a metallogenic province, but they also represent a well-defined metallogenic epoch following immediately after the intrusion of the igneous rocks with which the ore deposits are so closely associated. In chemical composition the rocks range from rhyolite to dacite, the more acid composition being the more common; texturally they are usually distinctly porphyritic, and might better be called quartz porphyry and quartz porphyrite, respectively. Bancroft (18, p. 186) calls them granular intrusive rocks. The first mentioned nomenclature is the more common in the literature. The age of the intrusives has been variously placed at Cretaceous, and usually late Cretaceous, to as late as Pleistocene. Earlier workers, as Forbes and d'Orbigny considered them pre-Tertiary and post-Jurassic. Bancroft (19, p. 306) says they are presumably Mesozoic. De Romaña speaks of them as Tertiary rhyolites (89, p. 37). Stelzner (106, p. 68), following Steinmann, regards them as late Cretaceous or early Tertiary, because they are older than the later Tertiary basic and acid flows that cover large areas in parts of the Cordillera. Wendt (111, p. 84) finding fragments of the plant-bearing tuffs in the rhyolite of Potosi, and the plants themselves being determined as of late Tertiary age, fixed the age of the intrusives as post-Tertiary. Berry[1] has more definitely determined the age of the flora as Pliocene and a marine brachiopod collected by the authors from the same series of rocks has been determined by Schuchert[2] as Miocene or Pliocene. If the usual assumption that all of these rocks are of the same age is correct, then the period of intrusion was at least as late as Pliocene. The probability is that they are older than Wendt was inclined to regard them, so that Pliocene seems to be

[1] Edward W. Berry: op. cit., p. 114.
[2] Edward W. Berry: op. cit., p. 117.

the correct assignment for them. Pliocene is consequently the probable age of this metallogenic epoch. Inasmuch as the characteristics of the deep vein zone are but feebly developed in the most pronounced tin vein type, and the characteristics of the more pronounced silver vein type are those of deposits formed at moderate depths, and because further the texture of the genetically related igneous rocks is that of rocks which solidified at not greater than moderate depths, it appears certain that ore deposition took place under conditions of temperature and pressure prevailing at moderate depths.

General Description.—The country rock of the deposits is either the intrusive rocks or sediments into which they have been intruded. In some districts the veins are confined wholly within the igneous rocks as at Pulacayo; in others, they cut both the igneous and the sedimentary rocks as is the case at Oruro; and in a few districts, as for instance in the Berenguela district, not only are the veins confined to sedimentary rocks, but there are no known igneous rocks in the immediate vicinity.

Veins in the eruptive rocks are generally well-defined fissure fillings, varying considerably in width, usually not exceeding 2 feet, but exceptionally attaining to a width of 4 to 5 feet or considerably more locally. The widest veins are lodes or zones of fracture in which the rock fragments are cemented in a matrix of vein minerals. Some districts are characterized by the presence of a few prominent veins, as exemplified by Pulacayo and less markedly by Uncia; in others there is a veritable network of fissures as represented by the vein system of Potosi.

The sedimentaries forming the country rock of the veins are principally lower to middle Paleozoics consisting of shales, sandstones, and graywackes. Fossil evidence at a number of localities fixes their age at Silurian and Devonian, and it has been generally assumed that all of the dark gray to bluish shales into which the igneous rocks have been intruded are of this age. The finding of late Tertiary marine brachiopods in shales on the flanks of Potosi mountain identical in appearance with the Paleozoic shales of other parts of the Andes, warns against a too general acceptance of this assumption, and shows that at some localities much younger rocks may be involved. Quartzite or sandstone is the more usual wallrock and as a rule veins passing into the shales lose their importance, becoming irregular and following the planes of cleavage. Veins in quartzites often cut across the bedding, but more commonly lie parallel or nearly parallel to the bedding planes. In a few instances quartzite has been extensively replaced by the mineralizing solutions. These veins show the same range in width as those in the igneous rocks, and the filling frequently has a brecciated structure.

The mineralogic composition of the ores shows great variation both with respect to the relative proportions of the primary minerals and with respect to the relation of the ores to the surface. Cassiterite is the principal ore mineral, and occurs for the most part in massive aggregates; well crystallized forms are notably rare. Pyrite is abundant and constitutes as much as 90 per cent of the vein filling. Microscopic investigation has shown that stanniferous pyrite contains finely disseminated cassiterite. Quartz is the principal gangue mineral. Other ore and gangue minerals are commonly present in smaller amounts than the aforementioned. They include tetrahedrite, jamesonite, and other silver-bearing minerals, native bismuth and bismuthinite, stibnite, galena, sphalerite, chalcopyrite, wolframite, arsenopyrite, and pyrrhotite among the metallic minerals; and tourmaline, siderite, calcite, barite, and occasionally apatite and fluorite as gangue minerals. In addition there are the rare minerals stannite $(Cu_2FeSn)S_4$, franckeite $Pb_5Sn_2Sb_2S_{12}$, canfieldite $Ag_8(Sn, Ge)S_6$, kylindrite $Pb_6Sn_6Sb_2S_{21}$, teallite $PbSnS_2$, argyrodite Ag_8GeS_6, the Bolivian deposits being particularly noted for the occurrence of the germanium-bearing members of this group. In the upper part of the sulphide zone, there has been marked enrichment in silver. Colquechaca was especially famous for the abundance of ruby silver in its ores. Stephanite, native silver, and other minerals carrying high percentages of silver were found in considerable abundance at this horizon, so that bonanzas assaying thousands of ounces per ton were encountered in the deposits characterized by a high silver-tin ratio.

The oxidized zone consists largely of iron-stained material varying in texture from compact to ocherous or cellular, mingled with quartz or cementing fragments of wallrock. Though having every appearance of limonite, it is a mixture of limonite and cassiterite in proportions represented by only a few per cent of tin to almost pure cassiterite. Through the oxidation and removal of the more soluble and less resistant minerals, particularly the abundant pyrite, the grade of the oxidized ores is frequently raised far above that of the primary ore from which they are derived. This process alone accounts for an appreciable enrichment in the zone of oxidation. Mechanical transportation of cassiterite has also been an important factor in producing enrichment in this zone. Small particles of cassiterite embedded in sulphides are liberated as the latter are dissolved and carried away by meteoric waters running and percolating through the porous oxidized material. Downward migration of the liberated cassiterite particles is caused by both the action of gravity and the descending waters until they are caught and recemented by a precipitation of iron oxide. The microscopic particles of cassiterite included in pyrite can be transported with considerable facility in this way. Mechanical concentration is particularly well exemplified in the Huanuni deposits. The extent to which cassiterite is enriched by solution and redeposition in the zone of oxidation is a mooted question. By many it has been regarded as too insoluble and resistant to yield at all to transportation in this manner, but the occurrence of wood tin and other forms involving deposition from solution characteristically in the zone of oxidation indicates that solution and redeposition is operative to a limited degree in effecting enrichment in the zone of oxidation. Deposits in which the silver ratio is high have also undergone considerable enrichment of that metal in the zone of oxidation and such districts as Oruro, Potosi, Colquechaca, and Chorolque were famous in their early history for the bonanzas of horn silver that they yielded. A large part of the Bolivian tin production has come from the pillars and fillings of the old silver workings in this zone.

Processes of disintegration and erosion have destroyed the outcrops of the tin veins and carried the residual cassiterite into the streams draining the tin districts so that tin placers are widely distributed through the tin region and have been worked at many places. The most extensive workings at present are in the Potosi district. Chorolque, Uncia, and Araca were other large producers of placer tin. A great drawback to the development of the tin placers is the aridity of the region, with the result that in most localities water is not available during a large part of the year; and often, when there is water, it flows in such torrents as to be unmanageable. Tin placers offer possibilities of considerable promise, if means are devised of circumventing these difficulties.

The Bolivian tin deposits have not been worked over a wide vertical range. In few instances is the distance as much as 1,000 feet, and in most cases it is far less. Except for the change in grade in passing from the oxidized to the sulphide ores, increasing depth has not yet shown any marked change in the tin content of the deposits. The average grade of the ore that is being worked is somewhat difficult to arrive at through the lack of attention to details in mining and milling that permit of accurate estimates. Three per cent is generally regarded as about the minimum tin content that can safely be expected to yield a profit. This limit can of course be lowered to correspond to a compensating silver content in the ores. The richest ores contain as much as 6 or 8 per cent tin. A higher tin content represents ore from rich pockets of limited extent or hand-sorted material. Ore rich enough to ship or that can be hand-sorted to shipping grade is called *guia.* The bulk of the ore is too lean to be handled in this way and is subjected to mechanical concentration to yield a concentrate or *barilla* containing 55 to 65 per cent tin.

Huayna Potosi Bismuth-Tin District (71).—The mountain of Huayna Potosi is a magnificent ice covered peak rising to an elevation of 20,000 feet about 20 miles north of La Paz. The veins on its flanks and spurs carry mainly silver, tin, and bismuth ores, with subordinate amounts of gold and wolframite. Oxidized silver ores were worked here years ago by the Spaniards and about 20 years ago, tin mining was commenced. Later on bismuth was found in some of the veins, and these are the two metals now actively sought in the district. The gold and tungsten deposits have not been actively worked. Some of the veins carry considerable sphalerite, but this ore has received little attention on account of prohibitive transportation costs. The active mines are in two groups, several kilometers apart—at Milluni, where the ores carry tin, and near La Union mill where bismuth also is found in considerable quantity. Huet Brothers, Frenchmen who have long been residents of Bolivia, are the operators.

The country rock of the Huayna Potosi region consists of black arenaceous slates, micaceous sandstones, and gray quartzites of Devonian age into which have been intruded many dikes of quartz porphyry and other closely related rocks. The sedimen tary strata rest upon a large mass of granite, which is exposed a few miles distant. The slates and quartzites strike approximately north-south and the dip is to the west at various angles from 5° to 50°.

The veins occur in shattered zones that approximately conform in strike with that of the enclosing slates and quartzites, but in general dip to the east at high angles instead of west as do the rock strata. In some cases the veins are true fissure veins, but in the main they consist of stringers of ore within shattered rock.

Mineralogically or structurally, four distinct types of veins are recognized at Milluni as follows:

1. Quartz-pyrite veins carrying cassiterite in very fine grains. Near the surface these veins have been oxidized forming a gossan that carries fairly high values in tin or, where quartz predominates, a rusty mass of porous quartz containing small druses of quartz or cassiterite crystals. This is the most common type of vein and is represented by the Concepcion, Salvadora, and Coquelin veins.

2. Sphalerite veins containing siderite, quartz, and small quantities of cassiterite and carrying considerable silver. These veins are mainly fissure veins, and show prominent banding. Veins of this kind, represented by the Roche vein, are not extensively worked at present.

3. Brecciated quartz-pyrite-cassiterite veins cutting across the bedding planes of the quartzites, with occasional stringers of rich ore developed along the bedding planes adjacent to the shattered zone. These veins are variable both in width and in values.

4. A quartz-pyrite vein, no longer worked, which is reported to have contained some uraninite. Much silver was taken from this vein by the Spaniards.

The Milluni mines lie at elevations of 14,000 feet to over 15,000 feet. On a neighboring snow-capped ridge at elevations of nearly 17,000 feet are the Santa Rosa and other mines not now in operation, but which formerly produced considerable tin ore. The veins are in sandstone and contain cassiterite in association with quartz and pyrite. At their margins some native bismuth occurs.

Across this ridge, above La Union mill, are the Carmen, Esperanza, and San Alberti mines, of which the Carmen is the most active, and in the ores of which bismuth is of greater value than tin. The vein system in the Carmen mine is less definite than in the Milluni mines, much of the ore occurring in stringers in the quartzite where there has been considerable shattering of the rock. The greatest amount is found in the quartzite along its contact with overlying slate, with a small quantity of ore in small stringers in the slate.

The ore of the Carmen mine consists of native bismuth, bismuthinite, and bismuth oxide, associated with considerable pyrite, some cassiterite, and a small amount of quartz. The bismuth ochre occurs as a soft yellowish-white coating on the metallic bismuth and the bismuthinite. In some cases the native bismuth is surrounded by a band of bismuthinite but more commonly the two minerals alternate in radiating bladed forms indicating contemporaneous origin. The Carmen bismuth ores are notable for the relative abundance of native bismuth as compared with the relative amounts of the native and sulphide minerals at Tasna and Chorolque. A mass of native bismuth weighing over 100 pounds was taken from one of the larger pockets rich in bismuth.

The bismuth ores are hand-sorted into a first class native product and a first class sulphide product, both of which are exported. The remainder is sorted into a second class product carrying 5 to 6 per cent bismuth, which is either smelted or exported to Europe for treatment, according to market conditions; and a third class that averages 2 to 3 per cent bismuth. The latter is lixiviated and the bismuth recovered as oxychloride which is reduced to the metallic state by smelting. The production of tin concentrates in 1915 was 317 tons, and the bismuth production was equivalent to about 40 tons of the metal.

Araca Tin District.—The Araca district lies at the northern end of the Cordillera de Tres Cruces, a range separated from Illimani to the north by the valley of the La Paz River, which cuts through the eastern range between Araca and Illimani. In the period of the Spanish occupation the district was famous for its gold mines, but recent attempts to work the old mines have not met with success and the district is now of importance only for its tin production which in 1915 amounted to 529 tons of concentrates.

The granite core of the northern part of the eastern Cordillera extends far enough to the south to include the northern part of the Tres Cruces range. Araca lies on the northwest slope of the range, and the country rock consists of distorted and broken quartzites intercalated in slates dipping eastward and abutting against the granite core. The ore bodies are really mineralized fracture zones, rather than veins and are extremely irregular with a marked tendency to ramification and brecciation. The quartzites in particular have been fractured and had wide spaces opened in them which may suddenly pinch to narrow fractures in the shales. Ore deposition has taken place mainly by cementation of the fractured quartzite and also in part by impregnating it. Four principal veins have been worked, largely by open cuts, and yield an ore consisting essentially of cassiterite in quartz and frequently containing wolframite. The average grade of the ore is only 3 to 4 per cent, but rich pockets are encountered and streaks of *guia*, or high grade ore, an inch in width persist for long distances. Araca is one of the few localities in Bolivia yielding well-crystallized cassiterite. The mines lie at an elevation of about 15,000 feet and over 6,000 feet above the bed of the La Paz River.

Across the range, on its northeast slope, is Choquetanga, where there is a series of well-defined lodes which in some cases follow the walls of highly decomposed granulite dikes cutting the slates. The geologic relations are otherwise similar to those of Araca.

Tres Cruces or Quimsa Cruz Tin District (90, pp. 322–342; 61). —Further south in the Tres Cruces range is a group of districts or subdistricts of which the Quimsa Cruz and Santa Vela Cruz are probably the best known and most important. Their combined production is something over 500 tons of concentrates annually. When first discovered about 1900, the deposits of this district were noted for their rich outcrops that were worked by open cuts. Wolframite is often associated with the cassiterite.

The country rock consists of a series of inclined and vertical quartzites and slates which are often highly contorted, having an approximately north-south strike parallel to the range and into which have been intruded dikes and bosses of quartz porphyry. Trilobites in the rocks at Santa Vela Cruz fix their age as Devonian. The quartz porphyry is described by C. P. Berkey (90, pp. 336–337) as

> "a true quartz porphyry of fairly uniform type. As to secondary changes there is some difference in the specimens; in one there is much cassiterite in pseudomorphic growth after certain of the phenocrysts, especially after mica and apparently also after feldspar."

In the heart of the Tres Cruces district is the Monte Blanco mine characterized by a series of quartzite-cassiterite schists which can be traced for considerable distances. The mine is situated on a ridge with a northeasterly trend across which the quartzite beds cut with a northwesterly strike. There are three ledges of stanniferous quartzite from 30 to 40 feet wide. Locally the quartzite is massive and the ore is found in bunches and veinlets, but usually it has a well-marked schistosity with cassiterite and tourmaline between the laminæ. The average tin oxide content is between 0.25 and 0.5 per cent. The beds between the stanniferous quartzite are darker in color and much more slaty. There are also breccia lodes in the mine which likewise have a filling of cassiterite and tourmaline with considerable iron oxide at the outcrop. There are no outcrops of igneous rock on this ridge.

At the Barrosa Cota mine, 3 miles southeast of the Monte Blanco, the cassiterite occurs in pyritic veins associated with tourmaline, magnetite, and quartz gangue. The country rock is the same quartzite-slate series, but quartz porphyry occurs in the neighborhood.

The Concordia mine is at Santa Vela Cruz, 15 miles southeast of Tres Cruces. It is the property of the Andes Tin Company and has the reputation of being the most systematically developed tin mine in Bolivia. The mine is situated on the east side of the Santa Vela Cruz group of mountains at an altitude of 16,000 feet above sea level. The country rock ranges in composition from quartzite to quartz schist, and has a north-south strike and vertical dip. It is a dark-gray distinctly bedded rock which under the microscope is seen to consist of granules of quartz with muscovite and biotite and accessory tourmaline and apatite. Occasional zones of white quartzite which do not follow bedding planes contain disseminated cassiterite and considerable tourmaline. The veins showed a marked enrichment where they cross these zones. The Concordia vein lies approximately parallel to the rocks, having a direction about 10° east of their strike. It is characterized by numerous dislocations and pinches and swells in its width. It is essentially a brecciated lode in which the quartzite fragments are included in a matrix of quartz, tourmaline, cassiterite, sphalerite, pyrite, and siderite. The matrix contains segregations of quartz and feldspar of pegmatitic character in the form of rounded aggregates from 1 inch to 6 inches in diameter which are frequently rich in cassiterite, sphalerite, and pyrite. The mineralizers which deposited the cement of the breccia also corroded the breccia fragments and in some places completely replaced them by cassiterite. The fissure is also followed by quartz porphyry which occurs either on one side of the breccia, cutting through the breccia, or in places occupying the entire fissure. The quartz porphyry includes fragments of the breccia but never forms part of the breccia. On the other hand, pseudomorphs of cassiterite after mica and feldspar indicate that the intrusion of the porphyry preceded ore deposition. The average width of the vein is 3 feet, but at one point called "the grotto," it swells to a pocket 14 feet in width containing a coarse breccia with iron oxide, pyrite, and tourmaline, carrying an average of 7 per cent cassiterite. Other lodes in the Concordia mine show analogous features.

About 15 miles north of Quimsa Cruz are the Argentina and Enrique mines on the east side of the range and the Mallachuma on the west side. The granite of the Araca region, which is here called a quartz monzonite, extends as far south as the Argentina and Enrique mines of which it constitutes the country rock. The igneous rock is sheeted almost perpendicularly in a direction varying from N 75° E at the Argentina to N 17° W at the Enrique. The veins are numerous, strike in all directions, and frequently branch and cross one another. Typical ore consists almost entirely of tourmaline and cassiterite, the tourmaline occurring in radiating groups of dark green acicular crystals ⅛ to ½ inch in diameter with brown cassiterite filling the interstices. The Mallachuma mine is in quartzite close to the quartz monzonite contact. The veins form a linked system, striking N 10° E to N 80° E and with nearly perpendicular dip, cutting across the quartzite. The filling consists of quartz, pyrrhotite, arsenopyrite, pyrite, cassiterite, and a little hematite, chalcopyrite, and tourmaline. Traces of lead, antimony, zinc, and silver are shown by assay. The average of a number of samples collected by Lincoln in the district was 4.83 per cent tin.

Tin placers derived from the lodes of the Quimsa Cruz district are found in the Aroma and Yaco rivers on the west side of the range. River gravels are 5 feet to 12 feet thick, and consist of equal amounts of finer materials. The cassiterite varies in size from powder to boulders a foot in diameter and is concentrated on and near bed rock. Production is small and solely the result of primitive operations. Gold nuggets have been found in these placers, but the gold is very irregularly distributed and of little commercial importance.

Colquiri Silver-Tin District (10, p. 185).—Colquiri lies about 25 miles southeast of Tres Cruces. The country rock is a series of quartzites and slates which have been intruded by dikes. The veins were extensively worked by the Spaniards in the oxidized zone for silver chloride and bromide. Nearly 30 years ago the mines were reopened for the tin ores, but the production is small. The ores are similar to those of the Oruro district, though some veins are characterized by an abundance of argentiferous sulphides and others are solely tin-bearing. Mineralization has occurred about and in thoroughly decomposed masses of igneous rocks which in some instances seem to have been aplite injected between the slates. The material consists of kaolin with angular grains of quartz, sericitized mica, fluorite, and apatite. The main vein can be followed in the direction N 80° E for 3 miles by a line of dumps. In the middle of its course, the mineralized zone which includes bands of country rock is 43 m. wide. Toward the north and south the vein splits into branches that have been worked only in the oxidized zone. The ores below that zone consist of cassiterite, argentiferous galena, sphalerite, pyrite, chalcopyrite, arsenopyrite, and magnetite. The galena yields 60 to 100 oz. silver, whereas the sphalerite and pyrite carry less than one-third that amount.

At Ocavi, a mile and a half north of Colquiri, are similar ores. There are two groups of four veins which are probably continuous, separated by glacial débris. The veins have a length of 1 km. in a belt 120 to 170 m. wide. They cut across the stratification and converge in depth. Mineralization is intimately associated with aplites. Work has been confined chiefly to the oxidized zone and the ores average 3½ per cent tin. In the sulphide zone white quartz contains cassiterite, pyrite, galena, sphalerite, and arsenopyrite. The rich sulphides are said to have contained pyrargyrite.

Berenguela Tin District (57).—The Berenguela district is located lower down the eastern slopes of the Cordillera Real than the districts previously considered and lies at an elevation of 12,000 feet and less, and consequently has a less rigorous climate. The mountain in which the veins are found consists of an alternating series of shales, quartzites, and sandstones. No igneous rocks are found in the vicinity, but in the Arque valley at the foot of the mountain and about 4,000 feet below its summit are hot thermal springs with temperatures as high as the boiling point.

On the west side of the mountain, the strata strike northwest and dip 30° northeast; the veins strike northeast and usually dip 45° northwest, though some have the opposite dip. On the east side of the mountain folding and crumpling has been more severe and the beds stand on edge, whereas the veins strike west to northwest and dip northeast.

In the oxidized zone the only minerals recognizable are limonite, quartz, and cassiterite with broken and pulverized rock. The concentrates carry a little silver and sometimes traces of copper and antimony. In the sulphide zone, the vein filling in addition to rock fragments is quartz, pyrite, cassiterite, and occasionally stibnite and small amounts of chalcopyrite. Galena and sphalerite are also reported to occur. The cassiterite manifests a marked preference for the hanging wall and for quartzite and sandstone over shale as wallrock. Oxidation has extended to greater depth in the quartzites than in the shales. No apatite or fluorite is reported. Cassiterite occurs either massive or as a fine powder, predominantly in the latter form. The ores carry 2 to 3 per cent tin and the 1915 production was 243 tons of tin concentrates.

Oruro Silver-Tin District (95).—Oruro was one of the most productive of the silver districts worked in the Colonial days, and the oxidized ores contained immense quantities of rich silver chlorides. During the first half of the preceding century mining had almost ceased, but a slow revival set in and in 1891 the silver production amounted to 1,800,000 oz. In 1915 it was 780,000 oz., which was one-third of the Bolivian silver production, and ranked the district second to Huanchaca. Though the silver production has decreased materially since 1891, tin mining has compensated for the decline, and in 1915 the production of about 1,200 tons of tin concentrates had a value equal to the silver output. The district is of particular interest for the reason that the ratio of silver to tin is higher than in most of the important tin-producing districts so that it affords today the best illustration of the silver-tin ores. The mining operations are consolidated under two Chilean companies, the Compañía Minera de Oruro and the Compañía Minera de San José.

The Oruro hills are a group covering about four square miles, rising above the *altiplanicie* on the western edge of the town of Oruro. They constitute a western outlier of the Cordillera Real from which they are only a few miles distant. The elevation of the plateau is a little over 12,000 feet and the hills rise 1,200 feet above it.

The main mass of the hills is made up of igneous rock intermediate in composition between quartz porphyry and dacite which frequently carries large phenocrysts of orthoclase. On the southern side and on the west slope are numerous areas of dark-colored early Paleozoic shales. In the mine workings the shales are frequently encountered as isolated blocks in the igneous rock that probably represent pieces broken off as the intrusion forced its way through the shales.

The mineralized area includes the northern part of the hills, and the richest portion is a belt extending diagonally across them

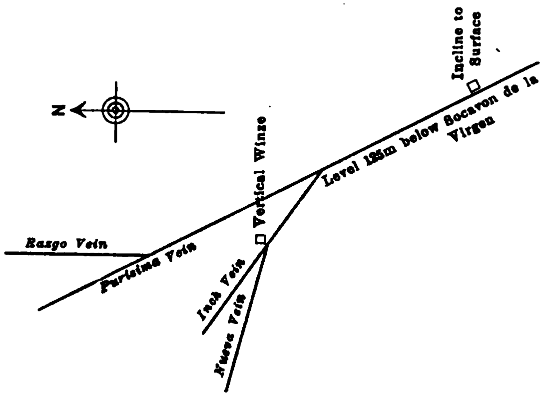

Fig. 11.—Plan of 125-m. level, Socoavon de la Virgin mine, Oruro.

from Oruro in a direction a little north of west, which is marked on the surface by countless old openings and dumps, evidences of the extensive activities of years gone by. There are now three important mines located on this belt, known from southeast to northwest as the Socavon, the San José, and the Itos. All are working the same system of veins, the most important and persistent of which is known as the Purisima in the Socavon ground. The country rock of the veins is almost entirely the porphyry, but more shale is encountered in the Itos mine than further east.

The Purisima vein has a strike N 15° W and dip 45° to 70° W, and branching from it are several subordinate veins, the more important being the Nueva, Inch, and Razgo, the relative positions of which are indicated in figure 11. The veins are fissure fillings with frequent inclusions of fragments of wallrock. Only occasionally is there a well-defined parting, but for the most part the veins are frozen to the walls and at some places there has been replacement of the wallrock so that the vein material gradually merges into barren country rock.

The Razgo vein runs into slate and changes its character completely at the contact, for, whereas in the porphyry it is a well-defined vein rich in tin, in the slate it splits up into a number of minute stringers less than 1 cm. wide, which carry no cassiterite or iron sulphides, but consist entirely of the argentiferous sulphantimonides carrying 1 to 2 per cent silver. Otherwise the veins are quite uniform in character and filling. The average width is 4 feet and the maximum 20 feet. On the level of the Socavon, the ore is practically continuous but it breaks up into three nearly vertical ore shoots, the stope lengths of which decrease in depth.

The main mass of the filling in the present workings consists of the iron sulphides with but a small percentage of non-metallic gangue. A little quartz occurs, but no boron or fluorine-bearing minerals were seen. Next in prominence to the iron sulphides are cassiterite and the silver-bearing minerals. The cassiterite is usually of a light-brown or yellow color and for the most part massive or finely crystalline. The principal silver minerals are tetrahedrite and jamesonite. The former occurs massive in bunches and stringers in the pyrite, the latter commonly in thick tufts of acicular crystals or fine needles in druses in the pyrite. This manner of occurrence is equally characteristic of the lowest and of the highest levels. The tin and silver minerals occur in part separate and distinct in the pyrite and in part very intimately intermingled. It would seem that they must be essentially contemporaneous, with the silver depositing stage showing a tendency to continue just a little later than the period of tin mineralization. There is no sphalerite and only a small quantity of galena in the ore.

To a variable depth of 50 m. to 100 m., the sulphide ores have undergone oxidation and it was the rich accumulations of horn silver in this oxidized zone that were sought in the early history of the camp. Now only the leaner parts are left, and the ores after sorting do not average more than 5 to 6 per cent tin and 8 oz. silver. Immediately below the zone of oxidation was formerly a zone of rich sulphides which is now practically exhausted. This zone furnished picked ore running several thousand ounces per ton. It is succeeded by the zone of primary ores in which the silver content is much lower. In years gone by no ore carrying less than 150 oz. silver was profitable, so that many of the old stopes were filled with material that can now be worked, and except for the ore from the new deeper parts of the mine, the present output comes from lean pillars that were not removed and from the old filling. This filling sorted down to one in seven yields a product that averages 4 oz. silver and 1½ per cent tin. It has become so indurated and cemented as a result of the chemical decomposition it has undergone that it stands of itself and can be mined in the same way as the untouched parts of the vein. In fact, the oxidation of the sulphides is going on at such a rate that the air in some parts of the mine is extremely irritating to the throat and lungs, and at the bottom of the mine the temperature is 75°F. The crude ore is subjected to hand-sorting, reducing 3 tons to 2 tons, and the sorted material averages 35 oz. silver, 2 to 3 per cent tin and about 30 per cent sulphur. In addition it carries ½ per cent copper, which occurs chiefly as tetrahedrite.

On passing into the San José territory, the Purisima vein takes a westward swing and by the time it reaches the Itos mine, it has an east-west strike. The mine is being worked through the Itos tunnel, which is 76 m. higher than the Socavon de la Virgen, but on the opposite or west side of the hills. Going down from it is a 300-m. shaft at the bottom of which is an 80-m. inclined winze, making this the deepest tin mine in Bolivia, and one of the deepest Bolivian mines. In the levels of the incline the vein enters a mass of slate in which it splits up, but on passing out of the slate into the porphyry on the opposite side again assumes its original character. Some very rich silver ores have been encountered in these lowest levels, running as high as 500 oz. to 600 oz. silver, and the rich silver ores of this mine carry 150 oz. to 300 oz. silver. In these same levels patches of almost pure cassiterite are found. After having gotten below the zone of secondary sulphides, there seems to be no further impoverishment with depth down to the present limits of the workings. Some excellent specimens of ring ores can be obtained at this mine. They consist of centers of pyrite coated with brown cassiterite and the interstices filled with the silver-bearing minerals. Here again is evidence to show that the silver mineralization continued later than the tin, though in part the two must be contemporaneous. In the vicinity of the Itos are several cross-veins, the oxidized zone of which is being worked on a small scale for tin. This material runs as high as 6 to 10 per cent tin, and is sorted into a shipping grade containing 60 per cent tin and a milling ore with 5 to 6 per cent tin. The ores from the Itos mine are taken over the hill by means of an aerial tram.

Before the consolidation of the mines under the ownership of the two large Chilean companies, the ores were treated at a number of small mills, but now each of the companies has a single large mill. Owing to the scarcity of water about Oruro, the mill of the Compañía Minera de Oruro is located at Machacamarca and that of the Compañía San José at Poopó. Silver and copper are recovered from the ores by subjecting them to a chloridizing roast and leaching, and the tin is recovered from the residue.

Pazña Tin District (90, pp. 351–352; 64).—Though silver veins occur in the Pazña district, the production at present is essentially tin. The ore deposits are located on the slopes of Chualla Grande mountain and the active mines are centered about Avicaya on the western side, Totoral on the eastern, and Antequera on the northern side, though tin veins are also found on the southern side. The total production exceeds 1,000 tons concentrates annually and comes principally from Avicaya and Totoral, each of which produces over 500 tons. The country rock consists of the series of quartzites and slates which have been intruded by dikes and masses of quartz porphyry. The sediments have a north-south strike and dip 30° to 45° W. The quartz porphyry is characterized by large quartz phenocrysts and a holocrystalline, but exceedingly fine- and even-grained groundmass. Abundant phenocrysts of a dark mineral, presumably biotite, are altered to an aggregate of radiating tourmaline needles, and some secondary quartz is penetrated by these needles.

In the Chualla Grande mine at Avicaya are seven important veins roughly following the bedding of the quartzite, but showing a tendency to join and branch in dip and strike to form a linked vein system. Close proximity of the porphyry intrusions is indicated by a dike cutting one of the lodes in depth and by another intrusive in a lode. The veins vary in width from 3 feet to 30 feet and have been explored to a depth of 585 feet. The ore shoots are generally widest near the outcrop. The ores in the oxidized zone are the richest; in the sulphide zone the ore is poorer and the shoots are narrower. Primary ore consists of cassiterite, pyrite, and quartz, with a little tourmaline and occasionally chalcopyrite. Wolframite is found only in narrow stringers higher on the mountain than the tin veins. The ore is said to average 5 per cent tin. Other veins at Avicaya (40, p. 206; 78, p. 84) having an east-west strike and 40° to 60° dip to the north are enclosed in porphyry. They range from 1 foot to 5 feet in width, and contain streaks of pure cassiterite on the footwall and sometimes on the hanging wall or in shoots cutting across the vein.

The Exaltacion lode at Totoral strikes and dips parallel to the quartzites and is itself a hard, dark gray or green quartzite impregnated with tourmaline. It varies from 2 feet to 25 feet in width and seems to be an impregnation of the country rock rather than a fissure filling. Here and there a breccia is found, which varies from 2 inches to 1 foot in thickness, that contains angular fragments of cassiterite and quartzite with cassiterite, showing that the movement represented by it took place subsequent to the mineralization. What appear to be well-defined walls often have pay ore back of them. Besides tin and tourmaline iron oxide, pyrite, and a small amount of chalcopyrite occur.

The lodes of Antequera are analogous to those described above, and there is also a production of placer tin in the vicinity.

Negro Pabellon Tin District (90, pp. 344–349).—In the northwestern corner of the department of Potosi is a huge flow of andesite covering several hundred square miles, the western edge of which passes through Negro Pabellon, and which swings around to the east of Huanuni and north of Llallagua. Though the most important tin mines of Bolivia lie near the edge of this flow, no tin lodes appear to penetrate it, and it is consequently younger than the quartz porphyries and the tin mineralization. It is also likely that it has covered up important deposits that lie east and north of the districts mentioned.

The Negro Pabellon lodes occur in quartzites interbedded with shales, which strike N 30° W and dip 30° W, near where they are overlapped from the southeast by the andesite flow. A short distance to the northwest is an intrusion of quartz porphyry. The latter is of an extremely variable type. In some places the phenocrysts are crystals of orthoclase two inches long; in others the feldspar is plagioclase and in small crystals and the quartz is developed to large size. Occasionally the feldspar is entirely replaced by radiating aggregates of tourmaline. In the quartz porphyry close to the boundary with the sediments is an outcrop of breccia with a dark blue cement consisting chiefly of tourmaline but apparently free from cassiterite.

One of the deposits, La Unificada, is a *manto*, or nearly horizontal ore body, with a dip of 18° SE which increases in depth. Along the strike it is cut off on one side by a dike of quartz porphyry and on the other by quartzite, so that it is an ore body about 100 feet wide and averaging 3½ feet thick which dips into the ridge on which it is found. The hanging wall consists of quartz sometimes carrying a little tin. Beneath is a yellow sandy bed about 2 inches thick rich in tin. A chocolate-colored bed with considerable iron oxide, a little sand, and a small amount of tin follows and grades into a heavy dense band of iron oxide generally poor in tin. The footwall is clay with angular quartz passing into decomposed quartzite. Barite was found on one level. The other mines of the district are also in the quartzite beds but are usually well-defined lodes. The quartz porphyry on the west contains small veins and pockets of wolframite. The 1915 production of the district was 174 tons of tin concentrates.

Morococala Tin District.—An important group of mines which in 1915 produced 1,440 tons of concentrates occurs in a small hill of shale and quartzite, known as the Morococala hill, which protrudes above the andesite flow covering the region.

Huanuni Tin District (70, pp. 454–455).—The mines of this district, which were acquired about 6 years ago by Simon I. Patiño, Bolivia's largest tin operator, produced 1,700 tons of tin concentrates in 1915. The main workings are located on the south side of Mount Posoquoni, a mountain which rises above the town of Huanuni to an elevation of 14,738 feet. The lowest adit, the Socavon Patiño, has an elevation of 12,984 feet and the main one, the Socavon Hulman, 13,702 feet. Tin placers have been worked in the valley at the foot of the mountain.

Mount Posoquoni is composed of gray to pink compact quartzitic sandstones with interbedded bluish-gray shales and shaly sandstones. The mountain adjoining on the north is capped by porous porphyritic rhyolite or dacite, some of which occupies part of the depression between the two mountains. Intruding the sedimentary rocks are dikes and masses of quartz porphyry (90, p. 349), but no igneous rocks are encountered in the mines.

The veins of the mountain are numerous, although only a few are persistent and have received names. The main vein is the Cataricagua, which was worked by open cut at almost the crest of the mountain and has been located in all the lower tunnels with the possible exception of the Patiño. Its general direction is N 55° to 60° E with an average dip of 45° SE although in places almost vertical. In reality it consists of two parallel veins which are in most places rather close together yet apparently separated by a wall of firm rock that in one place had a maximum thickness of 450 feet. A steeply dipping offshoot in the upper levels is known as the Medina. A third important vein, outcropping lower down on the mountain, is the Tanitani. Many other veins contain pay ore for short distances but the values are not persistent.

The veins vary greatly in width up to 30 feet, and also vary in their tin content, so that it is not profitable to stope in more than a small part of the drifts. The veins are shattered zones filled with sandstone fragments and cemented by the introduced ore and gangue minerals. The brecciation is more pronounced in the oxidized zone, where the removal of the pyrite has left large open spaces and permitted fragments of the wallrock to break away. These have been cemented by limonite formed from the pyrite, yet less firmly than in the sulphide zone where open spaces, or vugs, are rather rare. Some cross-faults have dislocated the veins, shifting all of them down the hill on the north.

Until recently only oxidized ore was mined, but the richer oxidized ore is now largely exhausted and the sulphides are being developed through the Patiño tunnel. A large tonnage of oxidized ore remains, but most of it is too low grade to be profitably mined. No fixed line can be drawn between the oxidized and the sulphide ores. Even within the same vein some oxidized ores have been found at a depth of 300 m., and elsewhere sulphide ores are within 90 m. of the surface.

The oxidized ores are brecciated sandstone fragments cemented by cassiterite and so thoroughly coated with limonite that it is usually possible to distinguish between good ore and barren rock only by the specific gravity. In the best grade ore, vugs lined with cassiterite crystals occur. Some specimens show small amounts of siderite and quartz. In the oxidized ore the highest values are found near the footwall, probably due to the grains of cassiterite dropping there when released by the removal of the pyrite. That is, this concentration is mainly, if not entirely, mechanical. The sulphide ores include fragments of sandstone with much pyrite, cassiterite, in places considerable sphalerite, and small amounts of quartz, tetrahedrite, and siderite.

The tin values are about the same in both classes of ore. As the ore is brought to the surface, pieces of rich ore averaging 65 per cent tin are picked out by hand for direct shipment. The ore sent to the mill averages about 3 per cent tin.

Uncia Tin District (70, pp. 452–453).—The Uncia mines, known as La Salvadora, owned by Simon I. Patiño, are the most productive in Bolivia. The production in 1915 was 8,416 tons of concentrates, representing nearly one-fourth of the entire Bolivian production. The mines are located on the southeast slope of the Cerro de Llallagua, at the foot of which is the town of Uncia. On the northeast slope of the same mountain and about 3 miles distant are the Llallagua mines.

The mountain consists of a central mass of quartz porphyry which has been intruded through a thick series of slates and shaly sandstones in most places decidedly carbonaceous and dark in color, but with considerable red shale in the vicinity of Uncia. The shales outcrop on the lower flanks of the mountain. Below and around the Socavon Patiño, the main adit, are more basic intrusions.

The Uncia workings are confined to the igneous rock. The rock appears to have been shattered along certain zones and these zones cemented by a dark-colored matrix which probably consists largely of tourmaline. Subsequent fracturing in part followed the original and in part was independent of it, and the newly opened fractured zones were mineralized. Hence it happens frequently that the tin veins follow the dark-colored breccia zones, at other places they cut across them, or in many instances occur entirely independent of them. Still later movements are indicated by a fault toward the southwest end of the property which has a northwest strike and steep westerly dip. The veins on the southwest side of the fault are offset to the southeast. Vein One A also shows a seam of gouge.

Throughout the mountain are numerous veins, the most important of which have received names. The Socavon Patiño cuts in order the following veins: Victoria, Animas, Bismarck, San Miguel, Salvadora, Demasius, Inca, and One A. In general the veins have approximately parallel strike, about N 30° E, and dip steeply either to the northwest or the southeast. Several of the northwesterly dipping veins of the Salvadora mine dip over into the Llallagua property, which adjoins the Uncia on the northwest, and the One A extends over into the Llallagua ground along the southwestward extension of its strike due to the property line being nearer north-south than the strike of the veins. The veins are extremely variable in width. Within a few yards a vein may widen from a few inches to several feet, and perhaps entirely disappear a few yards beyond. The average width is not more than 30 cm.

The veins are in part true fissure fillings and in part cemented breccia zones. The principal ore mineral is cassiterite of very dark color, practically black. In the true veins, it is fine-grained and compact, but in the breccia there are numerous open cavities, or vugs, lined with cassiterite crystals. In some places the cassiterite crystals have been deposited upon previously formed quartz crystals. Some of the cassiterite ore crumbles very readily almost making a powder when broken.

Considerable bismuthinite occurs in the ore, but as yet no attention has been given it. Though the bismuth content is not as great as one may think from a casual examination due to the thin-bladed crystals of bismuthinite determining the place where the ore breaks and consequently showing prominently on the surfaces of the ore fragments, yet there is little doubt that pieces of rich bismuth ore could be sorted out by hand with profit. This mineral occurs chiefly in the Inca and the One A veins, but sparingly in the others.

Wolframite and scheelite are present, but until recently no attempt was made to separate them from the cassiterite. In March, 1916, the first shipment of tungsten concentrates was made. It assayed 56 per cent tungstic acid, and was being produced at the rate of 500 pounds per day. A little native copper and some chalcopyrite is found in the ore.

Pyrite occurs in greatest abundance, associated with which are small amounts of marcasite, arsenopyrite, pyrrhotite, quartz, siderite, and aragonite. Most of the quartz is in vugs. In the upper part of the mountain, where the veins have been almost worked out, there was considerable oxidized ore of porous character stained with limonite. Some pockets of unusually rich ore were encountered in the early workings near the top of the hill, but in general the veins in the oxidized zone carry about the same values as in the sulphide zone, except for the enrichment caused bv the oxidation and removal of the more soluble constituents of the primary ore.

Considerable alteration and replacement of the wallrock has occurred adjoining the lodes, which in some places has been very extensive. Most abundant and probably most extensive has been silicification. At some points the rock has been completely changed to a compact quartz mass which gradually grades over into the quartz porphyry. At other points, the rock is literally peppered with quartz particles which seem to be introduced and not original quartz phenocrysts. Much of the rock also has a bleached whitish appearance suggesting alteration of the feldspars to kaolin or some similar process of alteration. Rock on the dump shows sericite.

The Socavon Patiño, at an elevation of 13,200 feet, is 7,312 feet in length. A new adit is being driven 90 feet lower. The Socavon Salvadora is at 14,446 feet and the workings extend 600 feet above it. The ore is brought down by an aerial tram to the mill at the upper end of the town of Uncia. This mill, as also the one at Llallagua, ranks among the best equipped and most modern in Bolivia.

The streams near Uncia and Llallagua have long carried down much tin from the lodes, and rich placer deposits have accumulated in the vicinity. Below Uncia are two alluvial terraces where considerable work has been done. The lower one was prospected by a 90-foot shaft which reached a bedrock of slate. The richest gravels were found at bedrock, but pay streaks were also found at 45 feet and 55 feet. The cassiterite pebbles are mainly less than 1 inch in size, yet a few cobbles as much as 4 inches in diameter are found. Similar placers at Catiri, between Uncia and Huanuni, are producing over 100 tons concentrates annually.

Llallagua Tin District.—The mines of the Chilean Compañía Estañifera de Llallagua rank second to the Uncia mines as producers of tin, the output in 1915 having been 5,812 tons of concentrates. As stated in the description of the Uncia mines, the Llallagua property adjoins the Uncia and is working part of the same group of veins. The main points in the description of those veins apply equally well, therefore, to these. The principal veins of the Llallagua mines from east to west are the Reggis, which is the same as the One A of Uncia, La Blanca, and the San José. Though lying principally in the quartz porphyry the Llallagua veins also cut the slates, but on entering them the cassiterite tends to disappear and the veins carry principally pyrite, and also are apt to pinch out. The slates appear to be more favorable to silver veins as a number have been worked in the district. Sulphides of silver also occur in the tin veins in small amounts.

The mill which is 3 miles distant by aerial tram produces a concentrate containing 68 per cent tin and low in sulphur.

Colquechaca Silver District (81).—Colquechaca was one of the most productive of the old silver districts, and was noted particularly for the abundance of ruby silver in its ores. Peele estimates that $21,000,000 in silver was taken from the Bartolomé tunnel alone from 1865 to 1892. The Amigos tunnel, 800 feet higher, yielded nearly $6,000,000 from 1884 to 1892. In the following year the production of the consolidated mines was 809,000 oz. silver. In recent years, silver production has practically ceased, but the district is credited with a production of 243 tons of tin concentrates in 1915. The relations between the tin ores and the silver ores are not known, and the following description applies to the deposits worked 25 years ago.

Colquechaca lies at 14,000 feet and the surrounding hills rise to 18,000 feet. The ore deposits are fissure veins in dacite and rhyolite. The Embudo, the main vein, outcrops for 2 miles in an east-west direction between the altitudes of 15,000 feet and 16,000 feet, and dips from 75° to vertical into the mountain. The width varies from 2 inches to 12 inches and the ore distribution is very pockety both horizontally and vertically. Slickensides and gouge are common. The vein structure is banded and drusy, the druses lined with crystals of pyrargyrite and quartz with wire silver. First class ore consisted of pyrargyrite, native silver, argentite, and sometimes highly argentiferous tetrahedrite. Associated with these minerals were sphalerite and galena. Pyrargyrite occurred both massive and well crystallized and accounted for the greater part of the silver values. Rich ore ranged from 500 oz. to 5,000 oz. per ton. Second class ore ran from 100 oz. to 200 oz. Other lodes similar to the Embudo lie on either side and within 400 feet of it; they have produced largely, but the individual veins were of small extent.

Carguaycollo Silver District.—Silver veins were worked some years ago by Avelino Aramayo on the west side of the Cordillera de los Frailes, near Sevaruyo. Numerous parallel veins with a north-south strike and 80° to 90° E dip cut a country rock of soft quartz porphyry. They have been explored over a length of 1,200 m. but are only 4 inches to 8 inches wide. The ores consist of tetrahedrite, sphalerite, chalcopyrite, and pyrite in a gangue of quartz and a little calcite. The wallrock is impregnated with pyrite. The average grade of the ore was 70 oz. silver per ton.

Potosi Silver-Tin District (72).—The veins of the Cerro Rico de Potosi, discovered in 1544, have been worked con-

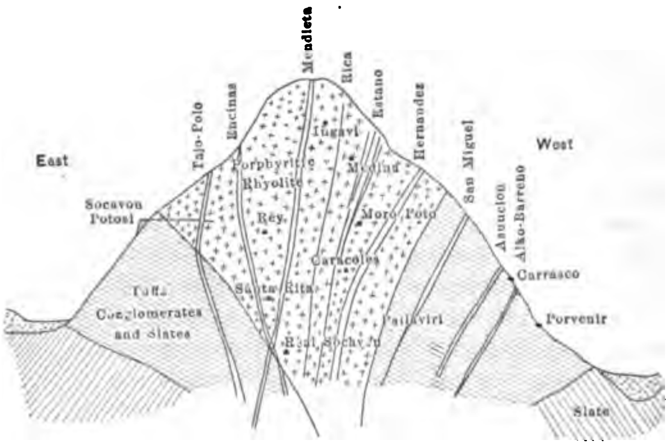

Fig. 12.—Ideal geological section of Potosi mountain.

tinuously to the present day. From the first unusually rich ores were encountered, and in a few years the population of the city established at the base of the mountain increased to 160,000. It seems certain that the total silver production exceeded 1,000,000,000 oz. and may have been twice that amount, ranking the district as the world's greatest silver producer. In later years the silver production has not been so important and the population of the town has dwindled to 20,000. The declining mining industry was revived between 1890 and 1900 with the advent of tin mining. The present output is principally tin, amounting in 1915 to 4,454 tons of concentrates; but there is also considerable silver and some copper extracted from the ores.

Potosi mountain is a fairly symmetrical conical peak with an elevation of about 16,000 feet. It consists of a central core of porphyritic rhyolite surrounded by conglomerates, shales, and tuffs that in most places dip away from the central mass. It has been assumed that the tuffs constitute one series of rocks which rest unconformably on the slates, constituting a second series. Figure 12 is a structure section after Louis Soux on the basis of this interpretation, in which also the principal veins are indicated and the levels of the main tunnels through which they have been worked. The shales are identical in appearance with the Paleozoic shales so widespread through the eastern Andean range and have been assumed of that age. The finding of a new species of marine brachiopod of Miocene or Pliocene age[1] at a horizon in these beds a short distance beyond the base of the mountain upsets this assumption, and makes part of these beds at least shallow-water, marine, late Tertiary sediments. Plant remains in the tuffs on the flanks of the mountain had established their late Tertiary age, a determination that has been substantiated and made more definitely Pliocene on the basis of collections made by the authors.[2] The tuffs contain horizons in which fragments of shale, usually fairly angular, are quite abundant, and in which there are also boulders of rhyolite of a somewhat different character from the rocks forming the core of the mountain. The relations of the shales and the tuffs along and across the strike are such as to suggest that the tuffs represent a local facies of part of the Tertiary shale series. At the summit of the mountain the rhyolite has been intensely altered by silicification. In places everything has been replaced by silica except the quartz phenocrysts which stand out just as distinctly in the silicified rock as in the unsilicified. At other places, the feldspar phenocrysts have not been replaced and on the outcrop have been leached out of the silicified mass. Lower down the mountain the amount of silicification decreases, but kaolinic alteration of the rock and impregnation with pyrite is marked everywhere in the vicinity of the lodes.

A great number of veins cut through the mountain, most of them in the rhyolite, but many also in the stratified rocks. In the rhyolite they are fairly well-defined fissures accompanied by more or less replacement of the walls. In the shales and tuffs, they are shattered zones with impregnation of ore in the

[1] Edward W. Berry: op. cit., pp. 116–117.
[2] Edward W. Berry: op. cit., pp. 103–164.

walls along the bedding planes. The main veins constitute a nearly north-south striking group with steep dip of 80° or more to the east or occasionally to the west. The most persistent and largest veins are given definite names, but there are countless unnamed veins between them often called *ramos* or branches of the nearest named vein. Crossing these veins are other systems, less pronounced and not of economic importance, called *cruceros.* A diagrammatic horizontal section of the veins after Louis Soux is shown in figure 13. The projections of the principal

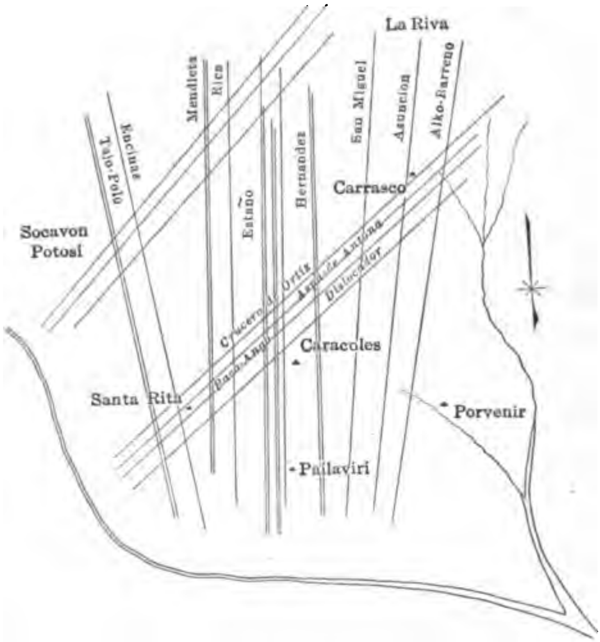

Fig. 13.—Horizontal section, Potosi mountain, showing vein systems.

adits are also shown on the sketch. The veins are so numerous and the country rock between so extensively mineralized, that the entire rock has been sampled with the view of determining the feasibility of mining the mountain with steam shovels. The veins have been attacked at so many points, that almost the entire upper slopes of the mountain are covered with mine dumps, as can be seen in figure 14. The width of the individual veins varies from a few inches to 12 feet, but the greater thicknesses represent compound veins rather than single fissure fillings.

The ores consist of two classes, the upper oxidized ores, *pacos*, and the lower sulphide ores. The depth of oxidation is not at all regular, and often a single drift will show repeated changes from one class to the other. The porosity of the ore largely determines the depth of oxidation, and much sulphide ore is found in high levels where the veins are more compact than usual. No oxidized ores are encountered in the Real Socavon which is 2,050 feet below the top of the mountain.

Almost all the veins carry both silver and tin minerals as well as a small amount of copper and a still smaller amount of gold.

Fig. 14.—The Cerro Rico de Potosi.

In the oxidized zone the silver occurs as horn silver, or cerargyrite, and native silver; in the upper part of the sulphide zone ruby silver is abundant; and at lower levels the silver values occur mainly in tetrahedrite. The tin occurs as light yellow cassiterite; in most cases in compact laminae, but occasionally as tiny crystals lining vugs. Pyrite occurs in considerable abundance, and in small quantities quartz and less abundantly barite. Through the removal of pyrite, the oxidized ores are porous and highly stained with limonite, in contrast to the more compact sulphide ores.

The tenor of the ores and their relative silver and tin contents are extremely variable. In places there are bonanza ore shoots extremely rich in silver or tin or both; elsewhere the veins may be too lean to stope. Some veins, as the Estaño, are characterized by their high tin content; others, as the Rica, are noted for rich silver ores. As the ore comes out of the mines, it is hand-sorted; from 10 to 50 per cent is discarded and the remainder sent to the mills. Careful sampling of the principal working mines about 7 years ago showed an average of 8 per cent tin and 30 oz. silver.

The operations are largely in the hands of three companies. Louis Soux, a Frenchman living in Potosi, is the largest operator. At his principal mill, the Velarde, at the lower end of the town, silver and copper values are extracted by lixiviation and tin by mechanical concentration. The tin middlings are smelted. Bebin Hermanos, operating on the northwest side of the mountain, work only oxidized ores and have simple mills for producing tin concentrates. The Royal Silver Mines, Ltd., operating through the Real Socavon, are working in sulphide ores and have a more complicated process analagous to that of Soux for recovering also silver and copper.

Vast quantities of cassiterite-bearing tailings found their way into the streams for several centuries through the disregard of the tin content of the silver ores. Much of this material has accumulated in the Tarapaya River, which flows to the northwest from Potosi, in gravels 6 feet to 15 feet thick and is now being extensively worked as placer deposits. The washing is done largely in a crude way by the Indians who sell a concentrate averaging about 40 per cent tin to the owners of the ground at a fixed price. This first concentrate is subjected to further concentration in mills to produce an export product containing about 62 per cent tin. These washings have averaged as much as 80 tons concentrates monthly, but are now producing about 50 tons per month.

Porco Silver-Tin District (98).—Porco was originally a silver district of considerable importance, and its mines were probably the first in Bolivia worked by the Spaniards. The rich silver ores were soon exhausted and for a long time the mines were practically abandoned. In recent years desultory tin mining was carried on by Bolivians who had a mill at Agua Castilla, a mile or two north of the mines, for extracting both tin and silver. These operations were taken over in 1912 by the Porco

Tin Mines, Ltd., who have erected a modern tin concentrating plant at Agua Castilla and contemplate making provision for the recovery of silver also. The average grade of the ore being mined is 12 oz. silver, and 2½ per cent tin, and the 1916 production was about 200 tons tin concentrates.

The chief mineralized area is confined to a mountain mass culminating in a peak of about 17,000 feet elevation called Apo Porco and having as one of its spurs a smaller and lower peak known for that reason as Huayna Porco. Both of these peaks are mineralized but with a different type of ore. The surrounding region consists for the most part of sedimentary rocks. Here and there are igneous intrusions and cappings of lava, some of them of considerable areal extent, and it is in one of these igneous areas that the ore deposits are found. The two peaks, Apo Porco and Huayna Porco, are composed wholly of igneous material. Their lower parts show quartz porphyry, rhyolite tuff, and agglomerate. The agglomerate in particular contains an abundance of shale fragments and a few of sandstone or quartzite, indicating that the underlying rocks through which the igneous materials came are the widespread shale-sandstone series of the eastern Andes, though these rocks were not seen in the immediate vicinity. The summit of Apo Porco, which appears to be entirely devoid of mineralization, consists of quartz trachyte with large feldspar phenocrysts, some as much as 2 inches long.

Mineralization is largely confined to a very restricted area that includes Huayna Porco and the adjoining portions of Apo Porco. By far the greater part of the mining in the past was done on Huayna Porco, which in places is almost as completely covered with the old mine dumps as is Potosi mountain. These veins yielded rich silver ores. They are usually narrow, run in fairly straight lines, and carry an ore consisting of high-grade argentiferous galena, sphalerite which is usually low in silver, and here and there pockets of ruby silver. The richest parts of these veins have long since been worked out and they are today abandoned.

In contrast to the veins of Huayna Porco, those of Apo Porco are wide, carry but little silver and galena, in the sulphide zone contain mostly pyrite and in places considerable sphalerite, and are characterized by a tin content that exceeds in value the silver. Mining in recent years has been confined to these ores and largely to the oxidized zone in which they average 12 oz. silver and 2½ per cent tin. The sulphide ores run lower in tin. No cassiterite is seen in the sulphide ore, indicating that it occurs in small particles in the primary ore. The same is true to a large extent of the oxidized ore; and where it is visible, it is seen as minute black specks either in the soft clayey material of the gossan or as a thin coating on the surface of rock fragments. Very little *guia*, or high-grade ore that can be hand-sorted is encountered in the veins.

The principal veins on Apo Porco from west to east are the San José, Misericordia, and Santa Rosa. They strike N 10° to 20° E. The San José is nearly vertical at the north end but assumes a flatter southeast dip at the opposite end; the other two have a steep westerly dip. At the lowest level, the San José vein consists of pyrite carrying only a fraction of a per cent of tin and about 8 oz. silver. The largest ore shoot has a length of 150 m. and average width of 2 m., with a maximum of 20 m. at the south end of its outcrop. It is not a simple fissure filling, but a lode fissure or shattered zone. In the sulphide zone, the veinlets are more or less distinct, though the intervening rock is impregnated with pyrite; but in the oxidized zone the pyrite has completely changed to limonite and the adjacent country rock is thoroughly altered and iron stained, so that the entire width of the lode fissure consists of the highly ferruginous, low-grade stanniferous, soft material that constitutes the great bulk of the ore. Some of it is of very smooth uniform texture like kaolin and is stained a light to reddish-yellow. Though usually soft, this material is in places silicified and hard. The Misericordia is a fissure vein of less than 1 m. average width, and filling consisting chiefly of sphalerite, in places almost pure coarsely crystallized dark zinc blende, mingled with more or less pyrite and locally a little galena. One face of such ore showed 3 per cent tin, but in general the tin content of the sulphides is lower. The Santa Rosa sulphide ores consist chifly of pyrite but contain considerable sphalerite. The oxidized ores are of the same character as those of the San José. The average width of the vein is 0.7 m.

Pulacayo (Huanchaca) Silver District (43, pp. 281–286).—Pulacayo has for many years been the largest silver producing district in Bolivia. According to Peele (80, p. 152), the production from 1877, when the present Compañía Huanchaca de Bolivia was formed, to 1892 amounted to $46,000,0000 in silver.

The 1891 production was nearly 6,000,000 oz. At this time the company constructed the railroad from Antofagasta to Uyuni which is now part of the Antofagasta and Bolivia Railway, and the extension to its mines to facilitate its operations. The ores then consisted largely of high-grade tetrahedrite carrying several hundred ounces of silver per ton. In 1895, hot waters at a temperature of 70°C. broke into the workings flooding much of the mine and consequently seriously hampering operations. It was some years before this difficulty was overcome. The ores mined at present are of lower grade, being essentially argentiferous zinc ores, so that the high production of the early years of the company's history is no longer achieved.

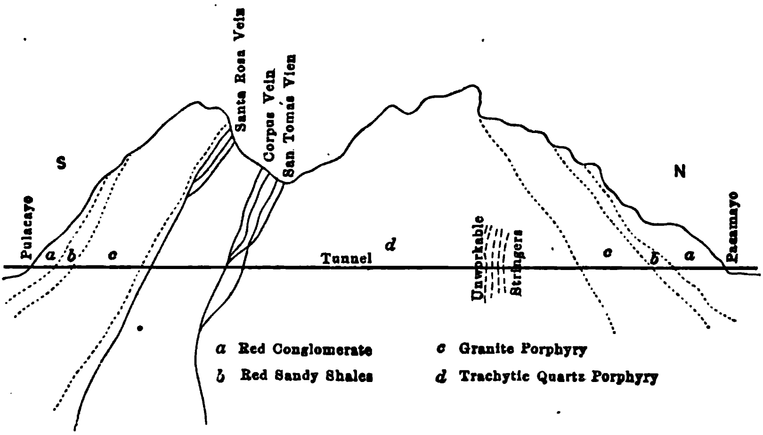

FIG. 15.—Cross-section of Pulacayo mine.

The ore deposits are found in a group of hills that are the last outliers of the Cordillera de los Frailes. The mountain in which the mine is located consists according to Gmehling (figure 15) of a central mass of trachytic quartz porphyry surrounded by granite porphyry which have been intruded into red sandy shales and red conglomerates. The veins have an east-west strike and have been developed by a tunnel at a depth of 270 m. cutting through the entire mountain from south to north which has a length of 3,300 m. and elevation of 13,600 feet. The principal veins are the Corpus and the San Tomás, which have been developed 2,350 m. along the strike and 750 m. in depth. The veins are much shattered near the surface, but about 50 m. under the tunnel level become more compact and finally unite at still greater depth to form a single vein. The width varies from one to three or four meters.

The vein filling consists of several fairly distinct layers. The walls are lined with quartz containing disseminated pyrite, then comes a band of pure pyrite followed by sphalerite and tetrahedrite, this by galena and some chalcopyrite and quartz, and in the middle again sphalerite and tetrahedrite. Rarer are ruby silver, stibnite, and occasional traces of bismuth and tin compounds. Tetrahedrite carries 3 to 6 per cent and even 10 per cent silver. Galena carries 70 oz. silver, sphalerite less but more than pyrite, and chalcopyrite runs low in silver. More or less galena is always intergrown with the sphalerite. There is a decrease in the amount of galena and corresponding increase in that of sphalerite and pyrite with increasing depth. In the upper levels is considerable barite, but this disappears in depth with an increase in the amount of quartz. The veins contain decomposed country rock and the rich ores are almost always accompanied by white bands of kaolin.

The rich tetrahedrite shoots yielded first class ore carrying 600 oz. and second grade with 180 oz. silver. In those days the dumps ran 30 oz. to 45 oz. silver. While the mine was flooded the dumps were treated, and later lower grade ore was produced averaging $\frac{1}{3}$ oz. to $\frac{1}{2}$ oz. gold, 20 oz. silver, 6 to 10 per cent copper, and 30 to 50 per cent zinc (52, p. 9). In 1907 the company was shipping ores averaging 50 oz. silver, 5 per cent copper, and 5 per cent zinc.

Ubina Silver District (86, p. 62).—On the south side of the Cerro Ubina are veins with a northeast strike and dip of 50° to 80° east, enclosed in porphyry and in a shale-sandstone-graywacke series into which the porphyry has been intruded. The zone of oxidation yielded chlorides of silver, and the sulphide ores consist of pyrite, chalcopyrite, tetrahedrite, chalcocite, galena, sphalerite, and ruby silver with barite, calcite, dolomite, and quartz as gangue minerals.

Tasna Bismuth (Silver, Tin) District (106, pp.103–104, 134–140).—Tasna, Chorolque and Chocaya are the centers of operation of Aramayo Francke & Company, one of the largest mining companies in Bolivia. At Tasna the ores being mined are principally bismuth ores which consist chiefly of bismuthinite with a smaller proportion of native bismuth than occurs at Huayna Potosi and a little of the oxide. The Tasna occurrence is the largest known deposit of bismuth ores, and the mines are producing at a rapidly increasing rate. The ores are treated at the company's smelter at Quechisla. In 1915 the district was also credited with a production of 32 tons of tin concentrates.

The Tasna mountain dominates a group of hills consisting almost entirely of slates, but cut by numerous rhyolite dikes. Though mineralization extends into the adjoining hills, the main mineralization is confined to that mountain. The veins are numerous and the filling differs at different points. The most productive bismuth veins are on the eastern slopes and contain in addition to the bismuth minerals pyrite, arsenopyrite, hematite, and quartz, and in smaller amounts argentiferous galena, stibnite, and siderite. On the south side of the mountain are veins of arsenopyrite with less bismuth and some cassiterite. On the west side an intersecting vein system in graywacke, with varying strike and dip and varying width up to 1 m., contains ores of bismuth and tin, one or the other predominating, with but small amounts of other metallic minerals, in a gangue of quartz and clay. The north side of the mountain has only narrow bismuth and antimony veins. The upper part of the mountain is highly silicified and contains veins of tungsten, tin, and bismuth ores associated with arsenopyrite. Apatite occurs sparingly and tourmaline abundantly in the Tasna ores.

Chorolque Silver-Tin-Bismuth-Tungsten District (88; 106, pp. 104–106, 132–134).—Chorolque mountain is a pyramid of quartz trachyte or quartz andesite rising nearly 3,000 feet above the surrounding country to an elevation of about 20,000 feet. The igneous rock has cut through the shale and quartzite series which outcrops on the flanks of the mountain, and at the contact is a breccia of silicified rock especially rich in tin. The veins occur usually in the igneous rock which in their vicinity has been considerably silicified. There is much variability in their filling which consists of ores of silver, tin, tungsten, and bismuth; in some veins one of these metals occurs, in others several, and the relative abundance is different in different veins. In general, tin ores are found chiefly near the summit, silver ores are more abundant at somewhat lower levels, and still lower are the veins which yield the bismuth ores.

The veins have an east-west strike, variable southerly dip and width of 3 feet, but not well-defined walls. Those most actively worked carry solely tin ores. The more complex ores of the sulphide zone contain pyrite, chalcopyrite, sphalerite, galena, tetrahedrite, bismuthinite, and bismuth. The prevalent gangue minerals are quartz, barite, and siderite. Some of the veins also contain tungsten minerals.

All the gullies leading from the peak contain rich alluvial deposits. The bed rock material for as far as 4 miles carries as high as 3 per cent tin and that on the hillsides before further concentration in the stream beds ½ per cent tin.

The operations of Aramayo Francke & Company are centered about two groups of mines, the older Chorolque group which has a mill at 16,000 feet and workings as high as 18,000 feet, and a second group on the opposite side of the mountain acquired about 10 years ago for which the Sala Sala mill was built. The tin production in 1915 amounted to over 1,200 tons of concentrates, and there was also produced 75 tons of tungsten concentrates.

Cotagaita Silver-Tin District.—At Cotagaita are veins in which cassiterite is accompanied by silver, lead, copper, and iron sulphides. Tin placers have been worked in the vicinity. The district is of no present importance.

Chocaya Silver-Tin District (55, pp. 48–51).—This district is one of increasing importance, particularly since the extension of the railroad from Uyuni to Atocha a few years ago so greatly improved transportation facilities. Aramayo Francke & Company and the Compañía Minera y Agricola de Oploco are active operators; the latter company owns mines in a number of other districts in this portion of Bolivia which formerly were important silver producers, as Portugalete, Tatasi, and Choroma. The ores are complex silver-tin ores, but in recent years attention has been centered on their tin content. The 1915 production was about 2,700 tons of tin concentrates.

The country rock of the district is slate cut by dacites. The veins are found in the latter. There are three centers of mineralization, Chocaya La Grande, Chocaya Animas, and Chocaya La Vieja. The veins strike northeast and northwest and dip in either direction. They range in width from 20 cm. to 100 cm. The filling consists of galena, sphalerite, chalcopyrite, pyrite, tetrahedrite, and considerable cassiterite. The galena and tetrahedrite are in places highly argentiferous and carry ruby silver. The picked silver ores carried 100 oz. silver. The tin ores now worked carry less silver. Quartz, barite, and calcite are the gangue minerals.

Portugalete (Tatasi) Silver District (55, p. 44).—Portugalete is one of the best known of the numerous silver districts in southern Bolivia that at one time were quite productive but which have lain nearly idle for many years. The veins are found in an intrusion of what is probably andesite, which has a diameter of about 27 miles, cutting Silurian slates. Tatasi is on the east side and Portugalete on the west side of a low ridge in which the mines are located. The veins were noted for richness in ruby silver, the Anjeles vein having streaks of it as much as 6 cm. wide. The common ore minerals are tetrahedrite, jamesonite, galena, sphalerite, chalcopyrite, pyrite, and a little stibnite and native silver. Galena is always present and is sometimes the predominant mineral. Rich ores carried 160 oz. silver, galena ores 100 oz. High silver values were found in pockets and shoots between which are relatively poor and barren areas. The veins are several thousand yards in length, from a few inches to several feet in width, and strike and dip in various directions, but usually the strike is east-west.

San Vicente Silver District (55, p. 40).—The San Vicente ores are also described as silver ores with no mention of the occurrence of tin. In the oxidized zone, chlorides of silver were mined and at deeper levels the ores contained native silver, ruby silver, and sulphides of lead, zinc, and iron. The gangue contained barite and calcite. In view of the occurrence of tin in the ores of the Esmoraca district, it seems likely that tin is also present in the ores of San Vicente and Portugalete.

Sud Lipez Silver Districts (55).—In the province of Sud Lipez, which lies to the west of the districts last described, are a number of districts which at one time produced considerable silver but which have been almost abandoned for many years. Descriptions of these antedate the era of Bolivian tin mining and no mention is made of the occurrence of tin or bismuth ores among them. Mineralogically they are analogous to the more distinctly silver ores of the silver-tin districts described on the preceding pages and their geologic relations are similar. In the absence of more complete and more recent data, it is a question whether they represent the extreme end of the silver facies in which no tin has been deposited or whether there was not a little tin deposited at the time these veins were formed.

Among the districts are included San Cristobal, San Antonio, and Santa Isabel.

These districts produced both rich oxidized ores and rich sulphide ores. The oxidized ores consisted largely of silver chlorides and iron oxide with quartz and barite. The sulphide ores were made up of the common sulphides, galena, sphalerite, chalcopyrite, and pyrite in a gangue of quartz and barite, with the latter most abundant near the surface. Associated with these minerals were richer silver minerals as tetrahedrite, ruby silver, and other sulphantimonides, and native silver.

CONDITIONS GOVERNING AND AFFECTING THE MINING INDUSTRY

The greatest difficulties encountered in mining in Bolivia are high altitudes, high transportation costs, lack of fuel, and scarcity of labor; in which it does not differ materially from other West Coast countries.

Though transportation problems are not easy in Bolivia, great advances have been made in their improvement in recent years. The completion of the Antofagasta and Bolivia Railway to Oruro over 25 years ago and the extension of the Southern Railway of Peru via Lake Titicaca to La Paz 15 years ago made it no longer necessary to pack everything to and from the coast on animals. In 1908, the former road was extended to La Paz, and in 1913 the direct route from La Paz to Arica was completed. There is now consequently a line running the entire length of the *altiplanicie* along its eastern edge, from which branch lines are constructed into the mineral belt to the east as fast as the resources of the country permit and the development of important deposits demands. The line from Oruro to Cochabamba has made the Berenguela district and other districts in the southwestern part of the department of Cochabamba more accessible to rail transportation. From Machacamarca, Señor Simon I. Patiño is building a private railroad to Uncia which will be of immense service to Llallagua also, and which has already made more accessible Huanuni, Morococala, and Negro Pabellon. The branch from Rio Mulato to Potosi has been in operation for 6 years and has stimulated the development of the Porco district. At Uyuni is a private line to the Pulacayo mines, and another road is under construction to connect with the Argentine railroads at La Quiaca. This line runs through a mineralized area that was once of considerable importance, and the introduction of modern transportation facilities should again make it an important contributor to the mineral production of the country.

With increased transportation facilities the fuel situation is not nearly so acute as it was. The most important native fuel is *taquia*, the droppings of the llamas. Incredible quantities are used both as domestic fuel and to run mining machinery and smelters. One of the companies at Corocoro alone consumes annually 10,000 tons of *taquia*, having a value of $4.00 per ton. Locally *yareta* is found in sufficient quantity to be of importance as a fuel. It is a plant that grows in large clusters of woody resinous fibers adhering to the rocks at high altitudes, and has the appearance of a large clump of moss. In addition, at a few places, there are sufficiently large accumulations of peat to make it an available fuel. Fuels other than these must be imported. The rapid extension of the railroads in recent years has made it possible to use increasing quantities of imported fuel, and especially oil. Diesel engines are being widely introduced as they furnish the easiest solution of the power problem at present.

The labor problem in Bolivia is a difficult one. The high plateau lies at an elevation of over 12,000 feet, and the mines are in the hills and mountains that rise above it to elevations of 18,000 feet. Most of the mines lie between 14,000 feet and 16,000 feet. At such elevations, imported labor can not be used as it can not endure the strain of continuous manual exertion and it is necessary to depend on the native Indian stock. The supply of this is limited and its efficiency not high, so that in regions where there has been the greatest development of mining operations difficulty is experienced in obtaining sufficient labor.

The backbone of the Bolivian mining industry is tin mining, but with the exception of the small amount smelted at Potosi, all of the tin concentrates are exported. Prior to 1915, the Bolivian tin producers were entirely at the mercy of European smelters and their ore buyers. In March, 1915, the American Smelting and Refining Company began tin smelting at Perth Amboy and in July 1917, increased their plant to 1,500 tons monthly capacity. The Chilean Tin Smelting Company, representing Llallagua interests, is erecting a smelter at Arica to treat those ores, and a small electric smelter is being erected at La Paz.

These developments mean that when normal conditions return there will be far greater competition for the purchase of the Bolivian tin ores which will result in a more stable and profitable basis for that industry.

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Description of the placer deposits which have produced large amounts of gold in the past and are still workable.

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35. FIREBRACE, W. E. GORDON: Suchez de Bolivia Hydraulic Mine. *Min. and Scientific Press*, Vol. 98, pp. 287–288, 1909.

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36. FLECK, A.: Der Kupferbergbau im Lateinischen Amerika. *Glückauf*, Vol. 47, pp. 466–474, 507–512, 550–554, Essen, 1911.

Bolivian copper industry discussed on pages 507–508.

37. FLECK, A.: Copper Mining in Latin America. *Mining Jour.*, Vol. 93, pp. 430–431, 436–437, 466–467, 496–497, London, 1911.

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38. FORBES, DAVID: On the Geology of Bolivia and Southern Peru. *Quart. Jour. Geol. Soc.*, Vol. 17, pp. 7–84, London, 1861.

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41. GAUTIER, FERNANDO: Yacimientos de Estaño de Bolivia. *Boletin* de la Sociedad Nacional de Minería, Vol. 6, pp. 241–248, Santiago de Chile, 1894.

Refers to the occurrence of cylindrite in the silver mines of Poópo, a new tin mineral. Tin derived in Bolivia from two sources—residues of amalgamation of silver ores and from ores from veins of tin oxide. Gives characteristics of five general areas in which tin ores occur in Bolivia—La Paz, Oruro, Huanuni, Potosi and Chorolque-Quetchisla-Pasna. Describes mining and concentration.

42. GLAIZOT, FRANÇOIS: Voyage Minier a travers le continent Sud-Américain (Bolivie-Brésil) de La Paz á Para, par les Andes et l'Amazon. *Bulletin* et Comptes Rendus Mensuels de la Société de l'Industrie Minérale, 4th Ser., Vol. 13, pp. 5–51, Saint Étienne, 1910.

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52. JIMÉNEZ, J. VELÁSQUEZ: La Compañía Huanchaca de Bolivia. *Boletín* de Minas, Industria y Construcciones, 2nd Ser., Vol. 1, No. 1, pp. 9–11 Lima, 1905.

Account of the difficulties of the company due to flooding of the mine and in the treatment of the ores. Gives character of the ore mined at this time.

53. LAMB, MARK R.: Bolivian Tin Mining. *Eng. and Min. Jour.*, Vol. 94, pp. 271–273, 1912.

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54. LAMB, MARK R.: Tin Mining in Bolivia. *Eng. and Min. Jour.*, Vol. 99, pp. 605–609, 1916.

A brief description of the character of the Bolivian tin ores and the difficulties attending their production.

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59. LINCOLN, FRANCIS CHURCH: Gold Mining in Bolivia. *Eng. and Min. Jour.*, Vol. 99, pp. 351–354, 1915. Translation by M. V. Ballivián: Bolivia Minera. Ministerio de Justicia e Industria, 1916, pp. 69–77, La Paz.

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65. LINCOLN, FRANCIS CHURCH: Oruro Tin-silver District, Bolivia. *Min. and Scientific Press*, Vol. 115, 1917, pp. 57–58.

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72. MILLER, BENJAMIN LEROY, AND SINGEWALD, JOSEPH T., JR.: Mining Conditions at Potosi, Bolivia. *Eng. and Min. Jour.*, Vol. 103, pp. 255–260, 1917.

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Describes the ore, its occurrence, and more fully the mine developments.

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83. PFORDTE, OTTO F.: The Mining District of Oruro, Bolivia. *Eng. and Min. Jour.*, Vol. 53, pp. 447–448, 1892.

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93. SCHILLER, WALTHER: Contribución al Conocimiento de la Formación Petrolífera (Cretáceo) de Bolivia del Sud. Revista del Museo de la Plata, Universidad Nacional de la Plata, Vol. 20, pp. 168–197, Buenos Aires, 1913.

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99. SÖHNLEIN, M. G. F.: Tin Mining in Bolivia. *Eng. and Min. Jour.*, Vol. 99, pp. 143–145, 1915.
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104. STEINMANN, G., HOEK, H., BISTRAM, AV.: Zur Geol. des S. O. Boliviens. *Centralblatt* für Min. Geol. u. Pal., pp. 1–4, Stuttgart, 1904.
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106. STELZNER, ALFRED WILHELM: Die Silber-Zinnerzlagerstätten Bolivias. *Zeitschrift* der deutschen geologischen Gesellschaft, Vol. 49, pp. 51–142, Berlin, 1897.
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111. WENDT, ARTHUR F.: The Potosi, Bolivia, Silver District. *Trans.* Amer. Inst. Min. Eng., Vol. 19, pp. 74–107, 1890.
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113. WEPFER, G. W.: Tin Mining in Bolivia. *Min. and Scientific Press*, Vol. 108, pp. 251–255, 1914.
Statistical data are given concerning the most important tin mines.

114. WIENER: Les Mines d'Argent d'Oruro (Bolivie). *Annales des Mines*, 9th Ser., Vol. 5, pp. 511–520, Paris, 1894.
Brief account of history of district and mining activities.

115. ——————: *Boletín* de la Oficina Nacional de Estadística, Republica de Bolivia.
La Paz. Publication begun in 1901. Contains tables of statistics of

mineral production and many articles on mining and mining districts. Many of these have been taken from other sources and translated for use in these bulletins. More important original articles contained in them are given under their own title in this bibliography.

116. ——————: *Boletín* de la Sociedad Geográfica, Potosí. Publication commenced August, 1913.

Gives historical accounts of Potosi and its mines.

117. ——————: Comercio Especial de Bolivia. Dirreccion General de Aduanas, Seccion de Estadística Comercial y Bancaria—Bolivia.

Beginning with 1912 publishes statistics of production of each of the metals by districts and countries to which exported.

118. ——————: Informe del Prefecto del Departamento. Memoria del Prefecto del Departmento. La Paz.

Under these titles reports are published from the prefects of the various departments which contain data as to operations of mining companies and at times description of mines.

119. ——————: Memorias del Ministro de Justicia e Industria. Memorias del Ministerio de Hacienda é Industria. La Paz.

Published annually since 1892 under latter title, and since 1912 included under first title. With the Anexos attached to the memoria, give some statistics of output of mineral products in returns of customs duties, and include remarks on status of the mining industry, and occasionally names of operating companies.

1912 Anexos has geologic map of Bolivia and mineral maps of each department giving location of mining districts and areas over which the different metals are found.

120. ——————: Revista del Ministerio del Ramo, Hacienda é Industria.

Published monthly from January, 1909 to November, 1911. Gives statistics of mineral production and occasional notes on mining industry. January, 1911, number has table giving tin production of every district for 1909 and 1910.

121. ——————: Tratado de Minería. *Boletín* de la Oficina Nacional de Estadística, pp. 19–38, La Paz, 1911.

Reproduction of a report made in 1810 to the Intendente of Potosi on the status of the silver and gold mines in territory that is practically the Bolivia of today.

CHAPTER IV

BRAZIL

The United States of Brazil, consisting of twenty states, one national territory (Acre) and one Federal district (the City of Rio de Janeiro) is the largest of the South American republics and comprises almost one-half of the South American continent. Although the area is not definitely known and is given differently by various authorities the most reliable data give a total area of 3,270,000 square miles. It is in contact with every South American country except Chile and Ecuador. From north to south it extends 2,675 miles and 2,691 miles from east to west. More than seven-eighths of the country is included within the tropics.

TOPOGRAPHY

Notwithstanding its great area, Brazil displays less variety of topography than most of the South American countries and is entirely devoid of the striking topographic characteristics which have made the West Coast countries famous for their scenery and at the same time have interposed such great obstacles in the construction of engineering projects for the development of those regions. The highest points in Brazil are Mt. Itatiaia in the Serra da Mantiqueira between the states of Minas Geraes and Rio de Janeiro and Mt. Caparão in southeastern Minas Geraes. Both are about 10,000 feet in height.

Topographically the country is divisible into two portions—lowlands and highlands—the former consisting mainly of the extensive low-lying areas bordering the Amazon and Tocantins rivers and their tributaries in the north and the Paraguay and Paraná rivers in the south whereas the highlands occur in two belts, a small area bordering Venezuela and the Guianas in the north and a much larger one extending from near the mouth of the Amazon River southwestward, roughly parallel to the Coast, to Uruguay.

Brazilian Lowlands.—Although the lowlands are penetrated everywhere by navigable streams to a greater extent than any other country in the world they nevertheless constitute the most thinly inhabited portion of the country and contain several unexplored areas. Large portions of these lowlands are subject to frequent inundations during periods of heavy precipitation while other portions with elevations of only a few hundred feet have a semi-arid climate. In the main the lowlands are covered with dense tropical forests and except for forest products—rubber, nuts, and lumber—are at the present time of little value. For forestry and agricultural purposes the lowlands of Brazil have great promise but for the present they must be regarded as reservations for the future. Economic mineral deposits are almost unknown in the Brazilian lowlands and there is no reason to believe that they will ever be of much importance from a mining standpoint.

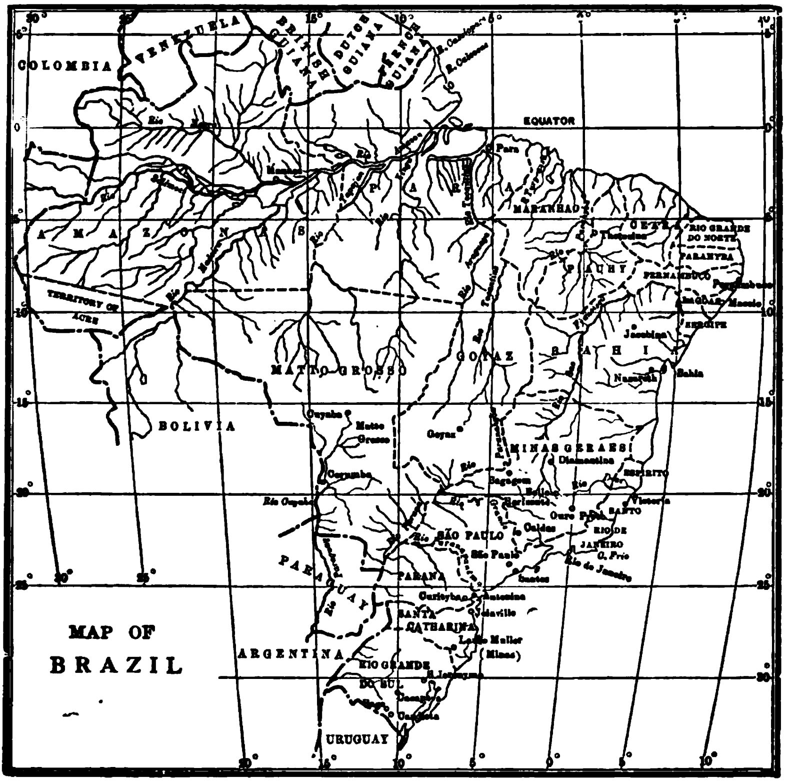

Fig. 16.

Brazilian Highlands.—The highlands of Brazil were undoubtedly at one time continuous but are now separated by the broad Amazon River valley into two bodies. The northern area bordering Venezuela and the Guianas, known as Brazilian Guyana, constitutes a part of what is generally known as the Guyanan Highlands. The region is uninviting on account of its aridity and is imperfectly known. The Guyanan Highlands lie within the trade winds belt and consequently the northern slopes included within the Guianas and Venezuela receive abundant moisture while the southern slopes, belonging to Brazil, are semi-arid. The greatest elevation in the Guyanan Highlands is reported to be 8,500 feet. Few mineral deposits of importance have thus far been reported in this region.

The larger area of the Brazilian highlands occupies the eastern part of the country bordering the Atlantic Ocean and extends from near the mouth of the Amazon to the extreme southern portion of the country. Throughout the area the belt varies in width, gradually narrowing to the southward. In addition there are projections extending to the westward into Goyaz and Matto Grosso.

Southward from Bahia the highlands border the ocean but northward a fairly continuous narrow band of coastal plain intervenes. Some of the best harbors of the Brazilian coast are found where the highlands extend to the coast as shown so notably in the magnificent harbor of Rio de Janeiro.

The highlands consist, in the main, of greatly dissected ancient mountains and plateaus. In many places the tops of the hills are in such accordance that it seems that well-developed peneplains have been formed at different levels although now so greatly dissected that accurate topographic maps must be prepared before correlations can be established. The present topography is the result of erosion and the highest hills and ridges are those composed of the most resistant rocks.

The highest portions of the highlands are in Minas Geraes, Espirito Santo, and Goyaz where the average elevation is about 3,500 feet with occasional groups of mountains containing peaks from 6,000 to 10,000 feet above sea level.

Practically all the railroads of the country have been constructed in the highlands belt where the greater part of the population is found. The lack of regularity in the distribution of the hills and their steep slopes have presented serious obstacles in railroad construction and some of the lines because of heavy grades and sharp curves are poorly fitted for transportation of ores.

A few of the streams penetrating the highlands are navigable, notably the São Francisco River which drains some of the most important mineralized areas of the highlands of Minas Geraes and Bahia. Most of the streams, however, contain numerous rapids, cascades, and water falls which interfere with navigation but on the other hand, furnish much water power. Only a very small part of the available water power of the country has been utilized. The scarcity of coal is partially offset by this great source of power and there is no doubt but that the future development of the country will be greatly aided by the utilization of the extensive water resources. At present two of the largest mining operations of the country obtain the greater part of their power from nearby streams.

With few exceptions all the known deposits of economic minerals are confined to the highlands belt.

GEOLOGY

Although Dr. J. C. Branner in his "Bibliography of the Geology of Brazil" lists over 2,000 titles, nevertheless geologic information concerning the country is scanty and, except concerning a few localities, of a most generalized character. Eschwege whose writings extend over the period from 1811 to 1846 was the earliest geologic investigator of note in the country. Hartt published numerous articles on the geology of the country between 1869 and 1898 as did also Gorceix between 1877 and 1891, Hussak between 1889 and 1906, Derby between 1874 and 1915, and Branner who is still active has made many valuable contributions beginning in 1884. J. C. da Costa Sena, Euzebio Paulo de Oliveira, Francisco de Paula Oliveira, Luiz Gonzaga de Campos, and M. A. R. Lisboa, have also contributed to the geological literature of their country. Dr. Derby above all others made the most valuable geological investigations and to his 40 years of practically continuous work in the country we owe the greater part of our knowledge of Brazilian geology.

The geology of eastern Brazil presents many similar ties to that of the northeastern portion of North America while the western part of the country resembles geologically the interior of the United States. A basal complex of pre-Cambrian and early

Paleozoic crystalline rocks overlain by some Devonian, Carboniferous, Permian, and Mesozoic strata constitutes the greater portion of the Highlands while the lowlands are composed of Mesozoic, Tertiary, and Quaternary rocks.

Pre-Cambrian Rocks.—The pre-Cambrian geology of Brazil is exceedingly complex and except in very restricted areas has, as yet, been only imperfectly investigated. With few exceptions all the economic mineral resources are contained in this basal complex that probably represents the Archean and Algonkian epochs and consists of a great variety of metamorphic rocks of both igneous and sedimentary origin. The most wide-spread rocks are the granites and gneisses, with many quartzites, itabirites, gabbros, and intrusive igneous rocks.

The pre-Cambrian rocks are represented in the Guyanan Highlands of northern Brazil and also in the Highlands of eastern and southeastern Brazil. They are present in every one of the states bordering the Atlantic Ocean from Piauhy southward as well as the interior states of Minas Geraes, Goyaz, and Matto Grosso. In Minas Geraes and Goyaz they are widely distributed. Small areas are also exposed in the valleys of the Madeira, Tapajoz, and Xingu rivers where the streams have cut through the thin cover of Mesozoic strata to the floor of crystalline rocks. With the exceptions of the last-mentioned occurrences the pre-Cambrian crystalline rocks are deeply buried in the Amazon River valley by deposits of Mesozoic and Cenozoic sediments.

Most of these ancient pre-Cambrian rocks have been so greatly metamorphosed by earth disturbances which they have suffered that they have been profoundly altered from their original character. It is probable that most of the gneisses were originally igneous rocks and that the quartz, mica, chlorite, garnet, talc, and amphibole schists are altered sediments. The quartzites, marbles, and slates have been formed from sandstones, limestones, and shales. Granites, diorites, and gabbros have been intruded into these metamorphic rocks.

The structures of the pre-Cambrian rocks are complex and have only been deciphered in a few local areas. Folding and thrust faulting have taken place on a large scale with the maximum application of pressure apparently from the southeast.

Portions of the present pre-Cambrian areas have not been beneath the ocean waters since very early Paleozoic times consequently erosion has probably removed great thicknesses of rock thus making it still more difficult to interpret the structures and establish correlations. Differential erosion is mainly responsible for the present topography in which the quartzites, siliceous schists, or gneisses constitute the highest ridges and hills and the calcareous strata and softer schists underlie the valleys.

Paleozoic Strata.—There is a possibility that some of the metamorphic strata previously described may belong to the early Paleozoic but evidence of this is lacking. Strata of undoubted Paleozoic age have been reported from many places. These belong to the Cambrian (?), Ordovician (?), Silurian, Devonian, Carboniferous, and Permian periods and consist of limestones, sandstones, shales, and coal beds. Cambrian (?) strata have been found north of the Amazon River bordering the area of crystalline rocks and in a few places south of the Amazon. Ordovician (?) and Silurian strata were deposited in Southern Brazil between the Serra do Mar, the main range of Coast Mountains south of Rio de Janeiro, and the Paraguay River, although now largely concealed by overlying strata of more recent age. Strata of supposedly Ordovician and Silurian age are well developed in the basin of the São Francisco River.

A band of Devonian rocks appears about 25 to 50 miles north of the Amazon River in its lower course and a similar band outcrops at a somewhat greater distance to the south of the river. These probably represent the outcropping edges of a syncline through which the great river flows. Devonian strata are also well represented in Matto Grosso and adjoining states.

Carboniferous and Permian limestones and sandstones of marine origin are present in the Devonian syncline of the lower Amazon and extending to Piauhy. In the states of São Paulo, Paraná, Santa Catharina, and Rio Grande do Sul fresh water deposits of Permian age containing locally coal and lignite beds are found. Outpours of lavas seem to have taken place in these areas toward the close of the Permian.

Mesozoic Strata.—During the Mesozoic era the greater portion of the country received deposits which are in part of terrestrial origin and in part marine. They consist of horizontal sandstones which cover the greater portion of interior Brazil. Their exact age is still undetermined but they probably belong for the greater part to the Triassic. Marine Cretaceous strata are found along the coast in several places.

Cenozoic Strata.—Tertiary and Quaternary rocks are extensively developed in the basins of the Amazon and Paraguay rivers and also in narrow bands along the coast.

Briefly the geologic history of Brazil consists of two rather distinct divisions, the pre-Cambrian and the later periods. During the pre-Cambrian period sedimentation and igneous action resulted in the formation of a varied series of rocks that were later changed by regional and contact metamorphism into the complex of granites, gneisses, schists, etc. The igneous and metamorphic agencies seem to be mainly responsible for the greater part of the present mineral deposits. Following the deposition of the early Paleozoic strata there was some folding and faulting although slight in comparison with that which so greatly disturbed the pre-Cambrian rocks. From the Permian period, however, folding and faulting seem to have had little effect and the movements of elevation and depression acted vertically over large areas and the post-Carboniferous rocks have undergone very slight deformation. Also, with the exception of the volcanic outpours of lavas in Southern Brazil during the Permian, igneous activity has been of very slight importance since the pre-Cambrian period. In these respects the geology of Brazil presents striking contrasts with that of the West Coast countries.

GOLD

Gold is the most widely distributed economic mineral product of Brazil and is reported to occur in every one of the states comprising the Republic. In fact it has been produced in most of them at one time or another and probably there has not been a year during the past two centuries during which there has been no production of gold. Nevertheless, Brazil has not achieved first rank in gold mining in comparison with other South American countries and at the present time the industry is confined to a very small number of localities.

The lure of the yellow metal was the great incentive in the exploration of the country by the early settlers but not until 1699 did they discover any rich deposits. The Portuguese at that time discovered the rich alluvial deposits in the vicinity of Ouro Preto (long known as Villa Rica) and a city sprung up in a short time. The placers of Cuyaba in Matto Grosso were discovered in 1718 and those of Goyaz in 1724. Between the years

1730 and 1750 the mines of Minas Geraes were most active and Mawe states that during some years the King's fifth which the Crown claimed, "amounted to at least a million sterling annually," while the city of Villa Rica "was reputed the richest place on the globe."

Other rich placers were discovered in other sections and up to 1889, when slavery was abolished, gold mining remained an active industry. Since that time the scarcity and high costs of labor have seriously interfered with mining and the number of gold operations of importance can almost be numbered on the fingers. The leading ones are owned by foreign capital, mainly English.

The placers were the first deposits to be worked but in time a number of lode mines were opened and for several years past these have been the principal ones operated.

DISTRIBUTION OF GOLD IN THE COUNTRY

The primary source of the gold of Brazil is in the complex of crystalline rocks of the Highlands. Streams heading in these sections have carried the gold far down their courses so that alluvial deposits occur in many places in the valleys.

Although gold has been found in all the states, in most of them it is of so little consequence or so little information is available, that it is scarcely necessary to discuss them. The descriptions that follow are limited to the states of Minas Geraes, Matto Grosso, Goyaz, Bahia, Para, and Rio Grande do Sul.

Minas Geraes.—Gold in paying quantities was first discovered in Minas Geraes and this State has ever since occupied the first place in the list of gold producing states of the Republic. The principal deposits are located on either side of the so-called Serra do Espinhaço, one of the principal ranges of mountains of the State which running approximately north and south through Central Minas Geraes forms the division between the drainage basins of the Doce and São Francisco rivers (Fig. 19). The Paracatú district in the western part of the State also produced great quantities of gold during the eighteenth century.

The first work was confined to the alluvial gravels above the streams where the richest returns were obtained at little cost. Higher-lying terrace gravels were later worked by bringing streams of water to these places through ditches many miles in length, the ruins of which are still to be seen in numerous places. When one sees the enormous quantities of gravel that have thus been worked over for gold in scores of places throughout the country he can appreciate the one-time prosperity of the industry. Even yet some panning of the stream gravels is being carried on by the natives, while dredging for diamonds and gold has been done within recent years along the Jequitinhonha River.

Placer mining was followed by the working of the *jacutinga* ores, which consist of layers of uncemented hematite flakes and of loosely cemented itabirite, containing thin veins of native gold or gold-bearing quartz. In many places the rock was so soft that it would crumble and be washed away when water was directed against it almost as readily as though it were a bank of sand. The quartz and hematite flakes were thus carried into the streams while the gold was caught in sluice boxes. Along many streams, especially those near Cattas Altas, deposits of the specular hematite and quartz sand waste 15 to 20 feet in thickness cover many acres. In other regions the *jacutinga* ores are hard enough to require stamping to liberate the gold. Most mines of this character were of such low grade that they could be worked with profit only where water could be brought to the site of the working at low cost, but in some cases they were phenomenally rich. *Jacutinga* ore mines have been worked over an extensive area in Minas Geraes and are, so far as known, peculiar to that section.

The ordinary quartz and sulphide ore lodes were worked later and these are the only ones of consequence now in operation. The principal lode mines of this character center around Ouro Preto, Marianna, Santa Barbara, Caethé, Diamantina, and along the Rio das Velhas in the vicinity of Bello Horizonte and Sabará. The ore bodies occur in the basement complex rocks as well as in all the overlying formations of supposedly Algonkian age, described in the discussion of the iron ore resources.

The Gongo Socco Mine (134)[1] located about 18 miles east of Sabará was one of the most prosperous mines during the first half of the last century. The gold was found in *jacutinga* seams in soft itabirite. Between 1826 and 1839 the mine is said to have yielded 11 tons of gold. The Faria and Florisbella mines near Honorio Bicalho on the Estrada de Ferro Central do Brazil have quartz pyrite lodes similar to the Morro Velho mine described below. The São Bento and Sta. Quiteria mines near Santa Barbara con-

[1] Numbers in parentheses refer to articles in Bibliography at close of chapter.

tain series of ore shoots composed of quartz, hematite, limonite, and earthy materials representing the oxidized portions of sulphide ore bodies. The Carrapato and Juca Vieira mines near Caethé have quartz pyrite and arsenopyrite lodes. The Itabira mine near Itabira do Matto Dentro was a *jacutinga* ore mine. The Maquiné mine near Marianna was a *jacutinga* ore mine that produced a great deal of gold.

Except for intermittent work all active gold mining in Minas Geraes for several years past has been confined to the work of two English companies operating the Morro Velho mine at Villa Nova da Lima near Raposos and the Passagem mine between Marianna and Ouro Preto.

The Morro Velho mine of the St. John del Rey Mining Co., Ltd., at Villa Nova de Lima in the State of Minas Geraes, is the most interesting mine in all South America and in some respects one of the most remarkable in the world. The company is the oldest registered English mining company, having been organized in 1830 for working a gold mine near São João del Rey in Minas Geraes. In 1834 the company acquired its present property, the Morro Velho mine, which, with few interruptions, has been operated ever since.

At present the mine claims the world's record for depth; the deepest workings on Aug. 24, 1917 were 6,126 ft. below the surface, and the end is not yet. George Chalmers, the mine superintendent, states in his last annual report that

> "it appears that at any rate (of temperature increase) supposing the lode continues the same in size and value to horizon 26 (a vertical depth of 7,626 ft.), it could be worked profitably to that point and even to a much greater depth."

The persistence of the orebody and the absence of any material change in the tenor of the ores with depth are of especial interest, as both are in disagreement with ideas commonly held by mining men.

The Morro Velho mine is situated in a hilly region at an elevation of 2,774 ft. above sea level, with surrounding hills considerably higher, the steep slopes of which are covered with tropical vegetation.

The country rocks of the Morro Velho region consist of calcareous schists which have been greatly sheared in places with the development of considerable mica and chlorite. The orebody, which is pod-like and vertical, pitches into the earth at an angle of about 45°. The accompanying longitudinal section (Fig. 17) shows a side view of the workable parts of the vein. The vein, however, continues farther in a vertical direction but

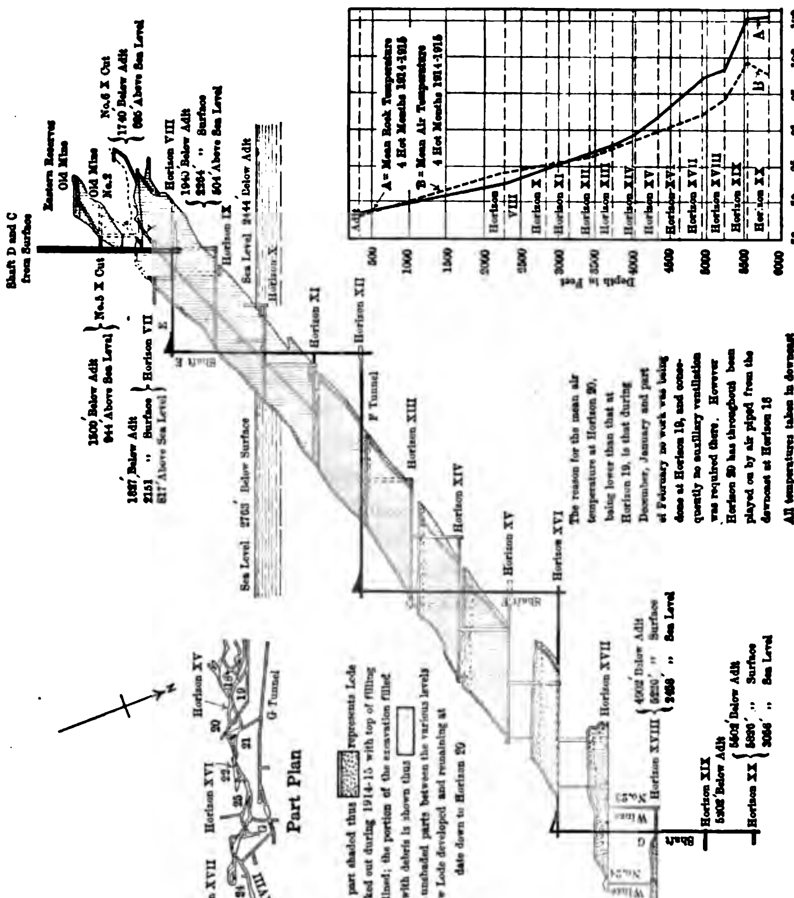

FIG. 17.—Longitudinal section of Morro Velho mine. Also temperature chart.

becomes too narrow to be worked profitably. The average width of the orebody is 10 to 12 ft., with a maximum width of 33 ft. In certain places it has been found profitable to follow the vein until the width decreases to 1 ft. The stope length throughout most of the mine is about 600 ft., but in the recently opened levels it is almost 1,000 ft. While the orebody is, in the main, approximately vertical, there are occasional irregularities, and at certain places a vertical cross-section would appear much like the letter S

There is no gouge present, and the schistosity of the rocks being parallel to the orebody indicates that the region suffered greatly by compression after the deposition of the ore.

The orebody consists mainly of quartz, siderite, dolomite, calcite, forming the gangue materials, and containing the sulphides—pyrrhotite, pyrite, arsenopyrite, and a small amount of chalcopyrite. The arsenopyrite carries most of the gold; free gold is rarely seen. Bands of quartz with practically no sulphides are sometimes found.

In the early operations of the mine the opencut mining method was employed and the walls were supported by heavy timbers. With increasing depth it became more difficult to support the walls, and after a serious fall of rock which closed the mine for some time, two parallel shafts were sunk in the country rock near the vein. From the bottom of these shafts a cross tunnel was run to intersect the vein some distance below the old workings. An adit strikes these shafts 324 ft. from the surface. As shown in the longitudinal section, in order to reach the bottom of the mine, one goes through the adit to Shafts C and D and then descends in a vertical shaft 1,940 ft. to Horizon 8. Passing through Tunnel E about 600 ft. to the top of Shaft E, which is 1,160 ft. deep, one descends to Horizon 12. In succession, through Tunnel F, Shaft F, Tunnel G and Shaft G, Horizon 20, which is 5,826 ft. below the surface, is finally reached. Every 300 ft. drifts are run to the orebody.

The ore as mined is brought to the surface at once, as it has been found that the contact of the surface air fanned into the mine for ventilation quickly oxidizes the broken ore with the formation of sulphuric acid and consequently more cyanide is required in the treatment of the ore. The pressure in the deeper horizons that are now being worked is so great that the stopes must be filled at once. Formerly the mill tailings were used for filling, but as considerable heat was generated in the oxidation of the pyrite which continued after the refuse had been returned to the mine, it became necessary to use other material. Rock quarried near the mouth of the mine is now used for this purpose.

In the upper levels there was considerable water, but in the lower workings it is necessary to sprinkle the passageways to keep down the dust. The dust from the drills has had some effect in causing lung trouble among the workmen, but by no means to the same extent that it has on the Rand.

One of the most interesting problems that the company has had to solve is that of ventilation. With increasing depth the mine has continually grown hotter, although fortunately at a rate lower than that prevailing in some parts of the world. The average rate of increase is about 1°F. for every 125 ft. of increase in depth. Nevertheless, at this comparatively low rate, in the lowest workings the temperature of the rocks is 115°F. and the air pumped from the surface is slightly more than 100°F. During the hot months of December, January, February, and March this air has a temperature above 70°F. at the surface. As it is forced into the mine, it increases in temperature owing to compression, at the approximate rate of 1°F. for every 180 ft. increase in depth and consequently is very hot when it reaches the bottom of the mine, and its cooling effect upon the workmen is mainly due to the evaporation of the perspiration.

In a recent report Mr. Chalmers states: "There are many other causes for increase in temperature in the mine—those due to the friction of the air, heat from machinery, lights, decomposition of mineral, heat from the bodies of men and animals, etc.—but the heating effect from the rock and that due to the compressing of the atmosphere as it descends into depth are, in the case of this mine, the most serious, and it is evident that unless the air as it enters the mine is made considerably cooler than the average surface temperature, it would in descending into depth arrive at a point below the present bottom where its temperature would not allow men to work."

The ore treatment is divided into two parts—the mechanical, where concentrating tables are used, and the chemical, or cyanide, treatment.

The power used by the company is hydro-electric, obtained from the Rio de Peixe, which supplies about 3,500 h.p. During the dry months some auxiliary steam and gas power is required. During the last few years the rainfall has been inadequate, the total for the year ended February, 1915, being only 42.54 in., while the average since 1875 was 65.34 in. This reduction coupled with the necessity of additional power on account of the increased depth of the mine, will shortly compel the company to build another hydro-electric plant along the same river. As all the coal consumed must be brought from England or the United States at great expense, the company must continue to rely almost exclusively on water power.

During the year ended Feb. 28, 1915, there was a total of 199,234 tons of ore mined; 4.11 per cent was rejected and 191,500 tons crushed. The gold and silver from this was sold in London for $2,215,805, an average of $11.57 per ton of material milled. The profits amounted to $700,287. At that time the ore reserves totaled 699,704 tons, a supply sufficient for 3½ years' work.

The Passagem mine of the Ouro Preto Gold Mines of Brazil,

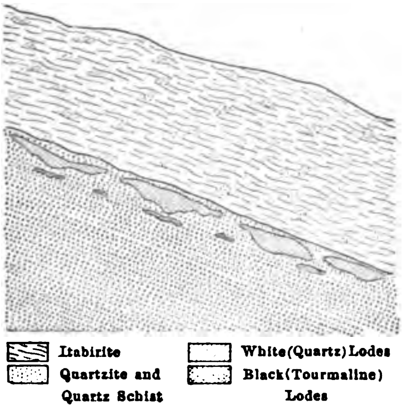

Fig. 18.—Geologic section of Passagem mine.

Ltd., is about 8 mi. east of Ouro Preto and a few miles from Mt. Itacolumi, from which the name itacolumite (flexible sandstone) has been derived. The town of Passagem has a population of about 3,000 all dependent upon the mine.

The Passagem mine is the second gold mine in Brazil in importance and, like Morro Velho, is very old, yet shows little indication of approaching exhaustion. Baron von Eschwege, a Prussian mining engineer who was employed by the Portuguese government to investigate the gold mines of Brazil, opened the Passagem mine in 1817 and, it is said, installed there the first stamps used in the country.

The country rock of the region consists of quartz schists or quartzites overlain by itabirite, a rock consisting of alternating laminæ of specular hematite and fine quartz sand. In places the itabirite consists of loose flakes of specular hematite (*jacutinga*), and the same formation a few miles distant contains beds consisting of high-grade iron ore.

The ore horizon is found at the contact of the quartzite and itabirite and dips to the southeast at varying angles, but in most places from 15° to 20° (Fig. 18). The lodes are of two kinds; close to the contact are the white lodes, consisting mainly of a white-quartz gangue, while below these are the black lodes, containing principally black tourmaline. The white lodes are practically continuous, and lie in the quartzite close to the itabirite, separated from it by a thin layer of Batatal schist ranging in thickness up to 18 in. This band of altered rock is known as *guia* (guide rock). The lodes are irregular, varying in thickness up to 36 ft. and extending through two or three levels in certain parts of the mine. The gold is irregularly distributed throughout the quartz, occurring in dark streaks or patches associated with tourmaline, pyrrhotite, and arsenopyrite. The gold is principally in the arsenopyrite as in the case of the Morro Velho mine.

The black lodes consist mainly of black tourmaline, pyrrhotite, and arsenopyrite, with some quartz. These lodes are smaller, seldom more than 3 ft. in thickness, and are found beneath the white lodes. In places the two lodes are in contact, but in most instances several feet of barren quartzite separate them. The black lodes are much richer, but the expense involved in searching for them and their small size decrease their importance.

The ore as taken from the mine averages about $7 a ton. Occasionally ore running only $5 a ton is removed, but this is only done when it is obtained with little additional expense while driving levels and stopes.

At the 920-m. level a pocket of ore containing about $2.50 a ton was recently found in the overlying itabirite, which is of considerable interest, as previously no gold has been found in that rock by the present company. However, in the early days considerable mining was done in the itabirite in this vicinity, as shown by the extensive dumps.

Much cyanite is found in the quartzite a short distance below the black lodes, but no gold. When the cyanite is encountered, no further search is made for ore. However, near Ouro Preto, a few miles distant, numerous quartz veins have been worked in such rock.

The ores have been formed by ascending highly heated waters that replaced the quartzite, and in places one can see the lines of stratification passing from the quartzite into the orebodies, both the black and also the white lodes. The presence of some minerals commonly found in pegmatites indicates that the veins are, in part, at least, of a pegmatitic character and somewhat different from the ordinary quartz veins. There is no doubt of the continuity of the orebodies to depths below the levels now being worked.

At the 770-m. level a disturbed zone has been encountered that in direction corresponds with a prominent valley cutting across the country. There are here numerous folds and a few small faults, so that it is difficult to keep the inclined shaft in the foot wall a short distance beneath the orebodies except by occasional changes in slope. The value of the ore in the disturbed area is lower on account of much rock being mixed with it.

The mine is worked by means of three inclined shafts that start at the mill and diverge underground. Cross-cuts from the shafts are driven, keeping near the contact of the quartzite and itabirite. When ore worth stoping is encountered, a 6-ft. slice is taken above the drift level and the old openings are filled as the work advances. Practically no timber is used in the mine, the *guia* forming a good roof in most places, but where it is broken through the itabirite scales off badly. The rock used for filling consists of the quartzite in part obtained in running drifts in search of the black lodes. The quartzite breaks readily into thin slabs well adapted for the construction of retaining walls and arches. In the upper levels there is some water, but this is carried out through a tunnel into the deep gorge that cuts through the property.

The gently inclined shafts, following the orebodies and approximately parallel with the slope of the hill, have been extended so far from the mill that a vertical shaft has recently been sunk which strikes the ore horizon at a depth of about 200 m.

The power for mine and mill is supplied from the Carmo River. During the dry season the supply is inadequate so that a new hydro-electric plant is in process of construction a short distance below the mill. A ditch and tunnel are being excavated along the side of the stream through which the water will be diverted and a 120-ft. fall obtained that will furnish an additional 500 h.p.

The mill is picturesquely situated along one side of the gorge of the Carmo River, which Derby likened to Watkins Glen. The lower part of the mill almost fills the gorge, and as it is extended, as it will be soon, it will entirely bridge the river.

No new features are involved in the mill. After passing across a picking table, where about 10 per cent. is rejected, the remaining ore is passed over a grizzly with 2-in. openings. The oversize passes through a Blake crusher and then, joining the undersize from the grizzly, is fed to the stamps. The pulp from the stamps passes over blankets 4 ft. long and 20 in. wide, where much of the coarser sulphides and gold is collected. At intervals the flow of pulp is shut off while boys replace the old blankets with clean ones. The further mechanical treatment consists of passing the material over vanners where fine sulphides and gold are collected. The final process of gold recovery is by cyanidation.

During 1914 there was a total of 80,138 tons of ore treated in the mill from which 27,085 oz. of gold were recovered. This bullion sold for $556,800, an average of a little less than $7 per ton of ore milled. The reserves on Dec. 31, 1914, were 112,678 tons.

Matto Grosso.—Gold was discovered in what is now the State of Matto Grosso in the forepart of the Eighteenth Century and mining has been carried on ever since. The State ranks next to Minas Geraes in its gold production. Practically all the gold has been obtained from stream placers or from Quaternary gravels (in some places cemented by iron to form a ferruginous conglomerate) that cover some of the uplands.

Gold is found in scores of streams (innumerable as one Brazilian writer expresses it) throughout the State but particularly near Cuyabá. During Colonial days the shallow streams were worked mainly but at present several large dredges have been built for working in the deeper streams. Most of these are owned by English or Argentine capital. It is believed that some of the dredging operations will prove to be highly remunerative.

Lode mining has only been carried on to a small extent. While many different lode mines have been operated most of them are extremely shallow workings. The gold occurs in quartz pyrite veins.

Bahia.—Branner (21) has given brief descriptions of the places where gold has been worked in the State of Bahia. Some gold is usually obtained in washing for diamonds but much less than in the diamond fields of Minas Geraes. Both placer and lode mining have been carried on near Jacobina. In the southern part of the Serra do Assurua gold occurs and some mining has been done near Gentio. Placer mining has been carried on at Caldeirão and in the vicinity of Rio de Contas.

Up to the present time the gold mining industry of Bahia has been of little importance.

Goyaz.—Although the auriferous gravels of Goyaz were discovered nearly 200 years ago and the sum total of gold produced is no doubt considerable, the gold resources of the State are even yet imperfectly known. Gold has been found in numerous streams and also many lode mines have been worked but the operations have been small. Little has been done since the abolition of slavery in 1889, the bulk of the gold being produced by the individual miners washing the gold from the stream gravels with their wooden *bateas*.

Rio Grande Do Sul (137).—The principal gold deposits thus far investigated in the State of Rio Grande do Sul are near Lavras, about 37 miles north of Bagé.

"The gold occurs, principally, in the syenite rock in small stringers of quartz and impregnations (stockworks) in the enclosing rock on each side of them. . . . The mineralization is irregular, and generally limited in area, the rock being found to be very rich in places but often pockety.

"Galena, iron pyrites and zinc-blende occur associated with the gold, the first-named being considered a good guide for auriferous ground, although as a matter of fact no rule can be established, as non-auriferous galena is common.

"At São Sepé, 22 miles northwest of Caçapava, auriferous quartz veins are plentiful over an area 12½ miles long by 4 to 6 miles broad. . . . The quartz veins vary in thickness from 1½ to 6½ feet and are fairly easy to follow, as compared with the stringers found in the syenite at Lavras . . . Near the village of Dom Pedrito, situated 37 miles to the southwest of Lavras, the Barcellos Gold-mining Company worked some auriferous deposits about 15 years ago." [About 1888.]

None of the operations described by Scott has been especially successful.

Pará.—In the territory bordering French Guiana in Northern Pará gold placers have been found over an area of about 150 square kilometers on the head waters of the Cassipore River. Active work began at Calcoene in 1893 and at one time about 6,000 men were employed. The project was not a success and only a few natives of the section are now engaged in gold washing. No paying lodes have been found.

Maranhão.—Considerable gold is annually brought by the Indians from the Tury-assú River in the State of Maranhão but the value and extent of the deposits are unknown.

IRON

For the International Geological Congress held in Stockholm, Sweden, in 1910, Orville A. Derby prepared a report on "The Iron Ores of Brazil" (56) which drew the attention of the entire world to the enormous deposits of high-grade iron ore which the country possesses. Earlier published accounts seem to have attracted less notice. Derby was cautious in the estimates which he made but did express the opinion that there were about 6,000,000,000 tons of hematite ore containing 50 per cent or more of iron in the State of Minas Geraes, of which one-third was much richer. At the time, this estimate seemed to most geologists excessive but subsequent workers in the region have made estimates of 12,000,000,000 tons for the hematite ores of Central Minas Geraes alone. These figures, however, are probably excessive. Harder estimates that the Central Minas Geraes region, roughly 100 miles square, contains in the thirty known deposits 410,000,000 long tons of Bessemer ores with over 68 per cent iron and less than 0.02 per cent phosphorus and almost 3,000,000,000 long tons of non-Bessemer ores with over 50 per cent iron and 0.05 to 0.3 per cent phosphorus. The largest single deposit contains at least 500,000,000 tons. When one realizes that supposedly extensive deposits are known to occur elsewhere in Minas Geraes, in Bahia, Espirito Santo, Matto Grosso, Goyaz, São Paulo, Paraná, Santa Catharina, and Rio Grande do Sul it becomes apparent that without much doubt Brazil contains the most extensive undeveloped deposits of iron ore of any country in the world.

The Iron Industry of Brazil.—Notwithstanding the fact that Brazil contains such an abundance of iron ore, no iron industry of any consequence has been developed and the larger proportion of iron used in the country is imported from foreign countries. This is due mainly to the lack of coking coal. In a few places in the Minas Geraes iron ore district the loose specular-hematite ores are being worked and iron is made in small forges. The loose ore, consisting of extremely fine bright flakes, is put into a small furnace and mixed with charcoal. At intervals more ore and charcoal are added until finally a ball of iron and slag is formed. This is then pounded by a trip hammer run by a waterwheel until the slag is largely removed. There are said to be a number of forges of this kind throughout the iron region, but thus far the attempts to smelt the iron ores in blast furnaces have not met with success, even though the Brazilian government has probably offered greater inducements than any other government has ever done to encourage this industry. There are three charcoal furnaces in the region one of which, located at Esperanza, has been in operation for many years.

Distribution of the Iron Ores of Brazil.—Although iron ore specimens of good quality have been brought from every State in Brazil little or no information is available concerning the character or extent of most of the deposits. In many cases the specimens have come from regions remote from the railroads and from thinly inhabited sections densely covered with tropical vegetation so that it is not surprising that so little is known concerning their occurrence. As a consequence the following descriptions include only the principal iron ore districts of the country.

Magnetite Ores.—The first iron ores worked in the country were the magnetite ores of São Paulo. but despite numerous attempts to utilize these they are still practically undeveloped. Many of the magnetite ores are high in titanium and consequently of less value.

Derby (42) has given a good description of the best known magnetite deposits of the country which are located at Ipanema and Jacupiranga in the State of São Paulo. The two districts are about 90 miles apart on opposite sides of the Serra do Mar. The Jacupiranga deposits are located in a region of low hills not far from the ocean while the Ipanema ore bodies occur in the center of an isolated mountain block on the northwest side of the Serra do Mar. The principal rocks in both places are schists of various kinds while the ore-bearing rocks have been called jacupirangite by Derby.

"The rocks included under this title are allied to the nepheline-bearing series and present the various types of pure magnetite, magnetite with accessory pyroxene, pyroxene with accessory magnetite, and pyroxene and nepheline with biotite and olivine accessory or (in the case of the former at least) essential elements. All these types are most intimately associated as parts of the same mass and the gradual passage from one to the other has been most satisfactorily proven."

At Ipanema the rock is greatly decomposed and blocks of high-grade ore occur in a clay resulting from the decomposition of the rock-forming minerals. The titanium content of the Ipanema ores is fairly low while the Jacupiranga ores contain as much as 20 per cent TiO_2.

At São João Baptista west of Oliveira station on the West of Minas Railroad, in south-central Minas Geraes, are some non-titaniferous magnetite ores composed of practically pure magnetite as shown by an analysis of the ore. The deposits are said to be extensive.

A string of deposits of magnetite ore estimated to contain 6,000,000 tons is located at Antonina, in northeastern Paraná only about 3 miles from a seaport. The principal one is Bom Retiro do Mundo Novo. Harder (82) describes the ore as occurring in the form of lenses within an igneous rock resembling diorite. The ore varies from almost pure ore to mixtures of rock and magnetite. Some of the ore is high in manganese, occasional samples containing as much as 25 per cent. An analysis made by H. K. Shearer is as follows:

	Per cent
Fe	64.00
P	0.031
SiO_2	6.94
H_2O (combined)	0.63
Mn	0.20

In the State of Santa Catharina, about 16 miles southwest of Joinville, and near the coast are a number of lenses of magnetite ore briefly described by Harder (82). An outcrop sample gave the following analysis:

	Per cent
Fe	71.30
P	0.041
SiO_2	0.45
H_2O (combined)	0.19
Mn	0.43

Of the other magnetite deposits little is known. Promising deposits are reported near Theresopolis in the State of Rio de Janeiro and in Espirito Santo. In view of the fact that the hematite deposits are richer and far more extensive it is not probable that the magnetite deposits of the country will receive much attention for many years to come.

Hematite Ores.—The hematite ore deposits of Central Minas Geraes have been carefully studied during the past decade and

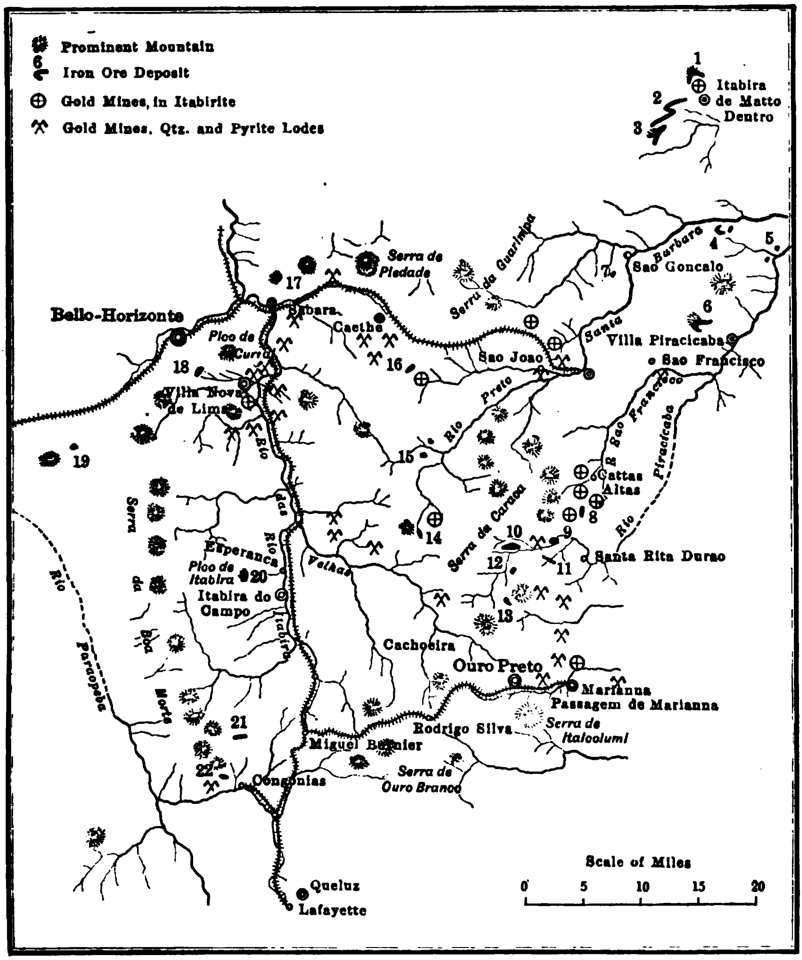

FIG. 19.—Map showing the location of the principal iron-ore deposits and gold mines of Minas Geraes. (*After Harder.*) 1. Caue. 2. Esmeril. 3. Conceicao. 4. Andrade. 5. Monlevade. 6. Morro Agudo. 7. Cocaes. 8. Bananal. 9. Morro da Mina. 10. Alegria. 11. Fabrica Nova. 12. Germano. 13. Timpopeba. 14. Capanema. 15. Mutuca. 16. Gongo Soco. 17. Gaya. 18. Aguas Claras. 19. Jangada. 20. Catta Branca. 21. Fabrica. 22. Casa de Pedra.

probably more definite information is available regarding these than any other mineral deposits of Brazil. These investigations have been made by Scott, Derby, Leith, Harder, Chamberlin, and Gathmann mainly, although many other geologists and mining engineers have visited the region.

Harder and Chamberlin (81) have proposed the following geologic classification for the district.

Tertiary and Quaternary.
- River gravels.
- Tertiary clay and lignite.
- Canga deposits.

Mesozoic or Early Tertiary.
- Diamantina conglomerate.

Probable Algonkian.
- Itacolumi quartzite.
- Piraçicaba schist and quartzite.
- Itabira iron formation.
- Batatal schist.
- Caraça quartzite.

Probable Archean.
- Gneiss, granite, and schist forming the basement complex.

Basement Complex.—These old rocks are imperfectly understood as they require more detailed study than they have yet received. They include a great variety of granites, gneisses, and schists, representing different kinds of originally igneous and sedimentary rocks that have undergone varying degrees of metamorphism.

Caraça Quartzite.—The base of the supposedly Algonkian strata consists of a great series of quartzites or quartzitic schists ranging in thickness up to 5,000 feet and widely distributed throughout the iron, gold, and diamond regions of Minas Geraes. It is called the Caraça quartzite from the Serra do Caraça in which the highest ridges are composed of this formation.

The most common phase of the Caraça quartzite is a light colored more or less metamorphosed sandstone in which cross-bedding is common. Grains of sericite or muscovite are abundant and, in places, the micaceous minerals constitute the greater part of the rocks producing white sericite or muscovite schists. It is not unusual to find layers of schists showing evidences of crumpling interbedded with the slightly deformed quartzite layers. In places the rocks are decidedly arkosic while pegmatites and quartz veins are numerous. Where the schistose phases are not particularly abundant the formation resists erosion so well that it forms the higher ridges of the region.

Batatal Schist.—Overlying the Caraça formation is a layer of argillaceous schists less than 100 feet in thickness seldom conspicuous as outcropping beds because of the ease with which it is worn away by erosion, known as the Batatal schist.

Itabira Iron Formation.—The formation most important economically is the Itabira iron formation named from Itabira Peak where the formation is particularly rich in iron. Its thickness varies greatly, even within short distances, with a maximum of about 4,000 feet. It consists of an intimate admixture of fine quartz sand and iron oxide, either finely laminated or massive. Ferruginous schists are also common in the formation.

Piraçicaba Formation.—The iron formation is overlain by a thickness of 1,000 feet or more of argillaceous schists, quartzites, and limestones, with some iron oxide layers. It is widespread throughout the region.

Itacolumi Quartzite.—The Itacolumi formation receives its name from Itacolumi Peak near Ouro Preto. At that point it is about 5,000 feet in thickness. The formation closely resembles the Caraça quartzite lithologically and, in many cases, the two have been correlated as the same unit. The occasional layers of flexible sandstone found in the same region have received the petrographic designation of itacolumite, but one usually looks in vain for as fine specimens of this interesting rock as have been found in North Carolina.

Diamantina Conglomerate.—Following the deposition of the last named formation, long periods of time elapsed in Minas Geraes during which mountains were uplifted and eroded away to their bases. In some parts of the country sediments were deposited at different times during the Paleozoic, but in the mineral districts of Minas Geraes these are absent. During the Mesozoic or, perhaps, early Tertiary, large areas were reduced to a peneplain and on these flat surfaces, particularly in old river channels, deposits of sand, gravel, and clay accumulated. Most of these have now been removed but, in places, they are still preserved on the uplands or *chapadas*. In general they have become consolidated and are termed the Diamantina conglomerate. Diamonds are found in these deposits as well as in the more recent sediments along the present streams.

Tertiary and Quaternary Deposits.—The latest deposits constitute the *canga*, made up of fragments of iron ore and itabirite cemented together; the Tertiary clays and lignites which occur in restricted localities; and the gravels and finer sediments of the stream terraces, floodplains, and stream beds.

Distribution and Character of the Ore Deposits.—The hematite ores form a part of the Itabira iron formation which is extensively developed in Central Minas Geraes (Fig. 19). The known ore bodies of importance are distributed over an area about 100 miles in length with a northeast-southwest trend and about 60 miles in width. They are located in a hilly region, a few thousand feet above sea level, drained by the headwaters of the Piraçicaba, Carmo, das Velhas, Santo Antonio, and Paraopeba rivers. In places the vegetation is dense along the streams while the higher portions are covered with scrub timber, low shrubs, or grass. The ore bodies may be regarded as a facies of the itabirite in which the grains of quartz sand are lacking. The itabirite itself might be called a lean iron ore as it usually contains more than 30 per cent iron but arbitrarily 50 per cent iron in that district is commonly regarded as the lower limit of the iron ore.

Fig. 20.—Typical view in iron district; foreground covered with *canga;* lower dark-colored hills composed of hard iron ore.

Harder (82) has proposed the following classification for the iron ores of the region.

Original or Bedded Ores.
- Hard massive ore.
- Soft powdery ore.
- Laminated or thin-bedded ore.

Concentration Ores.

- **Canga.**
- **Stream sand and gravel ores.**
- **Rubble ore.**
- **Enriched itabirite.**
- **Leached carbonate.**

The class of original or bedded ores includes the ores that have undergone little or no change since pre-Cambrian time when they assumed their present characteristics through regional metamorphism. The hard massive ore is the best ore of the region and almost everywhere forms hills as it has better resisted the forces of erosion to which the region has been subjected for vast periods of time. It consists, for the greater part, of compact specular hematite in which it is difficult to distinguish between the bedding planes and joint planes. In places amorphous hematite is prominent while some martite and magnetite are occasionally noticed. The average of 89 analyses of this ore, given by Harder is as follows:

	Per cent
Fe	69.65
P	0.0125
SiO_2	0.24
H_2O (combined)	0.38

Hard ore occurs in large masses where millions of tons could be quarried with practically no waste.

The soft ore is abundant in places and consists of minute flakes of specular hematite, so finely divided that nearly all will pass through a 100-mesh screen. Naturally this ore could not be readily shipped but at present it is more generally used than any of the other ores in the small forges throughout the district. This type of ore is commonly known as the "jacutinga" ore although the term was originally intended to apply only to this material where it contained gold or gold quartz stringers together with some other minerals. In places it is so loose that one can dig a hole in it with the bare hands as in a loose sand bank. In working the gold ores much of this ore was washed down the slopes into the stream valleys where it forms great banks containing thousands of tons of ore.

In composition the loose ores differ from the hard ores in that the iron content averages a few per cent less with a corresponding increase in the amount of silica.

The laminated ore shows more prominent bedding planes and is more porous than the massive ore. It contains more amorphous hematite and limonite than the types described above and is slightly lower in iron. Most of it is a non-Bessemer ore with the phosphorus running as high as 0.3 per cent in certain places.

All three kinds of the bedded ores may be found in the same deposit interbedded with each other or with itabirite or any one kind may be found by itself in large masses. The amount of laminated ore is considerably in excess of the other two kinds.

The concentration ores are formed from the ores previously described through disintegration or alteration of the original iron formation. The most prominent type of this class is that known as "canga." This consists of rounded to angular fragments of the hard massive or laminated ores cemented by limonite or hematite. It is present on the lower slopes of the iron ore hills or spread out on the level areas where it may cover several square miles continuously. In places it is from 50 to 60 feet in thickness, although commonly less than 10 feet.

In composition the canga ore is extremely variable as pieces of itabirite and other rocks may be included, especially where it is underlain by other rocks than the iron ore. Harder's analyses show that the better grades of canga contain from 50 to 60 per cent of metallic iron and from 0.1 to 0.3 per cent phosphorus.

Derby estimates that there are about 2,000,000,000 tons of canga ore containing 50 per cent or more of metallic iron.

Along many streams in the iron ore country almost all the loose sands and gravels consist of iron minerals, principally specular hematite. In one place where the writers examined a sand bank along a small stream it seemed as though 95 per cent of the sand consisted of specular hematite. Although in places these deposits are high enough in iron to be regarded as ore their variability prevents them from being considered as of any value under present conditions.

Loose boulders of iron ore along the hill slopes constituting the rubble ore are also of little value.

In the iron country the outcropping beds of itabirite locally have had most of the silica removed by solution and limonite has been deposited in its place, resulting in the formation of workable ore.

In the Piraçicaba formation some beds containing considerable quantities of iron and manganese carbonates have yielded workable residual deposits of iron and manganese oxides through surficial decomposition.

Origin of the Hematite Deposits of Minas Geraes.—The origin of these high-grade iron ores naturally calls for other than the usual explanations. Gathmann, Leith, Harder, and Chamberlin have proposed explanations. The hypothesis of Harder and Chamberlin seems most probable. They believe that the iron ore beds represent original sedimentary strata and that the iron was precipitated in the form of iron hydroxide from waters containing iron carbonate either through chemical

FIG. 21.—Outcropping ledges of high-grade iron ore.

action or more likely through the activity of iron bacteria. Where streams carried down mechanically suspended débris, itabirite or sandstones were formed while the purer iron ore beds were deposited in places where the waters were clear and terrigenous materials practically absent. The change to specular hematite, or occasionally magnetite, was brought about by regional metamorphism.

The evidence for original deposition as claimed by Harder consists of (1) the interbedded relation of the various kinds of iron ore as lenses with the itabirite, (2) the interbedding of the itabirite with unaltered limestone, a rock which would naturally be the first to suffer through replacement, and (3) the continuity of the ore beds in depth with little or no change in composition.

Economic Condition Affecting the Use of the Minas Geraes Hematite Ores.—Notwithstanding the liberal inducements which the Government has offered for the development of an iron industry in the country, little progress has been made. The industry cannot be built up by using charcoal for smelting; coking coal would have to be brought from North America, Europe, or possibly Colombia; while water power for electric smelting is scarcely sufficient except in a few localities. It seems as though most of the ores must be shipped to foreign countries for smelting. As the ore bodies are distant from shipping ports from 250 to 350 miles, and the only road that traverses the district, the Central Railroad of Brazil, is not suitable for hauling a large tonnage of ore, it becomes apparent that for the present these rich ores are not available. The time will come, however, when a suitable railroad will be built into the region from Victoria, and then the richest deposits of iron ore known will be developed.

Until 1910 nearly all the ore bodies belonged to Brazilians but since then many of the most important have passed into the possession of North American, English, French, and German capitalists. Although the bulk of the Brazilian iron ores seem destined to go to Europe or North America, Brazil will profit immensely by their utilization and ultimately an iron and steel industry sufficient to meet the country's needs is almost certain to develop through the importation of the necessary coke brought back by the ore-carrying fleet of vessels.

Other Hematite Ore Regions.—While it is improbable that there are any other hematite iron ore districts in Brazil comparable to those of Central Minas Geraes, hematite ore associated with itabirite is known to occur in the western part of Minas Geraes, along the São Francisco River and near the Pernambuco border in Bahia, in Central Goyaz, and in the Urucum mountains near Corumbá in Matto Grosso in association with rich manganese deposits. Scattered hematite deposits associated with itabirite have recently been reported in Ceará about 50 to 60 km. west of Camocim and about 15 km. from the coast. Little is known of any of these regions but the geological conditions are said to be similar to those occurring in Central Minas Geraes.

MANGANESE

Manganese, at the present time, is the most important of the mineral products of Brazil and has recently been extensively worked in several places in the country. Although deposits of this useful metal were known to exist many years ago, so far as known the first shipments were made in 1894. Every year since considerable quantities of manganese ore have been shipped to Europe and North America and present indications point to a steady increase in the annual production for many years to come.

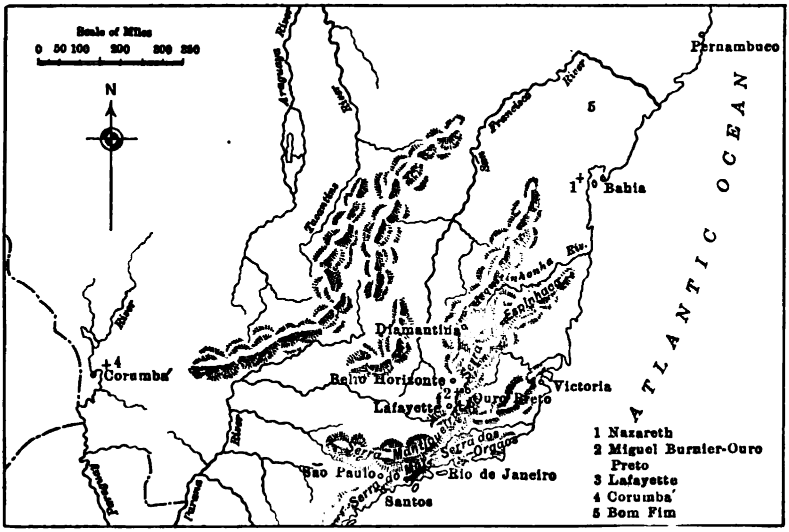

FIG. 22.—Map showing the principal manganese deposits of Brazil. (*After Harder.*)

The absence of an iron industry of importance, due mainly to the lack of suitable coal, necessitates the shipment of the manganese ore to foreign countries. During the first years of the European war the steel industry of North America was almost entirely dependent upon Brazilian manganese ores and it is probable that even after the close of the war North America will continue to look to Brazil for a considerable part of its manganese ore.

Manganese ores are reported to occur in the following states: Bahia, Maranhão, Matto Grosso, Minas Geraes, Paraná, Pernambuco, Rio de Janeiro, Rio Grande do Norte, Santa Catharina, and São Paulo. Deposits in Bahia, Matto Grosso (Fig. 22), and

Minas Geraes have been worked and will be described in detail. Little information is available in regard to the manganese deposits in the other states mentioned. The occurrences of Paraná are located near Curityba and Paranagua, those of Pernambuco near Goyanna, and those of São Paulo at Perus.

Particular attention was first drawn to the manganese deposits of Brazil in 1888 when a body of ore was encountered near Miguel Burnier, Minas Geraes, in a railroad cut during the construction of the Ouro Preto branch of the Central Railroad of Brazil. At that time conditions were such that no attempt was made to work the deposits, but in 1893, Mr. Carlos da Costa Wigg obtained possession of a tract of land near Miguel Burnier and in 1894 began active production. In 1897 a second and in 1899 a third firm began operations in the same region. Since then many other mines have been operated in the same vicinity. Soon after the opening of the first mines near Miguel Burnier several other manganese deposits of different character were discovered near Lafayette about 18 miles distant where mining started in 1900. These two centers have probably yielded to date considerably more than 95 per cent of the total manganese production of the country.

In 1899 the Pedras Pretas mine near Nazareth, Bahia, began production. A promising deposit at Urucum, Matto Grosso, has been prospected but has not been actively mined.

The total manganese production to the close of 1917 amounted to approximately 4,000,000 long tons. In 1916 the production was 495,172 long tons, more than twice as much as that of any year before the War. The remarkable increase in production since 1914 has been due to the unusual demand from the steel companies of the United States on account of the shutting off of the supplies which formerly came from Russia and India because of the War.

Manganese Deposits of the State of Minas Geraes.—The manganese ores of Minas Geraes are of two distinct types, occurring in separate but not far distant districts. The older district centers about Miguel Burnier, which is a station on the Estrada de Ferro Central do Brazil, 496 km. north of Rio de Janeiro, and parallels the branch line that runs from there to the ancient mining town and former capital of the state, Ouro Preto. The other district centers about Lafayette or Queluz on the same railroad at kilometer 463. The centers of the two districts are consequently but 20 miles apart. The former lies at the southern edge of the great iron-ore region of Minas, and the latter a short distance to the south of it.

Miguel Burnier District.—The manganese deposits of this district extend in a narrow belt with a nearly east-west direction from the Bocaina mine, which lies about 1½ miles southwest of Miguel Burnier to Ouro Preto.

Mr. Wigg started mining manganese ores in 1894 on what is known as Section 6 of the Wigg estate, and has the distinction of being the first person to work manganese ore in Minas Geraes. The first mine, located on a hill on the north side of the railroad at Uzina station, 3 km. east of Miguel Burnier, was worked continuously until about 4 years ago, when the opening had become so deep and so much water had to be contended with that it was finally abandoned. The output, aggregating about 100 tons per day, comes principally from Section 9, which lies 1 mile east of Uzina, and is supplemented by small amounts from a number of openings between Uzina and Miguel Burnier and from the Bocaina mine.

The Miguel Burnier manganese ores occur in the Itabira iron formation which is a sedimentary series of probable Algonkian age. It is the same formation that includes the great iron-ore deposits of this part of Brazil. In the vicinity of the manganese mines, it shows a rapid succession of itabirite, micaceous schist, calcareous schist, and limestone. Most abundant is the itabirite; the limestone occurs at various horizons in the shape of lenses of limited extent, sometimes in schist, at other times intercalated between schist and itabirite, and then again wholly inclosed in itabirite. The limestone is dolomitic, ferruginous and manganiferous.

There is some difference of opinion as to the relations of the manganese deposits to this series of rocks. According to one view they represent replacements and residual enrichments through the agency of atmospheric waters of some of the manganiferous limestone lenses. Harder and Chamberlin, on the other hand, look upon them as syngenetic deposits laid down as a part of the sedimentary series in the same manner as the iron ores. They mention the occurrence of the carbonate rocks but state that they occur at different horizons from the manganese beds.

Our observations lead us to the conclusion that the ores do not occur at any definite horizons, but are coextensive stratigraphically with the limestone lenses, and like them are lenticular in shape. Though it cannot be stated positively that they are not of sedimentary origin, it seems that they represent replacements of the limestone lenses. At all the mines visited, the inclosing wall rock, which is usually itabirite, has been subjected to considerable alteration under the action of descending waters, and where the schist is present it has been altered to residual clay. The alteration is most pronounced in the hanging-wall rock. It seems very likely, therefore, that the ore bodies represent replacements of carbonate rock intercalated in these strata.

At the Section 9 mine, the width of the manganese bed is from 1 to 1½ meters, and it has been developed for a length of 600 meters. At other places the width of the ore body is somewhat greater, as at the Uzina mine, where it had a maximum width of over 2 meters. The mines are usually started as open cuts, but on account of the narrowness of the ore bodies they run into depth so rapidly that underground mining must soon be substituted. The soft decomposed character of the wall rock makes the ground exceedingly heavy and calls for considerable timbering.

The ores consist for the most part of amorphous or finely crystalline compact manganese oxides, with which are associated many lumps and concretionary forms similar to those so common in the brown iron ores. There is also a certain amount of soft earthy material present. Psilomelane is probably the most abundant mineral and mixed with it is considerable pyrolusite. The ore is very high grade, averaging 50 per cent manganese, 1 per cent silica, and 0.03 to 0.05 per cent phosphorus.

The Rodeio mine lies on the south side of the Ouro Preto branch and is connected with the station Metallurgica by an aerial tram. It has been operated during the past five years by directors of the same company that owns the Morro da Mina mine under the name of Companhia Metallurgica, and has a monthly output of 1,000 to 1,200 tons. The ore body is associated with carbonate rocks but the relation of the ore to the enclosing rocks is not well shown.

Under the stimulation of war prices, a number of other manganese mines have been opened up along the Ouro Preto branch of the railroad as far as Ouro Preto and even a short distance beyond.

The ores are all of the Miguel Bürnier type as are those now being actively worked in the adjoining districts of Santa Barbara, Bello Horizonte, and on the property of the St. John del Rey Mining Co., Ltd.

Gandarella District.—About 35 miles north of Ouro Preto, Michaeli (115) has described several occurrences of manganese ore along the Lignito, Maquine, and Gandárella brooks. The ore occurs in decomposed schists associated with itabirite and limestone, similar to the ores of the Miguel Burnier district. A few excavations were made to determine the character of the ore and the extent of the ore bodies. The results seem to indicate the presence of a considerable body of ore. In one place where a stream cuts across the ore body a thickness of 65 feet of ore is exposed. Fine specimens of ore found in the soils of the region indicate the presence of other ore bodies than those observed. Mines have recently been opened in this district.

Lafayette or Queluz District.—Manganese deposits were discovered in the Lafayette district immediately after the inauguration of mining operations in the Miguel Burnier district stimulated a search for manganese ores in Minas Geraes, but it was not until the year 1900 that the district became a regular producer, an output of 31,000 tons coming from the Piquery and São Gonçalo Mines in that year. This was increased to nearly 75,000 tons the following year, a production considerably in excess of that of the entire Miguel Burnier district. In 1902, the Morro da Mina came in as a producer and firmly established the district as the chief manganese-producing district of Brazil.

Lafayette is a station, located at the edge of the town of Queluz, on the Estrada de Ferro Central do Brazil, about 32 km. south of Miguel Burnier and 463 km. from Rio de Janeiro. From the fact that the most important producing mines have been located in its vicinity the district has been generally referred to as the Lafayette district. The most important mine at present is the Morro da Mina, owned and operated by a Brazilian company, the Companhia Morro da Mina, which has increased its production to 700 tons per day. It is located 7 km. northeast of Lafayette. On the same hill, a German company under the name Mineração de Agua Preta has been working the rubble ores to the east of the Morro da Mina ground. This company is producing at the rate of 2,000 tons per month and in the 8 or

9 years it has been operating has produced a total of over 200,000 tons. On a small hill to the southeast of the Morro da Mina, the extension of that zone is being developed by a company known as the Companhia Queluz das Minas. The Cocuruto mine lies about 40 km. southwest of Lafayette and is connected with the railroad at Christiano, a station 23 km. further south, by a 60-cm. gauge line 40 km. in length. This mine has been operated about 10 years. It is owned by a Belgian company, the Société Anonyme de Manganese de Ouro Preto, which formerly worked the São Gonçalo Mine. After each had produced about 250,000 tons of ore, the São Gonçalo and Piquery mines were abandoned 10 years ago as worked out but the former is now being worked again. They were located about 15 km. northwest of Lafayette. The Piquery Mine is of particular interest in that it is the only one of which there is an adequate geological description and it was there that Derby obtained the first evidence of the original character of the manganese rock from which the ores were derived.

In addition to those mentioned, there are the Sabina and Paiva mines which are in operation and a number of other deposits that have been discovered and prospected to some extent, but apparently the results were not favorable enough to warrant further development. It is probable, however, that the district has not been thoroughly prospected and there is every reason to expect that systematic exploration would discover deposits equal to those that have been found.

The geology of the Lafayette district differs markedly from that of the Miguel Burnier in the complete absence of the calcareous and ferruginous beds so prominent in the latter district. It lies to the south of the area underlain by the great iron-bearing series, and its ores are found in the rocks forming the basement complex of supposed Archean age which underlies a large part of the state of Minas Geraes. The rocks making up this basement complex are chiefly granite and gneiss with which are associated amphibolite, and micaceous and quartzose schists. There are also small intrusions of diorite and gabbro, mostly in the form of dikes. The granite seems to be intrusive into the gneiss and schist, but the relations between the schist and gneiss are not clear.

The manganese deposits occur as elongated masses of more or less lenticular shape within the rocks of the basement complex.

They represent residual products of decomposition of an original manganiferous rock made up of manganese carbonate and silicates. The immediate wall rock of the deposits has likewise undergone decomposition, in many instances being nothing more than a clay in which the original rock texture is poorly preserved, so that it is usually difficult to determine its original character. In most cases, however, it seems to have been either gneiss or schist. The contact of wall rock and ore generally appears to be quite sharp, but closer examination often reveals small nests and stringers of manganese oxide in the decomposed rock. There are also horses of decomposed rock of the same character within the ore bodies themselves.

The geological relations of the Piquery ore body have been described by O. A. Derby in two papers published in 1901 (47) and 1908, (53) and the following account is abstracted from them.

"The Piquery orebody presents the appearance of a mass of secondary material, or gossan, resulting from the alteration of a vertical dike or vein, some 10 or 12 m. wide. . . . The ore is a hard spongy black oxide, apparently consisting for the most part of psilomelane but with an admixture of other oxides that frequently occur in beautiful crystallizations in the spongy cavities. . . . In the midst of the merchantable ore occur inconstant bands and patches of hard siliceous material with the appearance of a quartzite, but which on examination proves to be composed almost exclusively of a finely granular mass of ashy white manganese garnet. A complete series of alteration phases between perfectly typical garnet rock and merchantable ore can be readily selected, and there can be no doubt that the latter results from the decay and leaching of the former."

Derby describes three phases of the garnet rock that he observed in 1901:

"1. A very fine-grained, compact and finely jointed rock of bluish-gray color with partings lined with asbestos. Under the microscope the rock is seen to be composed almost exclusively of closely appressed idiomorphic grains of white garnet showing a clear border but with the center highly charged with a fine black opaque powder that appears to be graphite. . . .

"2. A dark brown rock heavily charged with manganese oxide and too friable to permit the preparation of microscopic sections is evidently of the same type but more completely decomposed. . . .

"3. A milky white rock which under the microscope is seen to be composed of about equal parts of garnet and quartz. . . . The quartz in a fine mosaic about the garnet grains and in minute refilled joints is almost certainly secondary."

Residues of manganese garnet were likewise found by Derby at the São Gonçalo, Morro da Mina, Agua Limpa, and Barroso mines. The last two mines were located about 10 km. southeast and 9 km. south of Lafayette respectively.

ANALYSES OF ORIGINAL MANGANESE ROCK AT PIQUERY

	I	II	III
CO_2	22.62	4.59	
SiO_2	11.80	27.69	38.47
MnO	47.52	57.48	27.90
Al_2O_3	7.50	1.41	21.07
Fe_2O_3	.....	2.48	7.38
CaO	3.76	1.82	4.70
MgO	6.27	4.60	
	99.47	100.05	99.52

The Morro da Mina Mine is located on a hill 2 or 3 miles north of the town of Queluz, which has an elevation of 1,110 m. above sea level and rises to a height of 200 m. above the surrounding country. A branch line of the railroad connects the mine with the Estrada de Ferro Central do Brazil at Lafayette, so that the ore can be loaded into the cars at the mine and requires no further handling until transferred to ships for exportation at Rio de Janeiro. The mine presents one of the most remarkable manganese deposits in the world both in respect to size and quality of the ore. Since it became an important producer in 1902, it has yielded a total of over 1,500,000 tons, and in 1915 its production was about 200,000 tons. Development work has proved an ore reserve of 10,000,000 tons, according to the manager of the property. The estimate is probably a very liberal one.

The orebodies occur at the top and on the flanks of the hill as a series of more or less overlapping lenses extending in a direction N 35° W, with a vertical dip and a pitch of 45° to the southeast. The relative positions, shapes, and sizes of the orebodies that have been developed as they occur on the level 55 m.

below the top of the hill are shown on the mine map in Fig. 23. The four largest are known as Zona I, II, III and IV respectively and have maximum dimensions of 200 by 30 m., 420 by 120 m., 140 by 70 m., and 100 by 20 m. In depth Zona I and Zona II have been cut by a development tunnel 130 m. below the summit of the hill, indicating that the ores extend at least that far down. In addition to the ores *in situ*, a large part of the hillside below the ore outcrops is covered with rubble ore derived from them.

The ore consists for the most part of psilomelane, which occurs in a variety of forms. Most commonly it is simply more or less drusy massive psilomelane, but mammillary, botryoidal, and concretionary forms are abundant and frequently quite elaborate. The surface of some of these, except for the black color, reminds one of cauliflower. Associated with the psilo-

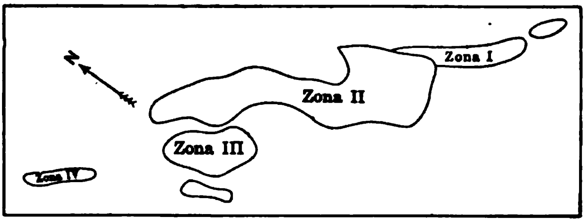

FIG. 23.—Horizontal section of Morra da Mina ore bodies at 55-meter level.

melane is considerable manganite and pyrolusite which occur for the most part as cavity lining and fillings in the former. The manganite occurs lining the cavities both in radiating groups of acicular crystals and in distinct prismatic crystals. The pyrolusite is often pseudomorphic after manganite showing that it has in part been derived from it. The average composition of the ore as shipped is:

AVERAGE ANALYSIS OF MORRO DA MINA ORE

Water at 100°C....	2.50	per cent.
Volatile...........	12.40	chiefly oxygen.
Insol. Residue.....	3.46	
Fe_2O_3–Al_2O_3.......	8.75	alumina about twice ferric oxide content.
Silica.............	1.76	
P.................	0.069	
S.................	Absent	
Manganese........	50.47	

The ore is mined by hand for the most part in open cuts. A number of tunnels and adits have been driven; these were intended either for development purposes or to connect the various open cuts to give access to the loading platforms and bins at the railroad but are now used for stoping purposes. The method in vogue is to strip the orebody of such overburden as it may carry, and then as the ore is mined screen it over iron screens with 0.8-inch square openings. The oversize is the merchantable ore. The screenings constituting 15 per cent of the crude ore, carry 34 to 35 per cent Mn and are being stored apart from the waste to be beneficiated at some future time. The ore *in situ* furnishes two-thirds of the present output, and one-third is derived from workings in the rubble ores.

Though decomposition of the original manganese rock has extended to considerable depth, in places in the Morro da Mina mine to at least 130 m. as demonstrated in the exploratory tunnel, portions of the rock have escaped alteration and are well exposed in the mine workings.

Most of this rock has the appearance of a fine-grained dark gray crystalline limestone and is easily scratched with the point of the pick. Its specific gravity, however, is considerably above that of limestone. Here and there are brown patches and streaks with a violet tinge that consist of massive garnet, and there are frequently spots and stringers of pink rhodonite that at once attract attention. A closer examination reveals the presence of sufficient light pink silicate in much of the material to give a pinkish tone to its dominant gray color.

Examination of thin sections shows that the essential constituents are manganese carbonate, spessartite, rhodonite, and tephroite. Taking the average of all the rock, the manganese carbonate is the most abundant mineral and the tephroite the least abundant. The spessartite is more widespread in its distribution but probably not much in excess of the rhodonite in actual quantity. The relative quantity of the different minerals varies most widely, so that some of the rock consists almost entirely of one of the minerals while some has them present in almost equal quantity, with the exception of the tephroite, which, in the sections examined, was never present in more than subordinate amount.

The manner in which this rock undergoes alteration to manganese oxides is very interesting. As the oxidizing solutions penetrate the rock they first break down the manganese carbonate, tephroite, and rhodonite and leave behind embedded in the manganese oxides the grains of garnet. That is, oxidation does not run ahead decomposing the manganese carbonate first and then as a more advanced stage tephroite and rhodonite successively, as one might expect; but the three minerals are replaced simultaneously at the very front of the advance of oxidation.

The problem of the origin of the manganese rock is not easy to solve. One is at once confronted with the fact that our knowledge is rather meager concerning the exact nature of the rocks with which it is associated and its geologic relations to them, a full knowledge of which is essential to a final solution. The chemical, mineralogic, and petrographic characters of the rock, however, do rule out some explanations, and point strongly to another. Further, the geologic relations that are reasonably well established are not at variance with this explanation but in a measure support it. That is, the sum of all evidence points to an analogy of this rock with the gondite of India. We believe that the rock is the product of dynamo-metamorphism of manganese sediments deposited in the form of manganese carbonate with varying but considerable quantities of silica and varying but smaller quantities of alumina. These sediments differed, therefore, initially from the gondite sediments in averaging much lower in silica, and by the deposition of the manganese in the form of carbonate instead of oxide; and this initial difference in composition accounts for the present difference in mineralogy of the two rocks.

Barbacena District.—Derby (47) has published the following description of the Barbacena district:

"Some 50 to 60 kilometers to the southward of Queluz and in the municipal district of Barbacena is another ore district. The region, like that about Queluz, is characterized by gneissic rocks abundantly injected with granite. The ores are of two types, of which one, corresponding to that of the Queluz district, consists of a garnetiferous rock impregnated with secondary manganese oxide evidently derived from the garnet. One specimen is heavily charged with well-crystallized graphite and gives in the residue a white amphibole, neither of which minerals have been noticed in the other specimens. The second type is a manganiferous magnetite of which a specimen from near the station of Ressaquinha was analyzed by Mr. Scott, who found 11.60 per cent. of metallic manganese with 40.08 per cent. of metallic iron. The other specimen at hand seems to be somewhat richer in manganese but is still essentially an iron-manganese ore. The appearance of this ore is that of an ordinary finely granular magnetite charged with pulverulent secondary manganese oxide. The original type was a magnetite-spessartine rock from which the silica and alumina of the garnet has been almost completely removed by leaching, leaving a residue of manganese oxide."

Manganese Deposits of the State of Bahia.—Much less attention has been given the mineral deposits of Bahia than to those of Minas Geraes which undoubtedly, in part, accounts for the fewer number of mines in the former State. Manganese is known to occur in several places in Bahia but, up to the present time, only a few localities have been carefully prospected and in only one place have mines been opened.

The deposits that have been worked are located near the village of Santo Antonio de Jesus, about 26 kilometers west of Nazareth, and along a narrow gauge railroad which runs between Nazareth and Amargosa. Nazareth is a city of about 20,000 population about 48 kilometers southwest of Bahia and located on the Jaguaripe River which is navigable by light draft vessels.

Three mines—Sapé, Onha, and Pedras Petras—have been operated in the district but for several years past all were idle until 1917. The deposits where mining has been carried on are thought to contain upward of 700,000 tons of ore.

The region is very hilly, although none of the hills are high, and heavy forests cover the region. The country rocks are schists which have undergone so much decomposition that hard rocks are rarely seen except along the streams where the soft decomposed rocks have been removed by erosion. The age of the schists is uncertain but they probably belong to the pre-Cambrian crystalline complex so extensively developed in eastern Brazil.

The ore and ore bodies of the Pedras Pretas are described by Branner (19) as follows:

"The ore is psilomelane, and, in so far as one can judge by looking at it, fine ore it is. Hundreds of tons of it were piled on the wharf at Nazareth when I was there, on the 24th and 25th of August, 1899. Compared with the Arkansas and Georgia ores, it appeared to me to be remarkably clean, though all of it is somewhat stained with red clay. Some of the lumps are botryoidal in form, but most of them are angular, and many are more than 2 feet in diameter. I am told that at the mines it is no uncommon thing to find lumps that weigh 1½ tons. The smallest pieces on the ore-piles I saw are larger than one's fist; and these pieces make but a small part of the ore on the heaps.

"The Pedras Pretas mine is in soft earth, save where large masses of solid ore have been drifted into. Most of the ore thus far shipped has come from the great horizontal sheet that spreads out, almost or quite on the surface of the ground. . . . It seems evident that there is a sheet, bed, or vein, as one may choose to call it, of ore, standing at an angle of 60° and varying in thickness from a few decimeters to 10 meters. The great surface deposits I take to be accumulations from the breaking up and weathering-out of the bed, and the removal of the clays about it—just as the Arkansas ores come from the decomposition of limestones. Most of the ore thus far shipped has come from these surface accumulations."

The ore is mined in part by the open-cut method and in part by shafts. Much of the ore when mined has considerable clay adhering to the masses of ore. Such ore is heated to dry the clay which can then be easily knocked off by striking the masses with hammers. The ore-cleaning is done by women. The average composition of the ore is as follows:[1]

	Per cent
Mn	43 to 49
Fe	3 to 6
SiO_2	3 to 4
P	0.016
Moisture	2 to 3

The Sapé and Onha mines are connected by a narrow gauge line 5.25 miles long with the Nazareth railway while the Pedras Pretas mine sends its ore to the railway by gravity. The ore is shipped to Nazareth where it is loaded on sailing vessels and taken down the Jaguaripe River to Bahia Bay where it is loaded on larger vessels for shipment to the United States or Europe.

Near Queimadas, Derby (47) states that there is a manganese ore body enclosed in granite. A specimen of associated rock was found to be essentially composed of manganese garnet and manganese pyroxene. From such a rock, which is similar to the original rocks of the Morro da Mina and Piquery ore bodies the manganese ores are formed by the decomposition of the rocks by the atmospheric agencies.

A large deposit in the municipality of Bom-Fim has recently been acquired and opened up by a North American company. The ore is found in a region of quartzites and occurs along a belt

[1] Hewett—Min. Res. U. S., 1914, p. 181. U. S. Geol. Surv., Washington, 1916.

in which the rocks have been greatly disturbed. Branner (21, 22*a*) has described some manganese deposits near Jacobina, in the same district.

Manganese Deposits of the State of Matto Grosso.—It has long been known that a large deposit of manganese ore occurs near Corumbá not far from the Paraguay River in southwestern Matto Grosso but in the literature there is scarcely more than mention of the occurrence.

In 1894 a concession to work the mines was granted to Francisco Conto da Silva which in 1907 was transferred to the Societé Anonyme d'Ongree Marihaye, a Belgian Company.

The following description is taken from an unpublished report by W. L. Cumings who visited the region in 1913.

The manganese deposits are located in Urucum and Morro Grande moutains which lie about three kilometers southeast of

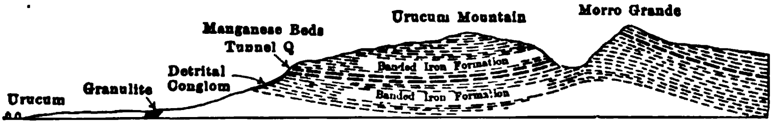

Fig. 24.—Section of Urucum mountain. (*After Cumings.*)

the small village of Urucum and about 20 kilometers south of Corumbá. Urucum Mountain is an isolated, nearly flat-topped butte rising 800 meters above the surrounding comparatively level country. About half way up the mountain two almost flat-lying beds of manganese ore outcrop and a tunnel driven at a lower level gave rather unsatisfactory evidence of a third bed. It happens that the line of timber is just about the level of the two ore beds, the lower flanks of the mountain covered with forest and the upper with grass and shrubs.

The strata of the mountain consist of banded ferruginous slates. The rock probably contains about 40 per cent iron and abundant SiO_2. The manganese ore beds are conformable with the strata of the lean iron ore formation. No other rocks are exposed in the mountain but between the mountain and the village of Urucum is an exposure of decomposed granite. About 4 kilometers to the north of Urucum flat-lying limestones appear which are extensively developed near Corumbá and for some distance down the Paraguay River.

The strata of Morro Grande are similar to those of Urucum with the exception of there being but one bed of manganese ore exposed.

Three tunnels were driven into Urucum Mountain in the ore beds to distances of 20, 36, and 48 meters. The average thickness of the ore beds in the three tunnels was 2, 2.2, and 3.1 meters. As the tunnels were driven on different sides of the mountain and the outcrop of the ore bodies cannot be followed continuously it is not known whether the same or different beds of ore were explored. In the generalized cross-section it is assumed that there are two continuous beds that extend through the entire mountain although sufficient evidence to prove this condition has not yet been obtained.

The ores are firm and hard varying in color from brown to black. Many specimens show the slaty structure of the lean iron formation. In one of the tunnels the ore encountered was unusually black and hard and broke with a slightly conchoidal fracture. Analyses showed that this variety contains from 14 to 16 per cent iron. Fifteen samples collected from the three exploration tunnels showed a variation in the manganese content of 40.24 per cent to 47.10 per cent. The average composition of the Urucum ores obtained from the analyses of the fifteen samples is as follows.

	Per cent
Mn	44.03
Fe	13.83
P	0.200
SiO_2	1.74
S	0.015
Al_2O_3	2.30
CaO	0.230
MgO	Tr
Ti	Tr
Cu	0.006
Moisture	2.84

It is estimated that about 250,000 tons of ore are in sight in Urucum Mountain and an estimate of the ore present in the entire mountain based on the assumption of the continuity of the beds amounts to 15,000,000 tons.

In the northwestern corner of Maranhão, about 150 miles west of the city of Maranhão and close to the Piracaua River, an important manganese deposit has recently been discovered. Three veins, with widths of 1.50, 1.70, and 2.70 m. respectively, are estimated to contain 200,000 tons of ore averaging 48 per cent. Mn.

OUTLOOK FOR THE MANGANESE INDUSTRY OF BRAZIL

In the foregoing pages descriptions have been given of the manganese deposits of the country as known thus far. That these represent only a small part of the existent deposits is the belief of almost every geologist and mining engineer who has studied the mineral deposits or geology of the country. Derby who was the best-informed person concerning the mineral resources of the country was confident that careful investigation would bring to light many other deposits of equal importance to those already discovered while Dr. Branner and others have expressed similar views. It is questionable whether any other country of the world possesses greater deposits of manganese ore than does Brazil so that we confidently predict that the Brazilian manganese industry is bound to increase steadily in importance. Certainly no other country, with the exception of Russia and perhaps India, at the present time, seems to offer more promise in the way of exploration for workable manganese ore bodies.

COPPER

Copper minerals have been found in numerous places throughout the country and large deposits of copper ores have been reported from various localities. In most instances these reports have not been verified. The only deposits that have been developed sufficiently to furnish adequate conclusions as to their value are those of Bahia and Rio Grande do Sul. In addition, copper ores occur in the following states: Ceará (at Minas de Pedro Verde), Goyaz, Maranhão (along the Grajahú River), Minas Geraes, Pará, Paraná and Piauhy.

Rio Grande do Sul.—The most important copper mines of Brazil are located a few miles from the Camaquam River and about 50 miles north of Rio Negro, which is a station on the line of railroad between Bagé and Rio Grande. The country rocks are mainly sandstones and conglomerates which overlie schists of pre-Cambrian age. These rocks are intruded by various dikes and sheets of basalt and gabbro, or overlain by extrusive flows of basalt. Veins carrying copper minerals are found in both the schists and the more recent sedimentary rocks but the former are of less importance and are not worked The veins in the hard conglomerates are more regular and continuous than those of the softer sandstones Considerable chalcocite occurs in the upper levels with bornite, chalcopyrite, and iron pyrite in the lower workings. Some native copper has been found close to the intrusive igneous rocks that have been responsible for the mineralization. Quartz and barite are the principal gangue minerals. The four main veins worked average about 4 feet in thickness.

The ore is brought from the mine through adits and hand-picked to eliminate the barren rock and also to separate the best ore which averges about 30 per cent copper. The remainder carrying about 7 per cent copper is milled and concentrates containing 28 per cent copper obtained. The product which also yields some gold is shipped to England for smelting.

The Cerro Martini copper deposits located about 86 miles from Rio Negro station and about the same distance from Cachoeira, which is a station on the railroad between Santa Maria and Porto Alegre, are similar to the Camaquam lodes, the ore occurring in fine conglomerates associated with basalt intrusions. The ores contain from 7 to 25 per cent copper.

Near Caçapava is the Primavera mine in which the lode occurs at the contact of granite and mica schist and consists of quartz, pyrite, chalcocite, and some native silver. It averages about 7 per cent copper. The Cerro do Geraldo copper deposits located about 2½ miles from Caçapava show chalcocite impregnating micaceous schists.

Other occurrences of copper ore have been reported from various places in the State of Rio Grande do Sul but reliable information concerning them is lacking.

Bahia.—Copper minerals have been found in the pre-Cambrian crystalline rocks of the State of Bahia in several places. The best known occurrence is at the Minas de Cobre de Carahyba about 25 miles west of Angico, a station on the railroad which runs from Bahia northwestward to Joazeiro on the São Francisco River. The mine is said to have been first opened in 1783 and has been worked at intervals ever since.

All of the ore thus far obtained is in the oxidized zone and consists of small veins of malachite and chrysocolla forming a network in an altered igneous rock which ranges from a pyroxenite to a hypersthene gabbro. The ore probably averages about 3 per cent copper. The character of the ore below the oxidized materials is not known as none of the pits and shafts is more than 90 feet in depth. The Carahyba deposit is commonly supposed to be an extensive one but this opinion seems to be mere conjecture.

Other deposits of a similar character are present in the crystalline rocks east and northeast of Angico but little is known in regard to them.

CHROMITE

Deposits of chromite were discovered in the State of Bahia several years ago but not until the early part of 1918 were there any developments to determine their character and extent. The most important are in the vicinity of Queimadus and Bom-Fim where ore containing 44 to 46 per cent Cr_2O_3 is now being mined and shipped to Philadelphia. The ore bodies being worked are expected to yield from 20,000 to 25,000 tons. Other occurrences of chromite in the same vicinity may prove to be of commercial importance. Farther inland, near the São Francisco River are other undeveloped deposits of chromite ore containing 35 to 40 per cent Cr_2O_3.

PLATINUM

Platinum has been found in several places in Minas Geraes, usually in association with the diamonds and gold in the stream gravels. The most important localities are the Abaeté River, the eastern flank of the Serra do Espinhaço between Conceição and Serro, and from the Corrego das Lages stream near Conceição. So far as known no placers have been worked primarily for platinum although some has been obtained in the gold and diamond workings.

MERCURY

Some cinnabar-bearing gravels have been found in a stream not far from Ouro Preto. It seems unlikely that they are of economic importance. The gravels have been derived from the itabirite of the region. Cinnabar is said to also occur in other parts of Minas Geraes.

TUNGSTEN

Tungsten minerals have been reported from several places but so far as known none has ever been mined. Wolframite is found in quartz veins at Encruzilhada in Rio Grande do Sul;

some scheelite has been found in the Morro Velho gold mine and at Sumidouro da Marianna in Minas Geraes; while columbite has been found near Peçanha in Minas Geraes as well as other places.

BISMUTH

Native bismuth and oxide of bismuth have been noted in a number of the gold mines of Minas Geraes, especially in the Passagem mine.

LEAD AND ZINC

Lead and zinc, in small quantities, have been reported from numerous localities, particularly in places where pyritic gold ores are worked but, so far as known, no deposits of commercial importance of either of these substances have ever been found.

NICKEL

An occurrence of nickel ore near Villa de Livramento, Minas Geraes, has recently been described by Horace E. Williams in a publication of the Serviço Geologico da Agricultura e Mineralogico do Brazil. It is in the municipality of Turvo, about 157 miles from Rio de Janeiro. The nickel occurs in a rock rich in olivine, largely altered to serpentine, which has been intruded into nepheline syenite. The outcrop of the serpentine contains the nickel as garnierite. Much of it shows an assay of 3½ per cent nickel while some runs as high as 8 to 15 per cent. It is thought that this serpentinized belt may also be found to contain important deposits of chrome ore.

Nickeliferous pyrrhotite has also been reported from Minas Geraes but has never been worked.

SILVER

Most of the gold of the country and also the small amounts of galena found contain small percentages of silver.

TIN

Occasional grains of cassiterite have been found in the gold and monazite placer deposits.

COAL

The lack of workable coal deposits has been a serious drawback in the development of the great natural resources of the country.

This fact has been so generally appreciated by the Brazilian Government that in 1904 a Coal Commission was appointed to make a careful investigation of the coal deposits which had long been worked in a desultory manner in Rio Grande do Sul and Santa Catharina. I. C. White was selected as the Chief of the Commission and from his final report (148) most of the following data have been obtained.

COAL DEPOSITS OF SOUTH BRAZIL

Geology.—Although coal, lignite, or peat have been reported from a number of the states, it has long been recognized that the most important deposits were those of Southern Brazil, extending from southern São Paulo to the Uruguay border. Dr. White has worked out the following stratigraphical succession of the formations that occur there.

The entire series from the base of the Permian to the top of the Triassic is composed of conformable beds which Dr. White calls the Santa Catharina System and correlates with the Karroo System of South Africa.

	Thickness in meters
Mesozoic	
São Bento Series	
Serra Geral eruptives	600
Botucatu sandstones; great cliffs of red, gray and cream-colored sandstones	200
Rio do Rasto red beds, with fossil reptiles (*Scaphonx*, *Erythrosuchus*) and fossil trees	100
Permian	
Passa Dois Series (Upper Permian)	
Rocinha limestone	2
Estrada Nova gray and variegated shales with cherty concretions and sandy beds	150
Iraty black shale (*Mesosaurus* and *Stereosternum*)	70
Tuberão Series (Lower Permian)	
Palermo shales	90
Rio Bonito shales and sandstones with Coal Measures and *Glossopteris* (*Gangamopteris*) flora	158
Orleans conglomerate of glacial origin	5
Yellow sandstones and shales to granite floor	27

The São Bento series is closely correlated with the Upper Karroo and the Tuberão series with the Lower Karroo while the Middle Karroo is less definitely referred to a part of the Passa Dois series.

The Rio Bonito beds of the Tuberão Series are the only ones so far known to contain coal deposits of any importance. The Tuberão series outcrops in a band, about 12 miles in width, extending from Minas, Santa Catharina, in a northwesterly direction passing through Boa Vista, Paraná, to the Rio Tabagy. The beds outcrop near Itapetininga in São Paulo. In Rio Grande do Sul the same strata appear in a narrow band extending from São Jeronymo in a southwesterly direction to Suspiro and in detached areas at Candiota and near Jaguarão along the Uruguayan border.

White believes the beds to be continuous although realizing the possibility that the Brazilian Coal Measures may occur in isolated or detached basins that were never connected. The Tuberão beds disappear to the west beneath the overlying beds of the São Bento Series and their extent can only be determined by drilling.

While coal has been found in almost every place where the Rio Bonito beds have been investigated, in many places the coal seams are too thin to be worked. The most promising beds are in Santa Catharina and Rio Grande do Sul where most of of the coal mining to date has been done.

A section of these beds and the underlying strata of the series measured along the Estrada Nova near Lauro Müller Station (Minas), Santa Catharina is as follows in descending order:

			Meters
Gray sandstone and sandy beds			6.096
Coal, Treviso bed	Coal	0.152	0.660
	Clay	0.254	
	Coal	0.254	
Concealed and sandstone, Upper Barro Branco			6.62
Coal, Barro Branco	Coal, slaty	0.25	1.11
	Clay, white	0.555	
	Coal, slaty	0.305	
Shales with fossil plants			0.15
Sandstone, massive, white, Lower Barro Branco			9.14
Slaty coal (Irapuá), fossil plant fragments			0.15
Sandstones and shales			30.49
Sandstone, gray			3.05
Coal, Ponte Alta			0.15
Shales			2.13
Sandstone, massive, Upper Bonito			12.20
Coal, Bonito Rider			0.455
Clay and coaly shale			0.555
Bonito coal bed (coal and slate)			2.13

	Meters
Fire clay and light colored shales	4.57
Sandstone, massive, pebbly, Lower Bonito	10.67
Shales, often weathering reddish, and concealed	22.86
Sandstone, massive pebbly	15.24
Shales weathering reddish and yellow above, but light gray at base	7.62
Light gray sandy micaceous shale, containing plant remains	0.305
Sandstones and shales	12.20
Sandstone, and concealed to mouth of boring at 197.2 meters above tide	12.20
Orleans conglomerate in boring	5.35
Shales and sandstones alternating, to granite	27.00
Total	190.051

Sections taken elsewhere present slightly different characteristics. Of the various coal beds named, the Barro Branco is of the greatest importance and was the earliest one to be worked in the first half of the last century at Barro Branco Velho, Santa Catharina, on a tributary of the Rio Ponte Alta. A section at the mouth of the mine is as follows:

			Meters
Sandstone, grayish-white, Upper Barro Branco			9.14
Shales, dark, bituminous			0.18
Coaly layer			0.05
Clay, light colored			0.15
Coal	Coal	0.33	1.94
	Shale, dark	0.10	
	Clay, light	0.11	
	Coal	0.08	
	Clay, dark and light	0.69	
	Coal, with clay parting near center	0.63	

Dr. White believes that thin coal beds at Cedro near Imbituva, and along the Rio Tibagy in Paraná and on a branch of the Rio d'Onca between the Rio Feio and Rio Tatuhy in São Paulo represent the Barro Branco bed.

About 50 kilometers southwest of Porto Alegre, in the region of São Jeronymo a coal bed known as the São Jeronymo seam has been worked in several places. It probably should likewise be correlated with the Barro Branco bed of Santa Catharina.

A section of the bed at the Poco Fe Mine is as follows:

	Meters	
Black slate and bony coal with fossil plants...........		
Coal, fairly good....................................	0.86	2.68
Clay, light gray......................................	0.10	
Slate and coal in alternate thin layers 3 to 8 centimeters each...	0.81	
Coal, some slaty layers..............................	0.91	

Quality of the Brazilian Coal.—White (148) has succinctly discussed the quality of the coals of Southern Brazil as follows:

"Many analyses and reports on Brazilian coal have been published in the past. In most of these reports, the samples appear to have been selected from the purest portions of the coal beds in question or from average samples which would include the entire bed. By this method of sampling, very contradictory results were obtained when the same coals were submitted to test of actual commercial use.

"The analyses published led many people to hope that a purer coal would eventually be found in good quantity, something that would in its natural state displace Cardiff coal in Brazilian industry.

"The result of the work of the Coal Commission during the year 1904 (which was fully confirmed by the further studies in 1905–6) was to abandon hope of finding beds of pure coal of exploitable thickness in Brazil, since it was only too apparent at every outcrop and exploitation visited that the coal was everywhere of practically the same quality; that while some fairly pure coal existed in every bed, it was so interstratified and ingrained with bituminous shale or slate as to render the separation by ordinary mining methods impossible."

In the following analyses sample No. 1 was taken from the upper bench and sample No. 2 from the lower bench of the mines of the S. Jeronymo Co., Rio Grande do Sul.

PROXIMATE ANALYSES

Sample No.	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Phosphorus	B.t.u.
1	3.43	27.28	37.52	31.77	12.96	0.053	10,095
2	4.87	27.89	44.20	23.04	0.60	0.014	11,117

ULTIMATE ANALYSES

Sample No.	Carbon	Hydrogen	Nitrogen	Sulphur	Oxygen	Ash
1	46.00	4.05	0.29	12.99	9.27	27.40
2	57.09	3.57	0.39	0.60	15.54	22.81

The results of analyses, showing the coal to be very high in both ash and sulphur, appeared to prove conclusively that the coal must be submitted to purification processes before there could be any hope for it to enter into general use for fuel except in the immediate region where it is produced.

A number of tests for the purification of the coal have been made in which the coal was crushed and washed and the pyrite, which occurs mostly in the form of nuggets, largely eliminated. Briquettes made from the fine coal dust compare favorably with those imported from Cardiff, Wales. White therefore concludes that it is "very probable, in view of the high price of imported coal everywhere in Brazil, that the coals of Santa Catharina and Rio Grande do Sul can be successfully marketed in competition with foreign coal if properly prepared by modern methods of purification."

During the past year the coal deposits have been worked more energetically than ever before and a number of new mines have been opened. The mines in the vicinity of S. Jeronymo were producing 650 tons a day in the early part of 1918. Some satisfactory results were obtained in washing the coal.

PEAT AND LIGNITE DEPOSITS

Peat and lignite have been reported from many places in Brazil and in a few instances have been dug for use. In Minas Geraes. lignite has been worked at Gandarella about 30 miles north of Ouro Preto, at Fonseca, and at Bom Jardim. Lignite is reported to occur at Quixambinha in the State of Pernambuco and in Bahia and also great deposits of peat are said to have been discovered in Amazonas, Pará, Maranhão, Parahyba do Norte, and Rio de Janeiro.

Undoubtedly there will come a time when the coal, lignite, and peat deposits of Brazil will be utilized but under present conditions, most of the fuel, other than wood, used in the country must be imported.

PETROLEUM AND ASPHALT

From time to time reports have been circulated to the effect that petroleum has been discovered in Brazil but while there is some basis for the statements it seems that at present no important oil wells have been obtained. Oil shales and asphalts do occur and these have been prospected in several places.

The oil-bearing shales of the coast of Brazil have been studied by Branner (20) who states that they form a nearly continuous band of fresh-water sediments that extend from Porto Alegre, just south of Caravellas in Southern Bahia to the basin of the Amazon River. The width of the band varies up to 50 miles. The formation containing the oil shales is from 100 to 300 feet in thickness. Within the belt oil shales of promise have been found in several places in Bahia and Alagoas and may be expected in the other Coast States to the north where Tertiary strata are found.

The shales near the mouth of the Camarigibe River and at Riacho Doce in the State of Alagoas have been investigated by an English company. Ten analyses showed a range from 7.5 to 46.3 per cent volatile matter. The sample showing the highest percentage was further investigated and upon distillation yielded 44.73 gallons of crude oil and 19.58 gallons of ammoniacal water to the ton. It contained 4.7 per cent sulphur.

Turfa (erroneously called *turba* by Hartt) beds are known to occur on the northern part of the island of Tinharé which is about 25 miles south of Bahia, along the Itahipe River in latitude 14° 44′ S., and on the Marahú River, just south of the Bay of Camamú, about 70 miles south of Camamú. Hartt (84) describes the last-mentioned occurrence as follows:

"The specimens of turba which I have seen were of a very light material, grayish or brownish in color, and felty in texture. The material burned readily when ignited in a candle, affording an abundant smoky flame. . . . The material appears to be merely a mud impregnated with bitumen; and as it appears to exist in large quantities, it would be very valuable for gas-making or the manufacture of kerosene."

A shaft in this turfa district 108 feet in depth passed through five beds of bituminous shales or clays aggregating over 20 feet in thickness.

Several years ago a company obtained control of these deposits and erected an extensive plant with the intention of extracting the oils but through mismanagement the project failed without demonstrating the feasibility of utilizing the materials.

In Southern Brazil, White (148) describes a thick formation of black shales which he terms the Iraty Black Shale. It extends from São Paulo southward across Paraná, Santa Catharina, and Rio Grande do Sul to Uruguay. The shales when freshly broken give out a distinct odor of petroleum. In places the petroleum has been oxidized into asphaltite (albertite?) and this in turn in a few localities has been metamorphosed into natural coke by contact with eruptive diabase. The asphaltite has sometimes been mistaken for coal and exploratory shafts have been sunk.

Asphaltic sands are also present in some of the other formations of Southern Brazil but under present conditions it does not seem probable that either the petroliferous shales or the asphalt beds have any commercial value. Some of the asphalt from asphaltic strata near Bofete in São Paulo has been tested and appears to be of good quality.

Dr. White believes that many of the strata of Southern Brazil at one time contained petroleum, but due to the extensive fissuring which the region suffered, when great flows of diabase and basalt came to the surface, avenues of escape were afforded and there is little likelihood of oil being found in commercial quantities. Oil is reported to have been found recently near the Jangada River, Paraná and some drilling has been done in the Rio Claro region, São Paulo.

The most likely places for petroleum in Brazil appear to be in northwestern Brazil near the Colombian border or in the Amazon River valley but as yet no exact information is available.

MONAZITE

Monazite is one of the rare earth minerals that within recent years has attracted a great deal of attention in Brazil. It is an anhydrous phosphate of a number of the rare elements, particularly cerium, lanthanum, neodymium, praseodymium, yttrium, erbium, and varying amounts of thorium. At present thorium is the only element of value in monazite. The percentage of thorium oxide, ThO_2, ranges from a fraction of 1 per cent to 12 per cent and only monazite containing more than 3½ per cent is of commercial importance. It is converted into thorium nitrate which is used in the manufacture of incandescent gas mantles. Mesothorium, a by-product in the production of thorium nitrate, is used in medicine, and seems to have a similar effect to radium.

Monazite has been found in many places and appears to be a rather widely distributed mineral although always present in the original rocks in very small quantities. Promising deposits have been found in India, Russia, Sweden, Norway, Africa, Australia, United States, and Brazil. The Brazilian deposits are so much more important, however, than any of the others that for many years past Brazil has practically supplied the world's demand which amounts to about 3,000 tons a year. At times, monazite mining companies in North and South Carolina have been able to compete with the Brazilian industry but not very satisfactorily since the great reduction in the price of monazite sand in 1906.

About 1884 a sample of a heavy yellow sand was sent from Bahia to Rio de Janeiro under the supposition that it was cassiterite sand. On examination, however, it was found to consist of grains of monazite. Previous to that time only small amounts had been obtained in Norway and Sweden for chemical purposes.

Mr. John Gordon, an American engineer, shortly after located some rich deposits along the ocean beach in the State of Bahia and made shipments to Hamburg. He soon obtained a monopoly of the thorium deposits of Brazil and was able to supply the world's demand at much less cost than previous prices. His chief source of supply was near Prado, State of Bahia. Until 1903 Gordon controlled the entire industry but in that year the Brazilian Government asserted its claim to a band extending 33 meters inland from mean high tide and advertised for bids for the lease of its monazite-bearing beaches. The lease was finally obtained by A. C. de Freitas & Co. of Hamburg and the industry has since that time been controlled by this company and John Gordon.

Through the use of the *batea*, Derby was able to discover the almost universal presence of monazite in the muscovite granites of Brazil or in their porphyritic or gneissic equivalents. He also found it present in biotite granites, in various kinds of schists, in magnetic iron ore, and in graphite but absent in the basic rocks. In no case, however, did he find it present in commercial quantities in the original rocks. The highest percentage of monazite known in the igneous or metamorphic rocks is less than 0.2 per cent.

It is only by the concentration by moving water of the monazite particles in the decomposed rocks that workable deposits are produced. In Brazil the monazite placers are of two kinds, (1) those formed along the beaches where the waves have re-concentrated, perhaps many times, the materials brought from the inland hills by streams, and (2) those deposited in the sand bars and flood plains of the streams. The former are by far the most important and have furnished almost the entire production of the country while the latter contain the future supplies.

The beach monazite placers have been noted in spots all the way from Maranhão to Rio de Janeiro but are of little consequence except in the states of Bahia and Espirito Santo. Gottschalk (79) cites the following localities where the best deposits are found:

"Praia Massanduba, near Cape Frio, deposits of titaniferous iron containing some monazite; Macahé, 45 miles farther north, a small deposit; at the foot of the Cliffs of Siry, 30 miles north of the southern frontier of the state of Espirito Santo, a reputedly rich bed; at Maratayso Praia, 2 miles farther north, a poor bed; at the foot of Mount Aga, at Piuma, just south of Benevente, two beds not far apart; at Ubu, 4 miles north of Benevente, a better deposit; 2 miles north, at Maimba, and 2 miles farther north, at Miahype, Federal beds with extensive private marginal deposits. Miahype is considered by some persons one of the richest beds in Brazil. Four miles north of this come the southernmost of the Guarapary beds—Rastinga, Canto de Riacho, Praia de Diogo, etc. Nothing occurs for 15 miles northward till Ponto da Fructa and Victoria. Eighteen miles north of Victoria is a deposit at Nova Almeida, and 20 miles farther one at Regencia, described as particularly large. Seventy miles farther north are the São Matheus beds. It is said that certain beds still farther north—those of Prado, in the state of Bahia—are constantly being renewed by the wave action of extremely high tides beating upon the clay cliffs. Two other beds in the state of Bahia are mentioned —one at the mouth of the Cahy River and another just north of the River Carahyba. It is said that neither is important."

In the early history of the industry monazite sands of sufficient purity to be shipped direct were gathered from the beach after each tide but in recent years the beach sands as dug are concentrated by oscillatory tables, in sluices, or by magnetic separators. As monazite is less magnetic than magnetite, ilmenite, hematite, garnet, epidote, olivine, and tourmaline and more magnetic than zircon, rutile, gold, quartz, feldspar, etc., the minerals that commonly occur in the beach sands associated with the monazite, a fairly pure product can be obtained. The Brazilian product as marketed contains about 92 per cent of monazite averaging from 6.2 to 6.4 per cent of thorium oxide.

F. H. Lee, chemist of the Brazilian Geologic and Mineralogic

Service furnishes the following analysis of Brazilian monazite sand:

	Per cent.
P_2O_5	29.28
Ce_2O_3	31.28
La_2O_3 / Di_2O_3	30.88
SiO_2	1.40
ThO_2	6.49
Loss on ignition	0.20
	99.53

There are many stream deposits which have received attention in Minas Geraes, Espirito Santo, and Rio de Janeiro. The best description of these is by Freise (67) who investigated the stream deposits of the Muriahé and Pomba rivers and their tributaries in the State of Rio de Janeiro. He states that the rocks yielding the monazite are gneissoid granites, granite dikes, mica schists, hornfels, quartzites, arkoses, etc. Associated with the monazite particles are thorite, gold, zircon, corundum, cassiterite, rutile, spinel, topaz, olivine, titanite, garnet, hornblende, augite, etc. Of 236 localities examined 177 were considered workable. They were estimated to contain 30,000,000 tons of placer materials (*cascalho*) which should yield 100,000 tons of monazite concentrates. In places as many as 5 layers of *cascalho* were found in the alluvial débris while the workable *cascalho* layers vary from 4 to 48 inches in thickness.

It is estimated that the beach sands of Brazil will furnish from 15,000 to 20,000 tons of monazite concentrates while the inland stream deposits thus far known will no doubt yield 10 times that amount and more are likely to be found. Brazil will in all probability continue to supply the bulk of the world's demand for many years.

ZIRKITE DEPOSITS

The zirkite deposits of Brazil have recently been described by H. C. Meyer in a commercial bulletin (113) of the Foote Mineral Company from which the following paragraphs are taken.

"The Caldas region (visited in 1915 by the writer), in which these zirconia deposits occur, is situated partly in the State of Minas Geraes and partly in the State of São Paulo, approximately 130 miles north of the city of São Paulo. It is a mountainous plateau, the main elevation of which is about 3,600 feet. The surface is undulating, presenting differences in level of from 300 to 600 feet. The whole area is bounded on all sides by ridges rising abruptly from 600 to 1,200 feet above the general level and forming a roughly elliptical enclosure with a major axis of approximately 20 miles in length and a minor axis of 15 miles. This peculiar arrangement of the higher ridges is very significant when coupled with the fact that the predominant rock of the plateau is a phonolite and the presence of highly mineralized thermal water of considerable medicinal value. No thorough geological survey has been made of this area with a view of determining the origin of the zirconia. The character of the ore, however, and the formation, seem to point to pneumatolitic agencies. A careful study of the relationship of the large masses of coarsely crystalline nephelite-syenite in this area, with pronounced segregations of eudialyte, might throw some light upon this subject.

"Zirconia ore can be roughly divided into two classes:

"First, alluvial pebbles ranging in size from one-half inch to three inches in diameter, generally carrying about 90 to 93 per cent zirconium oxide. These pebbles, known as "favas" and having a specific gravity ranging from 4.8 to 5.2, are found along small stream beds and on the talus slopes of low ridges.

"Second, zirconia ore proper, or zirkite, which ranges in shade from a light gray to a blue black, the lighter colored material carrying a higher percentage of zirconium silicate, as evidenced by analysis, which in some cases shows a minimum of 73 per cent zirconium oxide. The blue black ore generally carries from 80 to 85 per cent zirconium oxide. By careful sorting, however, a uniform grade carrying about 80 per cent is produced. Prior to the investigations of Derby and Lee, this ore was considered identical with baddeleyite. It has now been shown, however, that it is a mechanical mixture of three minerals; namely, brazilite, zircon, and a new and unnamed zirconium silicate carrying about 75 per cent zirconium oxide. Several large outcrops of the ore occur on the extreme westerly edge of the plateau, one or two isolated boulders weighing as much as thirty tons. No extensive development work has yet been attempted, although several cross-cuts have been run to determine the width of the vein, and a few shallow prospect holes to determine the depth, but seemingly, through indifference of the owners, this development work was not completed. Owing to the hardness of the ore, it is almost impossible to drill holes for explosives, and in handling large masses it is found necessary to resort to the primitive methods employed by the emery miners of Naxos. A large fire is built against an exposed face of the ore and kept burning for several hours, at the end of which time water is thrown upon the ore, which produces fracturing of the mass, permitting it to be sledged into pieces easily handled by one man.

In some of the deposits the ore occurs in the form of gravel and large pebbles embedded in a reddish clay matrix greatly resembling a boulder clay. This is mined by open cut methods. The clayey mass, on being exposed to the tropical sun and air, readily dries, and the zirconia can then be separated from the clay matrix by a coarse screen. Before shipment, it is thoroughly washed to remove the small percentage of ferruginous matter still adhering.

"This very cursory examination of the zirconia deposits makes it unsafe to venture any conjecture as to the quantity of ore available. Suffice it to say, however, that the deposits have been traced for a distance of fifteen miles between Cascata and Caldas, and if surface indications are of any significance, are of vast extent."

PRECIOUS STONES

Brazil has long been known for its variety and quality of precious stones. These include the diamond, topaz, aquamarine, beryl, chryso-beryl, amethyst, tourmaline, garnet, agate, and many others of less value. Among these the diamond is of greatest importance, although a considerable industry has been built up in the mining and marketing of the other precious stones mentioned.

THE DIAMOND

The exact date at which diamonds were first discovered in Brazil is in doubt but it seems to have been about 1727. According to one account a priest who had previously spent some time in the diamond fields of India recognized some of the bright pebbles found by the gold washers of Minas Geraes as diamonds and quietly gained possession of a number. Just as he set sail from Rio de Janeiro for Portugal he announced that diamonds had been found in the gold districts. The news precipitated a rush to the region and soon the diamond output exceeded in value that of gold. The Portuguese Government quickly took possession of the district and for many years obtained large returns from the monopoly. At the present time the South African fields are of so much greater importance that comparatively little is heard of the Brazilian diamond regions yet for about a century and a half they led the world in the production of these gems and even now the industry furnishes the support for perhaps 10,000 people. It is impossible to obtain accurate figures of the total production as large numbers were smuggled out of the country to escape the heavy taxes. One estimate places the total value at about $80,000,000.

The first diamonds found in the country were discovered at Tejuco (later changed to Diamantina, the present name) in Minas Geraes. The area was gradually extended to other parts of the same state while later discoveries were made in Bahia, Goyaz, Matto Grosso, São Paulo, Paraná and Piauhy. Minas Geraes and Bahia are the principal producers and will probably long retain their preëminence.

There are seven districts in Minas Geraes where diamonds have been found. These are designated as the Diamantina, the Grão Mogol, the Abaeté River, the Somno River, the Bagagem River, the Sapucahymirim River, and upper Rio Grande River districts.

Diamantina District.—The Diamantina district in east central Minas Geraes is practically confined to the drainage basin of the Jequitinhonha River. Diamonds have been found along this stream for a distance of about 250 miles in a belt averaging perhaps 6 to 8 miles in width but in places as much as 20 miles wide, especially in the region about the town of Diamantina. In fact, in that section where the Jequitinhonha, Arassuahy, and Doce rivers all head some diamonds have been found in the basins of these other two rivers.

The topography of the Diamantina district consists of rolling to flat uplands dissected by steep rocky-sided valleys cut in the Caraça quartzite. The strata have a general dip of 45° to 50° and because of the layers of unequal hardness present many picturesque rock forms.

The formations of the district (81) consist of the Caraça quartzite, the Diamantina conglomerate, and the terrace and river gravels all of which were described on a preceding page in the discussion of the iron ores. The Diamantina conglomerate persists only in the broad uplands, known as the *chapadas* and even there is very thin, except in pockets which were probably at one time stream channels. This conglomerate is largely composed of fragments derived from the underlying Caraça quartzite but with the introduction of some pebbles of igneous rocks whose source has not been determined. Whether the diamonds themselves were derived from the underlying quartzite is also in doubt. At the Sopa mine, about 8 miles northwest of Diamantina, the irregular contact between the conglomerate and the underlying Caraça quartzitic schists is well shown, the conglomerate varying in thickness from 0 to 18 feet. It is horizontally stratified, greatly cross-bedded, and rests upon the steeply inclined older strata in which are many quartz veins and pegmatite dikes. At São João da Chapada there is a marked gorge in the Caraça quartzite which was filled with the Diamantina conglomerate during the Quaternary.

Most of the diamonds of the Diamantina district have, however, been obtained from the more recent river gravels where they have been re-concentrated by stream work, perhaps several times. The most productive places have been the pot holes in the stream channels, some of which have been extremely rich. Everywhere gold is found in association with the diamonds in varying quantities.

Naturally the channel and flood plain deposits were worked first and have been, in places, re-worked many times. Indeed, certain places are worked over almost every year with satisfactory returns after freshets. The terrace gravels later attracted attention, while the upland peneplain gravels were the latest to be worked.

The minerals found in association with the diamonds are numerous. Quartz grains and pebbles and clay particles are the most abundant and these are easily separated from the diamonds because of their lighter specific gravity. Pebbles of limonite, martite, zircon, tourmaline, ilmenite, disthene, mica, etc., are also common.

The diamonds of the district are mainly of small size. Few stones exceeding 7 or 8 carats are encountered although in the long history of the region some of more than 50 carats have been found. During the days when the deposits were worked by slave labor the finding of a stone weighing 17½ carats entitled the slave to freedom. The diamonds are mainly of good color, most of them bluish-white, although some of decided blue, yellow, and pink shades have come from the district. Due to the fact that they have probably been transported several times, during which processes the poorer stones would be broken into small pieces, they are, in general, comparatively free from fractures. Good crystals are common.

The methods of mining and concentrating the diamonds are somewhat crude and yet on the whole fairly satisfactory and economical. Two methods will be described as typical.

The method employed by the natives is for the man to dig the diamond-bearing earth with a hoe and carry it to a nearby stream in a wooden vessel about 14 inches long, 12 inches wide, and 1½ inches deep, called a *carambé*, which he balances on his head. At the side of the stream he builds a sloping box, called a *bacu*, into which he shovels some of the diamond earth and then, standing in the stream, throws water against the earth by means of a circular wooden vessel about 3 feet in diameter and tapering to a point in the center where it is about 3 inches deep, and known as a *batea*. The water carries off the clay and pebbles of lighter specific gravity into the stream leaving the heavier particles. After washing the material for some time and greatly reducing the bulk he puts a small quantity into the *batea* with considerable water and rotates it vigorously as it rests on the surface of the water. The lighter particles are thrown to the side of the *batea* and then scraped off by hand into the stream. The process is repeated several times and finally the residue left in the center is carefully examined for any diamonds or gold.

At the Boa Vista mine the process is somewhat more elaborate. One set of men loosens the diamond earth by means of crow-bars; another set breaks the larger lumps by means of hoes; and a third set shovels it into *carambés* and takes it to a sluice through which water is running swiftly.

The water carries the earth to a small mill for concentration. It first goes over a coarse grizzly to remove the larger particles which, in some instances, are almost a foot in diameter. It then goes to a settling basin provided with baffle boards where much of the finer earth is carried off by the water. The gravels then pass through sizing screens and each size thence to shaking jigs, five in number. The heavy concentrates from the bottoms of the jigs are run over a sloping board with water and the diamonds picked out by hand. It is claimed that few diamonds are lost by this process.

At the Sopa mine an English company invested over $1,000,000 in an effort to work the deposit on a large scale by means of steam shovels, elaborate concentrating machinery, etc., but failed to make a success of the project.

Dredges have also been employed along the Jequitinhonha but with indifferent success. It has generally been supposed that in the deeper streams the channel gravels have never been worked but this is not everywhere true as Mawe (108) shows an illustration of a stream being diverted from its course by means of a dam in order to work the alluvial gravels and one dredging company has found a part of such an old dam. There may, however, be some portions of the larger streams that have never been worked where dredging would be highly successful.

Grão Mogol District.—The Grão Mogol district lies about 100 miles north of Diamantina along a tributary of the Jequitinhonha. Diamonds are said to have been discovered near this place in 1771. The occurrence of the diamonds seems to be similar to that in the Diamantina district except that some are reported to occur in a hard quartzite.

Bagagem District.—Along the Bagagem River in the southwestern part of the State of Minas Geraes several unusually large diamonds have been found. In 1853 a diamond weighing 255 carats, known as the Star of the South was found there and the Dresden diamond weighing 119.5 carats was found near the same place a few months later and in 1910 the Estrella de Minas (Star of Minas) weighing 175 carats.

Adjacent to the Bagagem district along the Verissimo River in the State of Goyaz, a stone supposed to have been about 600 carats in weight is reported to have been found in 1906 but destroyed in the foolish test to determine its hardness by means of an anvil and sledge.

The other districts of Minas Geraes mentioned have yielded some diamonds but are of less importance than those described although a stone found in 1791 in the Abaeté River weighed 144 carats. There are reports of diamonds being found in several other places in Minas Geraes in addition to those mentioned.

Diamond Deposits of Bahia.—Gem diamonds were discovered in the State of Bahia about 1831 but the carbonados or black diamonds were considered of no value and consequently ignored until about 1856. Since then Bahia has ranked first among the diamond-producing states of Brazil and mainly on account of the carbonados which, with the exception of a few small pieces found in the State of Minas Geraes, are unknown elsewhere.

The diamonds and carbonados generally occur together and are found over an extensive area east of the São Francisco River in the central part and also along the Pardo and Salobro rivers in the southeastern part of the state.

Branner (21, 23), gives the following table of geologic formations:

TABLE OF GEOLOGIC FORMATION IN THE INTERIOR OF BAHIA

Names	Thickness in meters	Probable ages
Alagôas series	?	Tertiary
Sergipe series	?	Cretaceous
Salitre limestones	350	Jura?
Estancia red beds	350	Trias?
Lavras series (diamond bearing)	700	Carboniferous?
Cambão quartzites	100	(possibly part of Lavras)
Caboclo shales (Paraguassú of Derby?)	500	Devonian?
Jacuipe flints	100	(possibly part of the Caboclo)
Tombador sandstones	400	Silurian?
Minas (or Jacobina) series	1000	Cambrian?
Crystalline complex		pre-Cambrian in part?

The diamonds and carbonados are found only in those regions where the Lavras series is present. The largest areas of these beds are about Lençoes and Morro do Chapeo although there are many smaller districts lying to the north, south, and west of these places. The Lavras strata are nearly all quartzitic sandstones or conglomerates, almost invariably of a pinkish color. The rocks which are greatly cross-bedded are gently folded into anticlines and synclines. Eruptive rocks are not known from the regions where the diamonds occur.

The diamonds and carbonados are found in the loose alluvial sands resulting from the disintegration of the Lavras sandstones although in a few cases the diamonds have been observed in place in the hard strata.

The diamond-bearing sands also contain the following minerals in considerable abundance: hematite, rutile, ilmenite, tourmaline, martite, nigrine, zircon, cyanite, magnetite, garnet, "favas" (hydrous phosphates of aluminum), monazite, staurolite, etc.

The Bahia diamond fields have yielded one brilliant weighing 76½ carats and one carbonado of 3,148 carats, 120 carats more than the famous Cullinan diamond.

The methods of obtaining the diamonds are similar to those employed in the Minas Geraes fields, only the simplest tools being used in the mining and washing of the gravels.

Diamond Deposits of Goyaz.—The diamond deposits of Goyaz are not well known but diamonds have been found in several places along tributaries of the Araguaya and Paranahyba rivers.

Diamond Deposits of Matto Grosso.—The diamond industry of Matto Grosso centers about the region of Cuyabá. Up to 1850 according to one writer over a million carats of diamonds were taken from the Cuyabá River while desultory work has been carried on there ever since with important discoveries from time to time. Intermittently the industry is revived and for a while furnishes employment to several thousand persons. The stones are mainly of small size.

Diamond Deposits of São Paulo.—Diamonds have been found in several places in the State of São Paulo, along the Paraná, Paranapanema, and Verde rivers.

Diamond Deposits of Paraná.—Some diamonds have been found along the Tibagy (Tipagy), Pitanguy (Pitangru) and other rivers in the State of Paraná in a region of Devonian sandstones and conglomerates.

Diamond Deposits of Piauhy.—Some small diamonds have been reported to have been found at Borracho Fonda about 100 miles east of Therezina in the State of Piauhy.

Origin of the Brazilian Diamonds.—Since the discovery of the diamonds of South Africa, Arkansas, and British Columbia in basic eruptive rocks geologists have generally come to accept such an origin for all diamonds and to regard the Brazilian diamonds as of secondary origin in the rocks containing them. The pipes from which the diamonds came are believed to have been covered by later sediments or to have thus far escaped discovery (81).

Branner (23), however, states that "he is strongly inclined to believe that the diamonds of Bahia have their origin in the quartzites (Lavras series) where they have been occasionally found in place, and that they are associated with minerals characteristic of metamorphic rocks for the reason that those minerals also originated in the quartzites under the same conditions as the diamonds themselves."

Gorceix advocated a similar origin for the Minas Geraes diamonds in which case the diamonds probably originated in the Caraça quartzite while Derby is inclined to think that in part at least, the diamonds are of pegmatitic origin in the quartzitic sandstones.

The evidence for reaching a final decision between the theories is still wanting. The writers are disposed to believe that their occurrence in the quartzites, sandstones, and conglomerates is secondary and that the igneous rocks in which they originated may some time be discovered among the great series of crystalline rocks constituting the basement complex. However, the fact that the diamonds found in certain adjacent localities possess distinctive features, as claimed by the diamond dealers of the Diamantina district, may point to a local origin in the Caraça quartzite. If they have come from volcanic pipes and were transported from their place of origin by running water, one might expect less distinction in near-by streams than if they owe their formation to metamorphism of the rocks which now enclose them. Igneous rocks have recently been discovered not far from the Diamantina district but information in regard to their character is not available. The question of the origin of the Brazilian diamonds must be regarded as unsettled.

Future of the Diamond Industry of Brazil.—Although diamonds have been produced in Brazil in considerable quantities for almost 200 years, the supply is not yet exhausted and the probability is that it will continue for many years to come. One may predict with confidence that new finds will continue to be made from time to time, as there are known areas that contain virgin ground, while many deposits will justify re-working.

Due to the restricted character of the deposits it will probably never be advisable to undertake extensive operations with elaborate equipment of machinery unless by means of dredging. Along some of the larger streams some extensive areas covered with thick deposits of stream gravels may be found sufficient to justify such methods as are employed in various gold placer regions.

Although all of the other kinds of precious stones together do not represent much value they are deserving of a few words.

Agates.—Agates are abundant in amygdaloidal rocks in the Serra Geral range of the State of Rio Grande do Sul. They are usually picked up as water-worn pebbles along the streams. Most of them are shipped abroad for artificial coloring and polishing.

They are also common along the Guayras River in the State of Ceará and along the São Francisco River near the Paulo Affonso Falls.

Amethysts.—Many beautiful amethysts have come from many places in Brazil. The best have been found in druses in amygdaloids in the State of Rio Grande do Sul, although the principal supplies have come from the states of Bahia and Minas Geraes.

Aquamarines.—Quantities of aquamarines have been found in pegmatite dikes about Minas Novas, Arassuahy, Peçanha, and Theophilo Ottoni in the State of Minas Geraes. Some of them are of unusually large size. The largest known was a transparent prism weighing 110½ kilograms.

Garnets.—Garnets are widespread in the ancient crystalline rocks of Eastern Brazil while some of gem quality have been found in Bahia, Minas Geraes, and Espirito Santo.

Topaz.—For more than 100 years Brazil has produced large quantities of topaz. The district about Ouro Preto has been the chief source although many have come from other sections of Minas Geraes, from Pernambuco, Rio de Janeiro, and Paraná. The ones found near Ouro Preto are mainly white or yellowish; near Minas Novas many of the stones are blue. In most places the topaz gems are found in the stream gravels but near Ouro Preto they occur, according to Derby (48), in dikes of eruptive rocks intruded into greatly metamorphosed schists.

At the present time the topaz industry does not seem to be especially profitable.

Tourmalines.—Many beautiful tourmalines of various colors have been found in the metamorphic rocks of Minas Geraes and adjoining states, especially in the valley of the Jequitinhonha River.

MICA

In a region where pegmatite dikes are common, as in the great area of crystalline rocks of Eastern Brazil one might expect to find some dikes containing large crystals of mica. It is not improbable that many places might be found if careful search were made. Thus far the places where mica has been mined are few in number and confined to the states of Minas Geraes, Bahia, and Goyaz. The quality of the Brazilian mica is excellent and the production has been rapidly increasing. In 1916 it amounted to 53,743 kg. valued at $55,859.

Minas Geraes.—The principal mica mines of Brazil are located near Santa Luzia de Carangola on the borders of Minas Geraes and Espirito Santo and at Peçanha, northeast of Itabira de Matto Dentro. Scott (136) says that a number of mines have been opened there in the pegmatite dikes which are included in the metamorphic schist. The feldspar of the pegmatites has altered to kaolin to a great depth thus permitting the miners to readily free the mica crystals from the associated minerals. Very close to the surface the mica itself has been altered sufficiently to be of very little value, the quality increasing with depth. Some mica crystals or "books" are encountered 10 in. × 20 in. × 6 in., but the average size is about 6 in. × 6 in. × 3 in. The pegmatite dikes vary in width from 20 in. to 10 ft.

The two principal mines are the Fonseca and Coronel Seraphino. The mica "books" are cleaved and trimmed at the mines, carried to Santa Luzia on the backs of mules, and shipped by the Leopoldina Railway to Rio de Janerio for export. A good margin of profit has been made.

Bahia.—Some mica mines have been intermittently worked in the State of Bahia. Branner (21) states that he has seen mica crystals 15 cm. in diameter in a pegmatite dike between Jacobina and Villa Nova and equally large crystals are reported to occur in the valley of the Itapicurú River and also in the vicinity of the Paulo Affonso Falls.

Goyaz.—Mica of excellent quality comes from the State of Goyaz but the deposits have been worked only to a small extent. The most important are in the municipality of Meia Ponte.

Rio de Janeiro and São Paulo.—The states of Rio de Janeiro and São Paulo also contain some promising mica deposits. Mines are in operation at Juquie and deposits have been discovered near Bananal, Itapecerica, Paranahyba, and São Bernardo, in São Paulo.

SALTPETER (POTASSIUM NITRATE)

In various places in the São Francisco River valley deposits of saltpeter have been reported. In some cases the saltpeter is found in association with other salts where ponds or lakes have formerly existed, but the most important occurrences are in the numerous limestone caverns of the district. Although these cave deposits have been worked locally on a small scale for many years no industry of importance has been developed nor have any systematic investigations been carried on to determine the quantity of such materials available. The remoteness from railroads and the small local demand is responsible for this state of affairs.

Along the Rio Salitre which is a tributary of the São Francisco, there are many of these limestone caves in which the cave earth is impregnated with saltpeter. Branner (21) believes that the saltpeter has

"been formed in many instances by the reactions produced by the potash minerals and the droppings of small rodents, called *mocó*, that live in the caves. In some cases it seems to have been washed in from the surface."

Some promising deposits of potassium nitrate have recently been discovered in the southern part of Piauhy. A sample of the earth yielded 11 per cent of soluble salt which on analysis was found to contain 82.39 per cent potassium nitrate and 27.00 per cent sodium sulphate. Nitrate deposits occur in Ceará and also in the western and especially the southwestern part of Pernambuco.

SALT

A large part of the salt consumed in Brazil is imported, although the country is not entirely lacking in salt deposits.

Rock salt is said to have been mined in limited quantities in Matto Grosso and Goyaz. Considerable salt is obtained in the states of Rio Grande do Norte, Alagoas, Sergipe, Ceará, Piauhy, and Rio de Janeiro through the evaporation of ocean water or the water of partially enclosed lagoons.

In the São Francisco River valley in Bahia considerable salt is obtained by leaching the surface soils where small ponds have disappeared by evaporation. Naturally such salt contains impurities as does that obtained from ocean waters.

FELDSPAR AND KAOLIN

The numerous pegmatite dikes of the country are believed to contain feldspar of economic importance as indicated by those which have been worked for the mica. Near the surface the feldspar has been altered to kaolin. Some kaolin deposits have been worked in a small way in the states of Rio de Janeiro, Rio Grande do Sul, Bahia, and Minas Geraes.

GRAPHITE

Graphite specimens of excellent quality have been brought from many places. In Minas Geraes graphite occurs near Ouro

Preto, Marianna, Santa Rita Durão, Tripuhy, and at Emparedado about 18 miles from the Jequitinhonha River. Some deposits at São Fidelis in the State of Rio de Janeiro have been worked and also some at Tripuhy in the State of Minas Geraes. The graphite from the former locality has been used in a pencil factory at Rio de Janeiro.

BAUXITE

Deposits of bauxite are said to occur in several places in the lateritic clays but have not been worked. Ferruginous bauxite also occurs in association with the Canga of Minas Geraes.

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CHAPTER V

CHILE

Among the countries of South America, Chile has long appealed to the mining profession because of the variety and richness of its mineral wealth. There was a time when the world looked to Chile for the bulk of its copper and after an *interim* of several years the copper mining industry of the country again challenges the attention of the entire world. It has furnished other countries with quantities of silver and now is beginning to contribute its share of iron ore for the foreign markets. In regard to its natural nitrates, however, it has no rival and probably never will and so possesses a monopoly that was never thoroughly appreciated until the Great War caused other nations to realize the value of these unique deposits.

PHYSICAL CHARACTERISTICS

In its physical features Chile is unique among all the countries of the world. With the exception of Brazil it extends through more degrees of latitude than any other country while in proportion to its size it possesses more shore line than any other continental country. It extends from 17° 10′ to 55° 59′ south latitude. It has a total length of 2,625 miles with an average width of less than 100 miles, excluding the islands, and contains about 291,500 square miles. Except in the extreme southern part where the regions bordering both sides of the Straits of Magellan belong to Chile, the country is everywhere bounded on the east by the crests of the Andes Mountains and on the west by the Pacific Ocean.

Topographically the country is divided longitudinally into three fairly distinct sections; the Maritime or Coast Range Mountains, the Central or Longitudinal Valley, and the Andes Mountains.

The Maritime or Coast Range is not continuous throughout the country from north to south but instead is broken in many places by transverse valleys or bays. However, as one sails along the coast from the Island of Chiloe to the Peruvian border the dominant feature observed is a mountain barrier rising precipitously from the shore and presenting a remarkably even sky line for long distances. The principal cities of the coast are either confined to narrow strips of land between the shore and the precipitous barrier or else located in the valleys of some of the transverse streams that enter the ocean.

Good harbors are practically absent from Puerto Montt northward, most of them being merely shallow indentations in the very regular shore line. Exceptions are the harbors of Talcahuano and Coronel where spurs of the mountains extending into the ocean as peninsulas and islands form protected bays. The mountains of the Coast Range are never high, the highest being only about 6,000 feet above sea level. They consist, in many places, of several parallel ridges separated by deep valleys. No volcanic peaks are present. From Chiloe Island southward the Coast Range is continued as a chain of islands representing the highest parts of the submerged chain.

The Central or Longitudinal Valley lying between the Coast Range and the Andes Mountains is, in some parts, more distinct than the Coast Range but elsewhere is interrupted by transverse river valleys or by knots or spurs of mountains that extend from the Andes to the Coast Range. In the Pampa of Tamarugal where there are extensive nitrate deposits it is well-defined, forming a broad plateau. South of this the valley feature is observed in the Atacama Desert and several other places as far as Copiapó and beyond, but in the provinces of Coquimbo and Aconcagua knots of mountains connect the Andes and Coast Ranges. From Santiago southward to about Lat. 39° S. the Central Valley is best defined and constitutes the agricultural part of Chile. From Lat. 39° S. it is continued as a series of lakes to Puerta Montt and thence southward to the end of the continent as a series of archipelagos.

The Maritime or Western Cordilleras which form the boundary line between Chile and Bolivia and the single range of the Andes which forms the boundary between Argentina and Chile, except in the extreme southern portion, constitute a barrier that has long interfered with free communication between the adjoining countries. There are few passes less than 10,000 feet in height. Even now with two railroads crossing the Chilean-Bolivian Andes and one crossing the Chilean-Argentinean Andes there is but

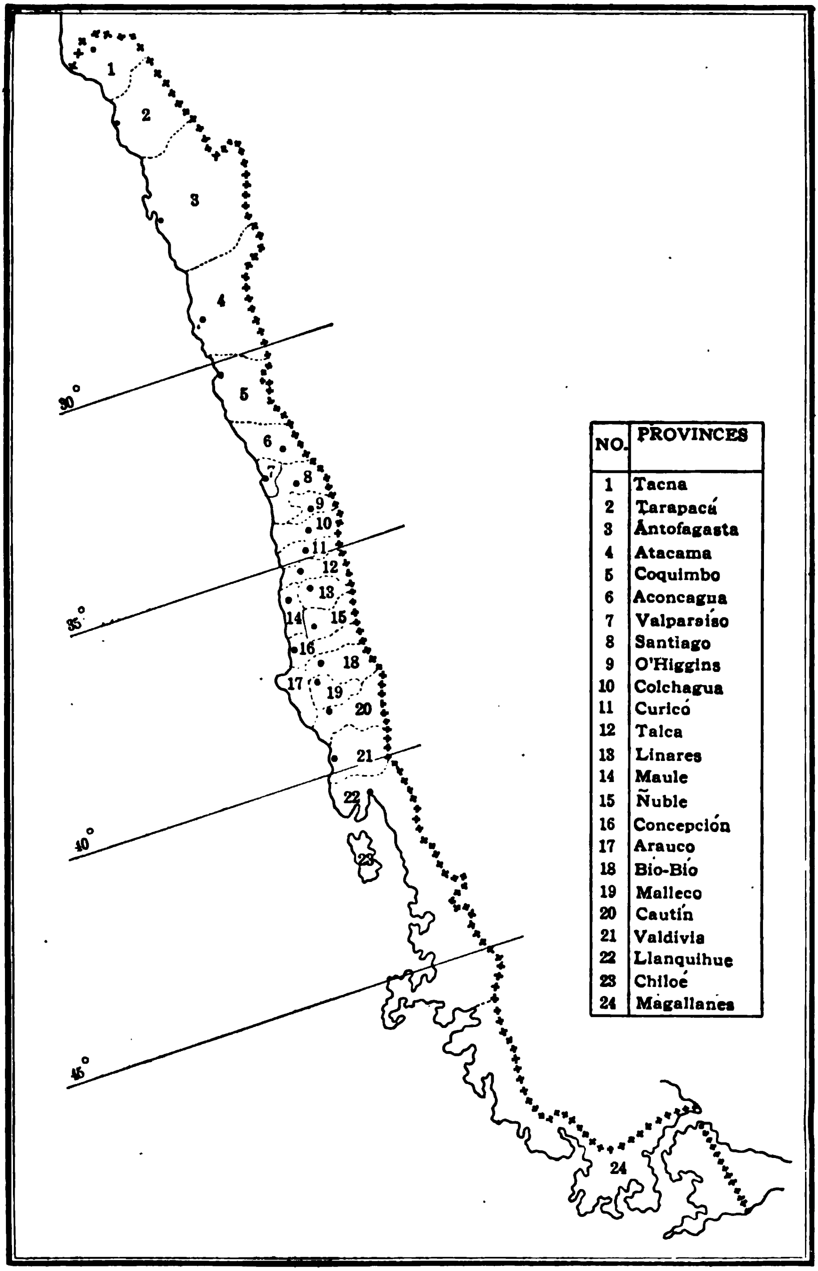

Fig. 25.—Map of Chile showing location of provinces.

little communication and only slight exchange of commodities. Were it not for the progressive spirit of its people Chile might easily become an isolated and hermit nation.

The Andes consist of a series of complexly folded mountains with numerous volcanic peaks rising above them. The culminating peak is Mt. Aconcagua, with an elevation of approximately 23,000 feet. They constitute about 35 to 40 per cent of the entire area of the country and owe their value almost entirely to the mineral wealth which they contain. Their mineral deposits furnish the basis for the country being known mainly for its mining industry. From Puerto Montt, where the Central Valley is succeeded by the numerous inland waterways, southward to Cape Horn the Andes extend to the water's edge but the decreased height in this portion renders them less impressive than where farther northward they form the eastern wall of the Central Valley or the nitrate pampas.

OUTLINE OF THE GEOLOGY OF CHILE

The geological features of Chile are geographically divided into three parts corresponding to the three physiographic divisions described above. The Coast Range mountains consist mainly of a central mass of ancient crystalline rocks—schists, gneisses, granites, gabbros, etc.—unconformably overlain by Cretaceous and Tertiary marine sediments. From Antofagasta southward to Puerto Montt these crystalline rocks are exposed almost continuously and appear in most of the fringing islands from Chiloe to Cape Horn.

From Antofagasta northward the crystalline rocks are exposed only in isolated patches as at Mejillones. The age of these crystalline rocks is undetermined. By some they are regarded as Paleozoic but by others are considered Archean.

The eastern range of mountains—the Andes—is composed of folded Mesozoic and Tertiary strata of both fresh water and marine origin associated with many igneous rocks—volcanic lavas, dikes, sills, etc. Vulcanism in this region continues to the present although it is gradually dying out and no lavas have been poured out within recent years. However, one does observe, in many places, fields of lava with such a fresh appearance that it almost seems as though they were poured out but a few years ago.

In both ranges of mountains the structures are so complex that generalizations are of little value. In certain sections the geology has been worked out in detail but for the larger part accurate geological information is still lacking.

Between the two mountain ranges, particularly in the Pampa of Tamarugal, the Desert of Atacama, and the Central Valley of Chile extending from Santiago southward to Puerto Montt, are extensive areas of Pleistocene or Late Tertiary land sediments washed from adjoining highlands. In the desert region these have afforded a locus for the accumulation of the valuable soluble salts of sodium nitrate, iodine, borates, etc., while in the rainy regions these loose sediments constitute the agricultural soils throughout almost the entire farming section of the country.

CLIMATE

It is doubtful whether any other country in the world furnishes a better example of the relation existing between the climate and the occupations of the people and the development of the country, while certainly no other shows more strikingly the relation between the climate and the character of the mineral deposits.

Climatically, Chile is divided into three fairly distinct regions that may be characterized as the rainless belt, the belt of moderate rains, and the belt of excessive rains. The first occupies the northern part of the country and extends southward to about the region of Chañaral in Lat. 26° 20′ S. In that section the high Andes receive occasional heavy rain storms in the summer but the lands to the west may not experience a rainfall for many years at a time. The only moisture received comes from the fogs, known as *camanchacas*, that occasionally come from the ocean. With the exception of the Loa River no stream of any consequence enters the ocean for a distance of 600 miles in the northern part of the country.

From Lat. 26° S. to Lat. 40° S. in the vicinity of Valdivia rain falls mainly during the winter season and the amount gradually increases from north to south. At La Serena the annual rainfall is about 6 inches, at Valparaiso 22 inches, at Concepción 48 inches, and at Valdivia 99 inches. In this belt the Central Valley receives least rain, the Coast Range more, while the high Andes excessive rains. The result is that many streams from the Andes have cut transverse valleys entirely to the ocean. This is the belt in which practically all the agriculture of the country is carried on.

In the southern part of the country the rainfall is excessive during all periods of the year. At Cape Raper in Lat. 47° S. an annual rainfall of 219 inches has been recorded. This region is, in the main, heavily forested, and contains large unexplored areas.

The presence near shore of the northward-flowing cold Humboldt current and the high chain of the Andes lying close to the shore are the chief causes for the climatic conditions described. The rainless area lies in the belt of the southeast trade winds which means that the prevailing winds come from that direction. As they rise to pass over the Andes they are cooled and depleted of their moisture which mainly falls on the eastern slopes of the mountains. As the air moves down the western slopes it becomes heated and becomes a drying air, able to take up any moisture that there exists in the liquid form. Even in the trade winds belts, however, the wind may come from the ocean, as it frequently does in the northern part of Chile, but it has been so greatly chilled by passing over the cold Humboldt current that on reaching the land it is seldom sufficiently cooled to produce more than a fog.

This rainless belt, the most desert part of the South American continent, long regarded as a dreary waste, has become the richest part of the entire country on account of the valuable deposits of sodium nitrate, iodine, borates, and soluble copper minerals that have accumulated there because of the absence of rainfall.

South of the trade winds belt the prevailing winds come from the west and increase in velocity until in the southern part of the country they blow with almost hurricane force. Going southward the temperature of the land decreases so that in the winter it becomes colder than the ocean and rain results, while in the extreme south the air over the Andes is always cooler than over the ocean and heavy rains occur throughout the year. As the aridity of the north has contributed to the mineral wealth of that section so has the rigorous climate of the south interposed obstacles in the search and development of any mineral wealth there contained and little information has been obtained in regard to the resources of the area lying to the south of Valdivia.

HISTORY OF MINING IN CHILE

Before the arrival of the Spaniards (Almagro in 1535 and Valdivia in 1540) the Indians produced some gold and silver which they used for ornaments for themselves and as tribute to the Incas who had conquered the northern portion of what is now included within the boundaries of Chile. It also seems probable that they worked some copper mines to a slight extent. The Spaniards went south from Peru in search of the precious metals and during their régime, terminating with the declared Independence of the country in 1810, produced much gold, silver, copper, and some mercury. During the period of Spanish rule about 231,000 kg. of gold was produced, 264,750 kg. of silver, and 83,050 tons of copper. The fact that more gold was produced under the administration of the Spaniards than has been obtained since, while the silver and copper production since 1810 is many times as great as before that time, conclusively shows that the Spaniards' main desire was for gold, most of which was sent to the mother country.

As usually happens in every mining country the period of mining is divided into two eras. In the first one, the rich and most easily obtained deposits are located and worked to the point of exhaustion or until the difficulties increase and new methods must be introduced. Most mines at this stage are abandoned and the industry falls into disfavor. Chile reached the climax of its metal mining between 1870 and 1880 and for many years the production steadily declined. Within the last few years, however, all this has changed due to the phenomenal success that has been attained in the operation of several extensive low-grade copper deposits and the entire mining industry is being revived with the prospect that the country is now entering upon the most prosperous period of its entire history. The nitrate industry which began much later than metal mining has not suffered the same depression that the other kind of mining did and yet it too is participating in the increased prosperity.

The chief reasons for the increased activity of the Chilean mining industry are the higher prices obtained for most of the mining products, the development of many new metallurgical processes by which lower grade ores can be worked with even greater profit than high grade ores at an earlier day, and the improvements in transportation facilities by which supplies can be readily obtained in regions formerly almost inaccessible and the products of the mines can be promptly and cheaply sent to the ports for shipment.

CHARACTER AND DISTRIBUTION OF CHILE'S MINERAL DEPOSITS

The country furnishes a wide variety of mineral wealth and many of the minerals exist in such large quantities that mining will long remain the most profitable industry of the country.

The major metallic products of Chile are copper, gold, silver, iron, and manganese; minor ones are lead, zinc, cobalt, mercury, vanadium, molybdenum, antimony, bismuth, and nickel with still others reported to occur. The important non-metallic products are sodium nitrate, iodine, borates, salt, guano, coal, and sulphur; graphite and feldspar are found but not actually worked. In addition the country contains many valuable building stones of various kinds.

Of the materials mentioned all the metallic products and graphite, feldspar, and sulphur of the non-metallic substances are found either enclosed by or closely associated with the igneous or metamorphic rocks and are found in the mountainous sections. Most of them are found in both the older and the more recent cystalline rocks. The deposits of nitrate, iodine, borate, salt, and guano are found in the desert regions of the north and with the exception of the guano almost entirely confined to recent alluvial deposits. Sulphur occurs in the volcanoes that are located along the crest of the Andes between Chile and Bolivia, while coal is found in a few widely separated localities, the most important area being situated in the provinces of Arauco and Concepción and less important ones near Punta Arenas and Copiapó.

Up to the present time, practically all mining has been confined to the region from O'Higgins province northward to Tacna, with the great proportion of mines situated north of Valparaiso, and it is probable that these sections will always contain the chief mining centers. This does not include the chief coal centers nor the gold placers of Tierra del Fuego. Southward from O'Higgins gold has been found in several places and other economic minerals reported but the rigorous climatic conditions existing there have deterred prospectors from making investigations.

With the exception of a few mines located at high elevations, such as the Braden Copper Mine east of Rancagua, most of the mines are located in areas of light rainfall or extreme aridity and in regions of moderate to high temperatures.

COPPER

Next to the nitrate deposits the abundant copper deposits constitute Chile's richest mineral possessions.

History of Copper Mining in Chile.—Before the arrival of the Spaniards it is believed that the Indians had worked some of the copper deposits. The early Spaniards were most eager for gold and silver and paid little attention to the copper consequently, according to the records, it was not until 1601 that copper mining was resumed under their direction. Since that time copper mining has been carried on in Chile although not until 1842 did it assume much importance. Up to that time the high-grade carbonate and oxide deposits found near the surface were worked and the ore smelted in charcoal furnaces. In 1842 Charles Lambert built the first reverberatory furnace at Coquimbo, and in 1857 followed this achievement by the erection of the first blast-furnace. For a few decades the production gradually increased; Chile became the leading copper-producing country of the world; and in 1876 produced 46,422 tons of copper.

There then followed a decline and in 1882 the United States displaced Chile as the leading copper producer while the Chilean production rapidly fell to about 25,000 tons a year which was maintained for nearly a quarter of a century. With the beginning of this century, the copper industry began to revive slowly; during the year 1916 Chile exceeded its former record production made 40 years before and advanced from sixth to third place among the copper-producing countries of the world. The production for that year was 71,340 tons.

Even yet the revival of copper mining in Chile is only in its beginning, so far as production is concerned, and the time may not be far distant when even the United States will need to look to its laurels in competition with this old, yet newly revived, copper mining country of the southern hemisphere. When we recall that one of the Chilean copper companies is now forming plans for a plant that will ultimately produce almost 300,000 tons of copper yearly from one mine, more than 6 times as much as the aggregate amount produced at the present time by several hundred mines, one can realize why the Chileans are so optimistic in regard to copper mining in their country. Chile will, no doubt, shortly displace Japan as the world's second largest copper producer. From 1811 to 1916 inclusive Chile produced 2,458,340 tons of copper.

The reasons for the fluctuations in the copper production of Chile are not difficult to discover and are due to the unusual climatic conditions prevailing in the regions where the copper deposits are largest and have been most energetically worked. With few notable exceptions, nearly all the developed copper mines of the country are located in those portions of the country where little rain falls. The arid conditions have favored deep oxidation of the country rocks and ores while erosion, reduced to a minimum by the scarcity of running water, has accomplished little in the removal of the decomposed rocks. Leaching of the upper layers has also had little effect because of the very infrequent rain storms. The result of these conditions is that Chile has had many hundreds of copper mines that were easily and profitably worked "from the grass roots." These were the mines first operated. In many of them within a depth of 30 to 40 feet the rocks became harder, additional equipment was required, and the mines were abandoned. In the active period from 1850 to 1880 many mines were operated in which sulphide ores were the main source of supply but these were only the richest ones. The decline in the industry from 1876 to 1900 was caused mainly by the exhaustion of the very rich deposits that could be worked with almost no equipment, although the scarcity of labor on account of the expansion of the nitrate industry, the lack of transportation facilities, and the price of copper were contributory causes.

The revival of copper mining in the country is due almost entirely to the improved methods of ore concentration which render the operation of extensive low-grade ore deposits not only feasible but immensely profitable. Fortunately Chile has great ore reserves of this character and from these the bulk of the country's future production is to come.

Foreign capital has also been very important in reviving copper mining. It is questionable whether a few years ago any one could have been successful in interesting local capitalists in a project in which millions of dollars would have to be invested in equipment and development before a pound of copper could be produced. Yet that was what was needed to make profitable mines where large deposits of low-grade ores occurred.

The many new railroad lines that have been constructed since 1900 have also done much to revive copper mining as one can readily appreciate by taking the trip over the longitudinal railroad between Coquimbo and Santiago and observing the number of stations where copper ore is piled on the platform awaiting shipment. Large companies may build their own lines of railroad but the hundreds of smaller ones of the country had to wait for the railroads unless they happened to possess mines situated close to the coast.

Distribution of the Copper Deposits of Chile.—Throughout the greater portion of Chile copper ores occur in two rather distinct mountain ranges separated by the longitudinal valley. In the western or Coast Range, most of the mining has been done on account of the proximity to shipping ports. Hundreds of mines near the coast have been worked in the vicinity of Iquique, Antofagasta, Taltal, Chañaral, Caldera, La Serena, Coquimbo, etc. The other belt of copper deposits lies inland in the foot-hills or even along the crests of the high Cordillera from 50 to 75 miles from the coast. These have, as yet, been worked only to a small extent but probably contain as valuable ores as the regions lying to the west. In addition there are other copper deposits occurring in isolated groups of hills intermediate between the Coast Mountains and the High Andes.

The copper mines extend from near the northern boundary of the country southward to O'Higgins Province, where the great Braden mine is situated, but Antofagasta, Atacama, Coquimbo, Aconcagua, Santiago, and O'Higgins are the leading copper-producing provinces. Copper ores have been reported in places in the southern provinces but the deposits have not been developed.

While naturally the rocks in the two bands described have not everywhere been sufficiently mineralized to be worked yet the number of occurrences of copper minerals in this great distance is quite remarkable. Even where copper ores are not expected to occur careful search will frequently show their presence. For example, in the excavation for the ship basin which the Bethlehem Steel Company is constructing at Cruz Grande several small veins of chalcopyrite were encountered in the basic igneous rocks. Sufficient pieces of ore were collected by the workmen to warrant a small shipment to a nearby smelter.

Character of the Copper Ores and Associated Rocks.—Generalizations regarding the character of the enclosing rocks of the copper ores are somewhat unsafe because of the wide variations as well as lack of data in regard to many of the deposits. It seems that practically all the deposits occur in or closely associated with igneous rocks varying from the basic to the most acid. Quartz porphyries, diorites, and andesites, are the most abundant rocks found with the copper ores yet in many places the basic rocks—diabase, gabbro, peridotites, etc.—contain the veins.

The rocks containing the ores have been greatly shattered in most mining districts while faults are abundant. The dynamic disturbances which are so common throughout Chile would naturally have this effect and, as much of the mineralization has taken place in the openings caused by the fracturing of the rocks, we have evidence furnished to show that the region has long been subjected to frequent and violent earthquakes. In some places hills of rocks have been so broken by these earth movements that it would be difficult to get out blocks large enough for the construction of buildings or bridge foundations.

The primary ore minerals, as in other regions, are mainly chalcopyrite, enargite, and bornite; the secondary sulphides are chalcocite, bornite, and chalcopyrite; and the minerals of the oxidized zone are brochantite, atacamite, chalcanthite, kröhnkite, malachite, azurite, chrysocolla, cuprite, and native copper. The great variety of minerals found in the oxidized zone and also the depth to which they occur are the unusual features which distinguish the Chilean copper deposits from those of any other part of the world. Brochantite, atacamite, chalcanthite, and kröhnkite have been found in other regions but never in commercial quantities, but in many of the mines of northern Chile these are the chief copper minerals. As all of these minerals are readily dissolved they naturally occur only in extremely arid regions and outside of Chile few copper deposits have been discovered in deserts. The depth of oxidation averages much greater in the Chilean copper mines than elsewhere. In the Dulcinea Mine, 45 miles northeast of Copiapó, oxidized ores are reported to occur at the depth of 1,500 feet from the surface.

Another peculiarity of the Chilean copper deposits is the thickness of the zone containing mixtures of sulphides and oxidized ores. In places this band is several hundred feet thick. In the Panizo mine, at Chuquicamata, at the same level and only a few feet apart, are veins of almost pure brochantite and others of chalcocite and enargite. The explanation for the lack of a more or less definite line of contact between the oxidized and the sulphide ores is found in the scarcity of the water which falling as rain carries the oxidizing agents downward. There is not enough rain at one time to saturate the earth down to a permanent water level consequently the small amount of water that does fall finds its way downward along the lines of greatest shattering or through the rocks of greatest pore space and the ores contained in the more compact rocks do not come into contact with the descending waters.

Since the oxidized and sulphide ores require different methods of treatment or concentration, when too low grade in character to be sent to the smelter direct, the mingling of the two classes is objectionable and may prove a serious obstacle in the operation of the low-grade deposits which are best adapted for steam-shovel work.

Unfortunately sufficient data are not available for the determination of the characteristics of the sulphide-enriched zone in many different regions, due mainly to the ephemeral history of the mines and the lack of any records of what was encountered in the old workings. Nevertheless, Chile offers a most unusual field for investigation of the secondary changes of copper ores and it is hoped that at some time geologists may be given opportunities to study these problems in the Chilean copper mines as they have done in the copper mines of the United States. Detailed investigations of this character would doubtless be of immense assistance to the future development of the mines of the country.

Apparently few copper mines of Chile have mined the primary ores so that they remain practically unknown. At the Braden Copper Mine, it has been stated, that the ores worked are all primary except in a few places where some cuprite and native copper occur; but recent developments seem to throw some doubt on this assertion, and it may be found that the ores so far proved are mainly the result of secondary sulphide enrichment. Whether the primary ores of Chile will prove to be rich enough to work in many places is as yet merely conjectural. The results of deep drilling indicate that they will not be found rich enough to be profitably worked at Chuquicamata but that is a low-grade deposit even in the enriched zone. It is probable that the disseminated ore deposits of low grade will only warrant working to the bottom of the zone of secondary sulphides but many of the vein mines can continue to be operated with profit in the primary ores. The great depth of the secondary ores, probably an average of 1,200 feet or more throughout northern Chile, means, however, a comparatively long existence for the mines even though they be abandoned when the primary ores are encountered.

Province of Tacna.—Several small copper mines have been worked in the Cordillera of the Province of Tacna but none of much importance. Promising copper deposits are said to occur near Putrez, Cochelimpo, Victor, and Tacna.

Province of Tarapacá.—Copper deposits are known in many places in the Province of Tarapacá both in the Coast Mountains and in the high Cordillera. The Collahuasi and Copaquire copper districts in the southeastern corner of the province are the only ones that have received much attention and merit individual descriptions (Fig. 32).

The Collahuasi (102)* district lies at an elevation of 15,000 feet above sea level in a cold and bleak region and includes a known mineralized area about six miles square. The entire region is composed of volcanic rocks, lavas and tuffs of andesite, diorite, and dacite, with intrusions of diabase and gabbro.

The copper-bearing lodes occur in lenticular masses in fissured zones of andesite. Some of the lenses attain a length of 100 feet and a thickness of 50 feet. The oxidized ores extend to a depth of 250 feet, below which is a thick zone of secondary sulphides. Chrysocolla, bornite, chalcocite, and cuprite are the common ore minerals but chalcopyrite, melaconite, azurite, malachite, brochantite, atacamite, tetrahedrite, and native copper are common.

The tenor of the ore is high, an average sample yielding 18 per cent copper, 6 oz. silver, and traces of gold.

A number of different companies own properties in the district but only two have been active in recent years. The ore is shipped over a branch railway line 50 miles in length to Ollagüe and thence to Antofagasta by the Antofagasta and Bolivia Railway. The annual production is about 50,000 tons.

The Copaquire (211) copper deposits are located about 130 miles east-southeast of Iquique in a barren rainless region about

*Numbers in parentheses refer to articles in bibliography at close of chapter.

11,000 feet above sea level. The deposit has only been worked to a slight extent because of the lack of easy transportation and the absence of any local water or fuel supplies.

Copper sulphate which is the chief copper mineral, occurs in the hydrated form disseminated in thin irregular veins throughout the rocks over a large area so that the amount of copper present is very great. The principal rock is decomposed porphyry but there are also granites and metamorphic rocks.

There is 3.25 per cent of copper in the form of copper sulphate, 0.80 as the carbonate, and 0.31 as sulphide, or 4.36 per cent copper altogether in the ore. The ores should be treated by leaching but as the nearest stream is 15 miles distant it would require a large amount of capital to secure an adequate water supply.

Province of Antofagasta.—The Province of Antofagasta at the present time occupies the foremost place which it will probably long retain on account of the extensive copper deposits at Chuquicamata. Yet these are not the only ones found in the province as deposits have been worked in numerous places both in the Coast Range and also in the Cordillera. All of the departments of the province contain copper mines.

In the Department of El Loa the leading mines are those of Chuquicamata near Calama, described in detail below, some mines near Conchi, and others near San Pedro. The latter are of interest as the ore consists of native copper impregnating sandstones similar to the ores of Corocoro, Bolivia, which have been so extensively worked. The San Bartolo mine of that district contains five ore-bearing strata. The ore is said to average 8 per cent copper.

The Department of Tocopilla contains numerous copper mines. They are all found in the ancient crystalline rocks of the Coast Range and close to the coast. The most important centers are near Tocopilla, at Gatico, and at Michilla about 30 kms. south of Gatico. The Toldo Mine at Gatico has been worked to a depth of about 1,400 feet. It contains a quartz fissure vein in granite having a width of 1.20 m. The oxidized zone extends to a depth of 500 feet. Brochantite and chalcopyrite are the chief ore minerals. The Michilla mines contain an abundance of brochantite.

In the Department of Antofagasta several mines have been worked near Mejillones as well as in other places and in the

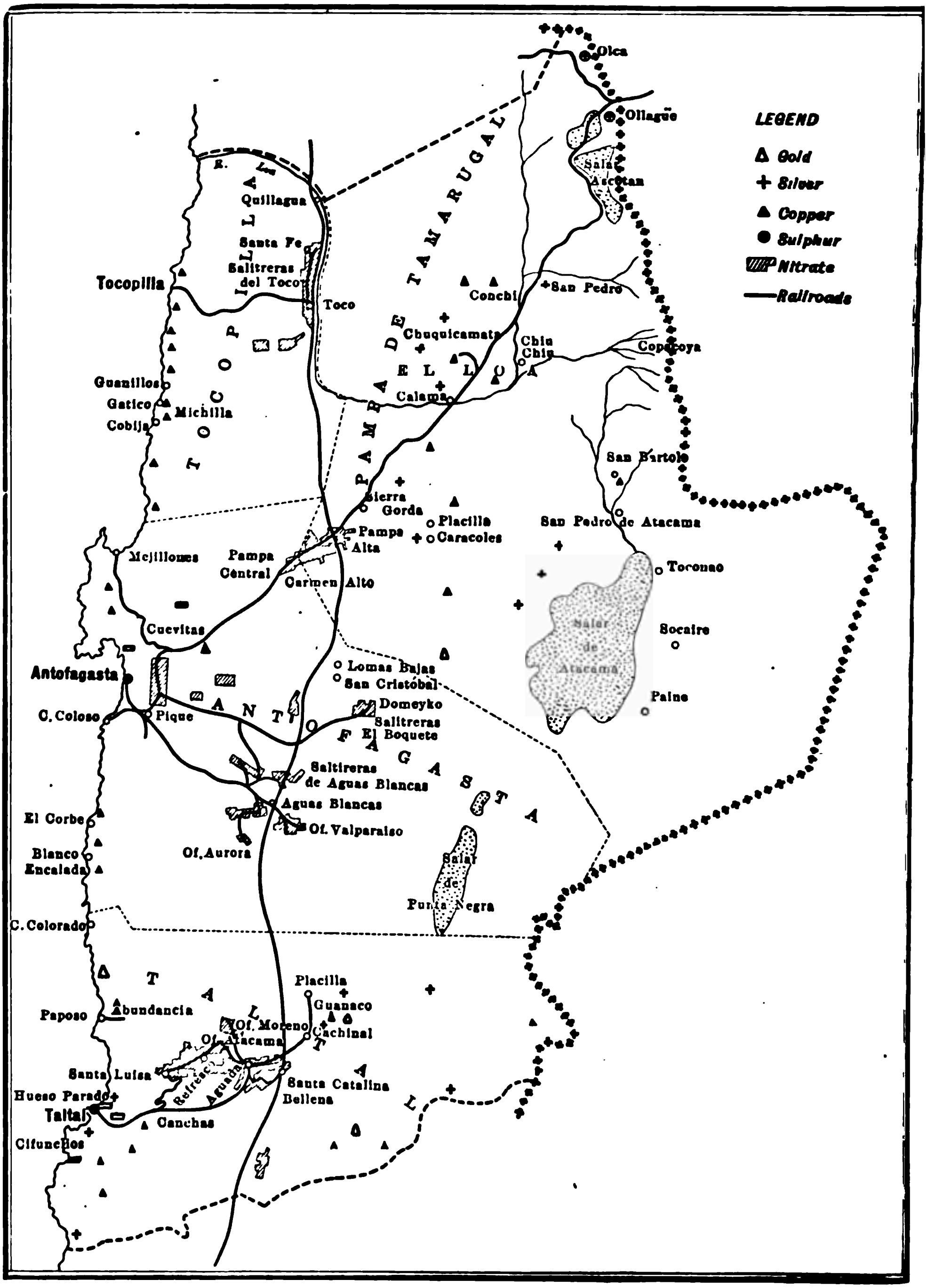

FIG. 26.—Province of Antofagasta showing location of important mineral deposits.

Department of Taltal the chief districts are near the port of Paposo and near the railroad stations of Canchas and Guanaco. In the latter district many veins in the upper levels were worked mainly for gold but in depth the gold decreased to a negligible quantity while the copper content increased.

CHUQUICAMATA COPPER DEPOSITS

The most extensive copper deposits thus far known from any part of the world are those of Chuquicamata located about 14 miles northeast of Calama and about 5½ miles from the Antofagasta and Bolivia Railway with which the mines are connected by a branch line. They occur in a hill about 2½ miles in length and one-third of a mile wide, the highest part of which has an elevation of 9,890 feet above sea level. The region is an arid one, rain or snow falling at such infrequent intervals that only a few cacti and thorny plants can exist. The rocks of the region are granodiorites.

The deposits of the hill are of two kinds. On the east side of the hill is an elongate area where wide fracture-zones of rich copper ore, usually spoken of as veins, are found cutting through the country rock while the remainder of the hill consists of greatly shattered rock so thoroughly mineralized that the entire mass of rock is considered ore. The latter class of ore is designated the "llamperas," meaning brittle mineral deposits, so called because the copper minerals are brittle and readily reduced to a powder and easily separated from the rock gangue.

The *llamperas* seem to have been worked by the Indians even before the arrival of the Spaniards as evidenced by ornaments made from the copper minerals found in ancient Indian graves. They were also worked by the early Spaniards. In the present operations mummified remains of several Indian miners have been discovered and numerous stone hammers. It seems that the deposits have been worked at intervals for several hundred years. Until the present operations were started only the richest streaks were worked and irregular openings and passage-ways are found throughout the deposit. The broken ore was brought to the surface where it was still further broken and then screened. The screenings rich in copper mineral were bagged and carried to smelters while the other portions, still carrying much copper, were thrown aside as waste. The success attained in concentrating low-grade copper ores in the United States led to the belief that the *llamperas* could be worked in their entirety and to the inauguration of the present operations that were started in 1912.

The so-called vein mines have not had such a varied history as have the others, but for several years past several of these have been actively operated. The amount of ore which they contain is very small in comparison with the *llamperas* although the tenor of the ores is much higher.

Fig. 27.—Central portion of Chuquicamata hill showing old workings.

Practically the entire area of Chuquicamata hill composed of the *llamperas* belongs to the Chile Copper Company. The mining area consists of 1,591 acres. Since the acquisition of the property in 1912 numerous drill holes have been put down in various parts of the property. As a result almost 700,000,000 tons of copper ore averaging about 2.12 per cent copper have been proved to exist while there is a strong probability that there is considerably more.

The country rock has been thoroughly shattered, due no doubt to earthquake shocks and the cracks subsequently filled with copper minerals, so that practically every piece of rock of the hill shows the presence of some copper mineral.

The unusual features of the ore deposit are the peculiar minerals of the oxidized ores. Yeatman (218) recognizes five different zones in the deposits. (1) At the top in certain portions of the hill is a leached zone from which the greater part of the copper minerals has been removed by leaching. This is of variable thickness from 0 to 545 feet. (2) The second zone is designated the "brochantite zone" from the principal copper mineral which it contains. The shattered rock is so filled with stringers of green and blue minerals that even from a distance it appears greenish in color. The minerals of this zone are almost all easily soluble and owe their presence near, or even at, the surface, to the great aridity of the climate. Beside brochantite ($CuSO_4$.-$3Cu(OH)_2$), the numerous cracks contain atacamite ($Cu_2ClH_3O_3$), chalcanthite ($CuSO_4.5H_2O$), kröhnkite ($CuSO_4.Na_2SO_4.2H_2O$), cuprite (Cu_2O), and some native copper, with some hematite, limonite, copiapite ($2Fe_2O_3.5SO_3.18H_2O$), and gypsum and sulphates of iron, sodium, potassium, and aluminium. The veins of these minerals are, in general, very thin although in some cases several inches thick. (3) The third zone is that of the mixed oxides and sulphides, there being no sharp contact between the two kinds of ore. In the vein mines, where the ores can be more carefully studied, chalcocite and brochantite are found together throughout a wide zone. (4) The fourth zone contains secondarily enriched copper minerals, mainly chalcocite and covellite. (5) The deepest zone contains the primary ore, composed of pyrite, chalcopyrite, enargite, and bornite.

Figures of the average thickness of the different zones are not available but Yeatman reports in some of the drill holes 361 feet of oxidized ores, 116 feet of mixed oxides and sulphides, and 59 feet of sulphide ores.

The ore reserves on Dec. 28, 1916, were estimated to be 700,000,000 tons. They were classified as follows:

Known ore reserves

Oxidized ore	232,900,000	tons averaging	1.89	per cent copper.
Mixed ore	73,100,000	tons averaging	2.98	per cent copper.
Sulphide ore	48,700,000	tons averaging	2.36	per cent copper.
Total	354,700,000	tons averaging	2.18	per cent copper.

Known and probable ore reserves.

Oxidized ore	339,000,000	tons averaging	1.91	per cent copper.
Mixed ore	151,000,000	tons averaging	2.98	per cent copper.
Sulphide ore	210,000,000	tons averaging	1.84	per cent copper.
Total	700,000,000	tons averaging	2.12	per cent copper.

The mining methods employed in the working of the *llampera* ores are very simple. The ore is removed in slices beginning at the top of the hill. It is blasted down, the larger pieces broken by smaller charges of powder, and then put into cars by means of large steam shovels.

The treatment of the ores by the Chile Copper Company is unique. It is accomplished by leaching the copper from the ore by means of sulphuric acid in huge concrete tanks. The chlorine derived from the atacamite must be removed before precipitation of the copper electrolytically. This is done by passing the solutions through revolving cylinders containing granulated copper which reduces the cupric chloride to insoluble cuprous chloride which is then separated by filtering and smelted. The remaining copper is precipitated by electrolysis, then melted, and molded into bars for shipment.

The present plant can handle 10,000 tons of ore a day. It is planned eventually to increase the capacity to 40,000 tons daily. No arrangements have yet been made to take care of the sulphide ores as it will be a number of years before they are reached in the mining operations.

Several mines have been worked in that portion of Chuquicamata hill where the ore minerals are concentrated in definite fracture-zones spoken of as veins. The ore bodies have a rather definite strike, approximately north and south and dip steeply. There are several of these ore bodies which are nearly parallel and continue for hundreds of feet. In width they vary up to 30 feet, or perhaps slightly more, in places. Parts of the ore bodies contain high values due to the large number of fissure and partial replacement veins but other portions are too low-grade to be mined. Between the fracture zones, or "veins," traces of copper minerals can be found almost everywhere but in quantities too small to be considered as ore.

The oxidized ores contain brochantite with only small quantities of atacamite and cuprite, and the sulphide ores much chalcopyrite and smaller amounts of enargite and chalcocite. The oxidized and sulphide ores are greatly mixed even within the same ore body. Sulphide and oxidized ores are found side by side. In the Panizo Mine oxidized ores occur at a depth of 240 feet. In general, the oxidized zone is not as deep as in the *llamperas* due to the less fractured character of the rock.

Mining of these ore bodies is done by the usual underground methods. The ore is sorted at the mouth of the mines, the higher grades being sent directly to the smelter at Calama and the remainder thrown on the dumps. In some cases these waste heaps have been worked over, the best pieces broken by hammers, and rudely concentrated in hand jigs. The concentrate so obtained is shipped to the smelter.

Province of Atacama.—Among the hundreds of copper deposits of the Province of Atacama it is difficult to select the most important for mention. The remoteness of many of the mines from railroad lines or from the coast has resulted in the working of the richest ores only. In some cases thousands of tons of ore containing from 8 to 12 per cent copper have been left in the mines or discarded on the dumps as too low-grade. Where the ores must be hauled long distances in carts, ores containing as much as 15 per cent copper are left on the dumps. In the main the mines are not deep and only oxidized ores have been obtained, although a few mines have reached the enriched sulphide zone.

In the department of Chañaral scores of mines have been worked in the Coast Range and in the western part of the Cordilleras. It is probable that other deposits are present in the higher part of the Cordillera, but, if so, their inaccessibility would render them of little value at the present time.

The Esploradora Mine in the Esploradora or Encantada Range, a counterfort of the Cordilleras, is one of the most important. In this mine there are several nearly parallel veins which join, in places, making thick ore bodies. The ore bodies have been worked for a distance of about a mile and to a depth of approximately 500 feet. The ores are now principally chalcopyrite and the product shipped in 1913 averaged 20 per cent copper. More than 75,000 tons of 7 to 8 per cent copper ores remain in the dumps. As the ores must be hauled by carts a distance of 125 miles the lower grade ores are useless. Taltal is the shipping port.

Many mines are located along the railway lines running eastward from Chañaral, the chief centers being Salado, Pueblo Hundido, Las Animas, and Los Pozos, all within the Coast Mountains. The ore bodies at Las Animas are in diorite. The oxidized ores extend to a depth of about 500 feet, below which are the sulphide ores consisting mainly of chalcopyrite. Some of the mines have reached a depth of 1,500 to 1,800 feet and, as the tenor of the ores is decreasing it seems that they are approaching the

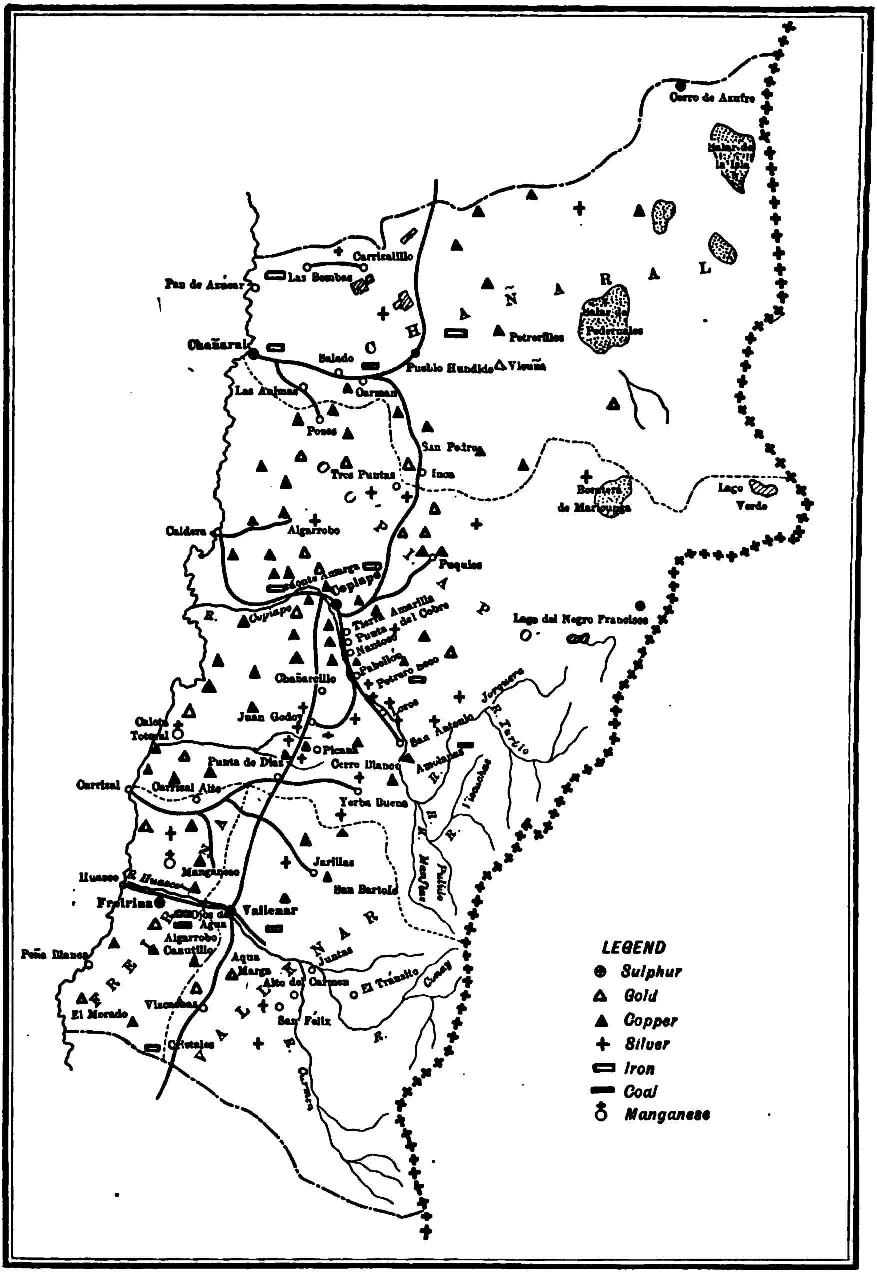

FIG. 28.—Province of Atacama showing location of important mineral deposits.

bottom of the enriched zone. The ore shipped averages about 7 per cent copper. The principal mines are the Fortunata, Fronton and Progress.

The Los Pozos district which extends into the Department of Copiapó contains many extensive lodes which have only been worked in a small way in a few places. The country rocks are porphyrites. Some of the lodes can be traced for several miles on the surface by means of copper-stained gossan. Parts of the Mante Monstruo ore body are said to be 300 feet in thickness. The gossan, where prospected, contains from 4 to 7 per cent of copper. At the Manto Verde mine the ore body is said to be 24 feet in width and to average 7 to 8 per cent copper.

At Pueblo Hundido are a number of mines of which the most important are the Carmen and the Tres Gracias. These have been worked to a depth of over 800 feet and have yielded much ore containing 12 per cent copper while lower grade ores are thrown in the dumps. The Carmen lode averages 15 feet in width. The country rock is mainly syenite with some porphyry. The oxidized ores contain much limonite and have been sought by the smelters even when the copper content was low. At Carrazilillo, also in the Coast Range, several extensive lodes have been worked far into the sulphide zone.

The most important copper deposit of the province has recently been described by J. E. Harding (98) in an article from which the following passages are quoted.

"Probably the largest project in mining development at this time is that of the Andes Copper Mining Co.'s Potrerillos mine in the Department of Chañaral, Chile. This mine is in the main range of the Andes, east of the Port of Chañaral, 90 miles from the coast and at an elevation of 10,500 ft. . . . Roughly this body of ore has been proved by churn drills to be 1,800 ft. long, 900 ft. wide and 850 ft. deep, a total of 32,000,000 tons of ore containing 1.5 per cent copper. Additional ore in the vicinity of this body has also been proved to the extent of increasing the total to 100,000,000 tons averaging 1.4 per cent copper. A cross-section of the ore body is roughly an inverted triangle, with altitude and base nearly equal.

"The geology of the ore body is simple, a late intrusion of quartz porphyry in limestone. The ore developed was formed as the result of secondary enrichment from a primary impregnation, although ore has been developed in the primary and oxidized as well as secondary zones. Copper minerals are disseminated both in the jointing planes and as inclusions in the rock. Since its intrusion the magma has been extensively faulted and brecciated and the ore has followed certain zones of fault movement which though widely separated, have formed channels for the circulation of enriching solutions and boundaries for the ore. The ore bodies do not appear to have been materially faulted by subsequent movements."

Preparations are under way for developing the property which will involve an expenditure of about $25,000,000 in the construction of a line of railroad from Pueblo Hundido, a 15,000-ton concentrator, an electric plant, a model town for 5000 inhabitants, etc.

The mines of the Copiapó region have long been worked on account of the railroad facilities, the railroad from Caldera to Copiapó having been built in 1852, the first railroad of the South American continent. A belt of copper deposits extends through the Department of Copiapó from north to south, lying for the greater part east of the city of Copiapó. Scores of mines have been worked in this belt and some to great depth. The Dulcinea mine, 7½ miles west of Puquios, the deepest mine in Chile, has been worked to a depth of 3,600 feet. From the zone of oxidized ores which extended to a depth of 600 feet considerable 30 per cent copper ore was shipped. Some oxidized ores were found to a depth of 1,700 feet. The chalcopyrite and pyrite ore now obtained carries 8 per cent copper, 3.8 ounces of silver, and some gold. The main vein has a width of 5 feet and is enclosed by diorite. Quartz is the chief gangue mineral.

The mining districts of Punta del Cobre and Amolanas are also important. In the latter which lies about 15 miles southeast of San Antonio the ores contain much atacamite, cuprite, and chalcocite. Many of the abandoned copper mines of the Department of Copiapó are believed to contain large reserves of low-grade ores which will undoubtedly be worked at some time.

In the vicinity of Carrizal Alto in the northern part of the Department of Freirina many copper mines have been worked, although most are now idle. Several are worked to a depth of more than 1,000 feet. One of the most important mines of the Department is the Socavon, situated about 15 miles from the port of Pena Blanca. The vein which is 6 feet wide is in granite. It yields ores averaging 18 per cent copper. The oxidized ores extended to a depth of about 150 feet, beneath which the principal ore mineral is chalcopyrite.

Numerous copper mines have been worked in all parts of the Department of Vallenar, but most of them were shallow and soon abandoned. Many of the deposits are thought to be worthy of investigation.

Province of Coquimbo.—Along the line of the Longitudinal Railroad through the Province of Coquimbo, hundreds of copper mines are being worked in a small way (Fig. 31). It is not uncommon to see more than a score of small piles of copper ore on the platform of a station awaiting shipment, each pile coming from a different mine. While most of the mines are small, there is no doubt but that this is due in part to the lack of capital to properly develop them. In the past the Tamaya and Brillador mines were extensively worked, as well as some near La Higuera, but in recent years the Panulcillo mines have been the most important ones. The building of branch railroad lines would greatly increase the copper production of the province.

Although copper mines have been worked in almost all parts of this province the region around La Higuera in the Department of La Serena has yielded the greatest amount of ore. Some of the numerous mines there have been worked intermittently ever since the Spanish Conquest. The ores occur in well-defined veins of variable width cutting different kinds of metamorphic rocks. The ore taken to the smelter contains from 10 to 18 per cent copper on an average, the lower grade ore being disregarded. Some of the mines are more than 1,000 feet deep and are now producing sulphide ores only, containing chalcopyrite and bornite mainly. The Compania district, a short distance northeast of La Serena, has had a number of important mines, especially the Brillador which has been worked to a depth of 1,650 feet and has produced a large quantity of ore. The principal ore body has a maximum width of 25 feet. It is enclosed in diorite.

Several copper mines have been opened in the Department of El Qui near the railway line that runs eastward from La Serena to Vicuña. In the Porongo district are several mines of importance.

Copper deposits have been worked in the vicinity of Cerillos, Andacollo, and Tambillos in the Department of Coquimbo. At Andacollo copper has been obtained by the precipitation of the copper from mine waters by means of iron.

The chief centers of copper mining in the department of Ovalle are Panulcillo, Tamaya, and Punitaqui. The Tamaya mines at one time were the most productive mines of the entire country, but in recent years have been worked only on a small scale due to the flooding of the deeper levels. The main lode consisted of twin veins which united in places where large bunches of high-grade ore were found. In one place the lode was 20 feet in width and yielded ore that contained from 30 to 35 per cent copper as mined. In depth, oxidized ores were first encountered, followed by bornite and chalcopyrite, and below 500 feet chalcopyrite alone. Quartz, calcite, and specular hematite occur with the copper minerals.

The Panulcillo district is where the Central Chile Copper Co. is operating. The rocks of the region consist of andesite and diorite metamorphosed by intrusions of granite. The minerals of the lodes are chalcopyrite, pyrite, pyrrhotite, quartz, and calcite with occasional garnets. The ore bodies are very large and in places constitute a stockwork. The tenor of the ore is variable, some of the ores worked containing only 3.5 per cent copper although others run as high as 44 per cent.

In the departments of Combarbala and Illapel are scores of small mines, especially along the line of the Longitudinal Railway, but nearly all are of small size. A traveler through this section in 1871 made the following statements: "Traveling northward through the Province of Aconcagua and the southern parts of the province of Coquimbo, one crosses chain after chain of hills, running E. and W., divided from one another by fertile, well-watered valleys. The hills are so saturated with copper that a *desmontes* or refuse heap enters as a conspicuous object into almost every bit of mountain scenery" (69). Since that time scores or even hundreds of other copper mines have been opened and worked from time to time on a small scale.

Province of Aconcagua.—Abundant copper deposits have been found in the departments of Petorca, La Ligua, and Putaendo, and some in San Felipe and Los Andes (Fig. 29). In the Catemu valley are some important copper mines which in their upper levels contained considerable quantities of lead, zinc, and silver. In general the copper deposits of the Province of Aconcagua seem to be of lower grade than those farther north, but in places the large ore bodies more than offset the lower tenor. Capital, however, is needed to develop them.

Province of Valparaiso.—A number of copper mines have been worked in the northern part of the Province of Valparaiso.

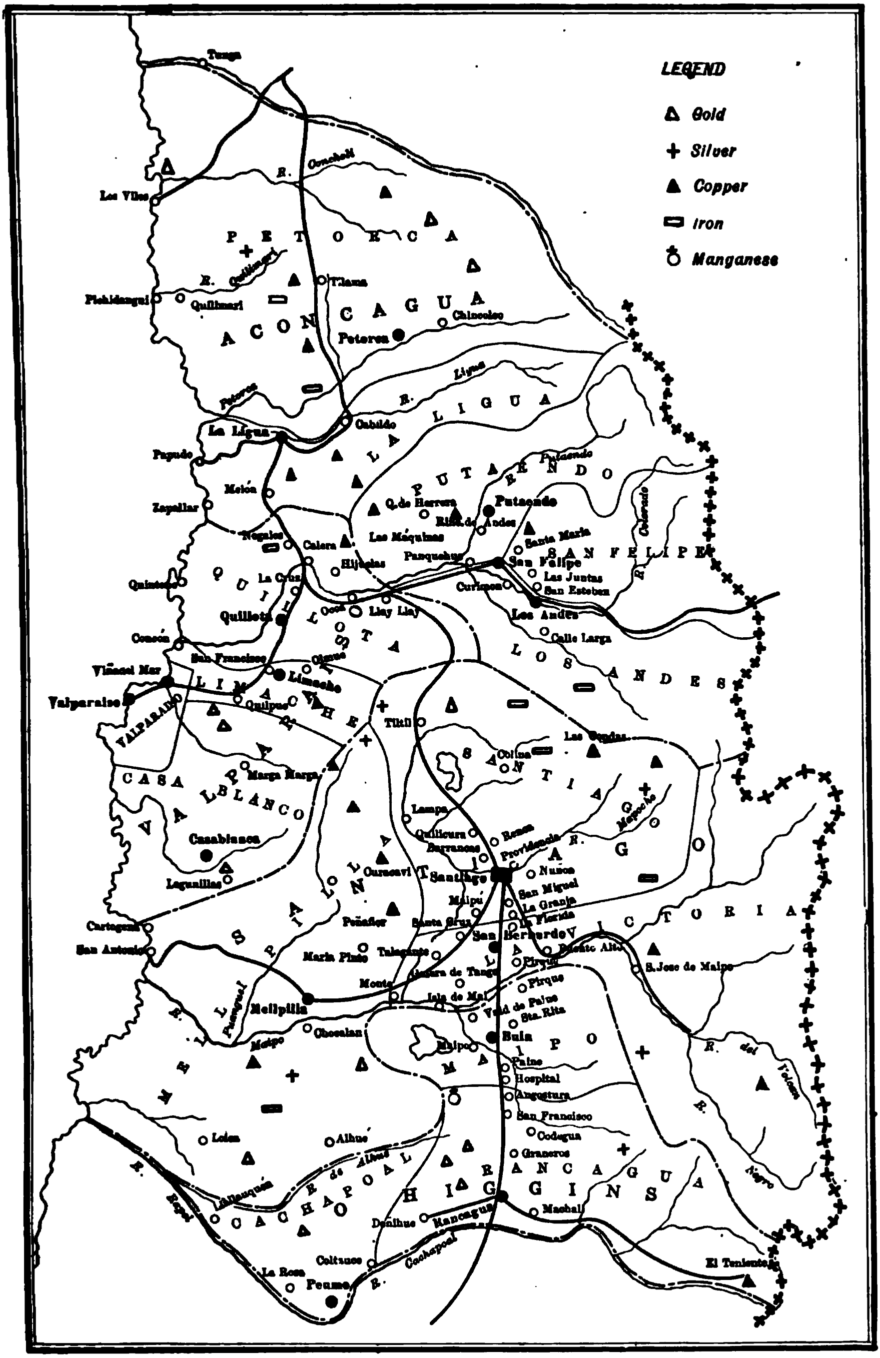

Fig. 29.—Provinces of Aconcagua, Valparaiso, Santiago and O'Higgins showing location of important mineral deposits.

Province of Santiago.—Copper has been mined in several places in the Cordillera east of the City of Santiago and also in the Coast Mountains to the west of the city. The three chief operations are Las Condes on one of the tributaries of Mapocho River, El Volcan in the valley of the Maipo River, and Naltagua near the station of El Monte on the railway between Santiago and Melipilla.

Las Condes mine is located at an elevation of more than 12,000 feet where weather conditions are extremely unfavorable during more than half of the year. The deposit is very extensive and it is compared with the Braden deposits. The chief ore mineral is chalcopyrite, which occurs as the cementing material of a volcanic breccia. The breccia is estimated to contain from 3 to 4 per cent copper. At present only the higher grade ores which carry as much as 24 per cent copper are being worked. In places there are very large masses of these high-grade ores. In the same district are some copper sulphate ore deposits similar to those of Copaquire.

El Volcan mining district is situated about 60 miles southeast of Santiago near the Volcan River. The country rock is syenite through which extend ore veins from 6 to 10 feet in width. Chalcopyrite is the chief ore mineral, the oxidized layer being very thin.

The Naltagua copper deposit near El Monte, Department of Melipilla, is very extensive. The average copper content is 4 per cent. To a depth of about 65 feet the ores are oxidized, but at lower levels bornite and chalcopyrite are found.

Province of O'Higgins.—Tbe only copper mines of importance of the Province of O'Higgins are the Teniente mines of the Braden Copper Co., located east of Rancagua and connected with the Longitudinal Railway at that point by a narrow-gauge line 43 miles in length (Fig. 29). The mines are situated in a very rugged portion of the main ridge of the Andes at an elevation of about 8,000 feet above sea level. In winter the snowfall is excessive, and snow slides, at times very disastrous, are common.

The ore deposits are said to have been discovered in the eighteenth century and worked at intervals ever since. Until 1906 the operations were on a small scale, the richest portions of the ore bodies only being taken out, the ore sorted by hand, and the high-grade material transported by mule back to a smelter 15 miles distant. The present company has been in control during the past 10 years and has put millions of dollars into plant equipment. Eventually it is planned to have a mill capable of treating 10,000 tons of ore per day.

The following succinct description of the ore and ore bodies is by H. R. Graham (94).

"Geologically, the property is peculiarly interesting inasmuch as it consists of a series of irregular lenses formed about the periphery of an old volcanic plug, slightly tilted to one side. On one edge the surface has been so eroded, as to have lost completely its mineral values; for active mining operations about four-fifths of the circumference of the crater is left. The volcano itself would rank as a fairly large one, having a diameter of about three-quarters of a mile, and a roughly circular outline about two and a half miles long. Supposedly of Tertiary origin, the country about the mine consists of andesitic flows, through which, at the time of some gigantic volcanic upheaval, the tuff plug now occupying the crater was forced. The great pressure tore apart and shattered the andesite flows, much as a missile thrown through a plate-glass window would affect the glass. The uprising hot alkaline carbonate waters, containing mineral sulphides in solution, found the cracks and minute fractures in the andesite an ideal place to precipitate, upon the lowering of temperature and release of pressure, and found their way for some distance out into the shattered rocks away from the crater.

"The materials close to the volcanic center were so thoroughly shattered that they formed a brecciated deposit, making a most favorable point of deposition; and it is in the brecciated portions of the lenticular ore bodies that the greatest values are found. The mineral sulphides, however, formed ore even in the blocky andesite at some distance from the crater. Generally speaking, the materials with which the mine is interested, are the tuff, composing the volcanic plug, a combination of volcanic mud and contained agglomerate; the breccia, essentially of tourmaline ground-mass with inclusions of angular andesite fragments; and the andesite, composing the country rock. The tuff is, as a rule, not mineralized except close to the breccia contact or at such point as fumarolic vents have been formed. The actual contact between the tuff and breccia is not always distinct, but if one remembers that the tuff includes rounded fragments of porphyry and the breccia, angular fragments of andesite, the difference is easy to detect.

"The contact between breccia and andesite is easy to note as a rule, but on the Teniente side the gradation from shattered andesite to andesite breccia, is a most perplexing one. The breccia does not always appear as an intermediate material between the tuff and the andesite, but in these cases where tuff and andesite contact, the ore width is not so great nor the values so rich. At various places in the mine old fumaroles are encountered, in which oxidation has taken place at depth, and at times small chambers containing heads of wire copper coated with oxide, are found in company with the usual black sulphides, and oxides, and yellowish iron stains of limonite.

"The limit of ore on the crater side is generally the tuff, although sometimes false contacts—thin tongues inserted into the breccia—occur on the inside of which there is good ore-bearing breccia. On the country rock side, the limit of ore has to be determined by assay, but is also detectable by the lessening of the fractures and the blockier, more entire appearance of the andesite.

"The copper values occur in both breccia and andesite, essentially as primary sulphides in the form principally of chalcopyrite, which is roughly 75 per cent of the copper mineral, and also as bornite, secondary chalcocite, and undetermined black sulphide between tetrahedrite and enargite, and some of the carbonates, silicates, sulphates, and oxides of copper. Zinc blende, iron pyrites, magnetite, galena, and occasionally native copper are also found. Tourmaline, quartz, calcite, ferromagnesium carbonates, and the usual products of devitrification, chlorite, kaolin, etc., are also found, as well as the plagioclase, biotite, hornblende, and pyroxenes of the different classes of andesite."

The ore body is of variable width, the maximum being about 500 feet. At the end of 1917 the reserves were estimated to be 149,192,000 tons of positive ore averaging 2.42 per cent copper and 90,000,000 tons of probable ore averaging 1.88 per cent.

The ore is being mined by the caving system and the ore hauled by locomotives to the concentrating mill at Sewell about 1.2 miles down the valley. The track is covered with snow sheds practically the entire distance. The concentration of the ore is elaborate. Both table concentration and oil flotation are employed. The concentrates are nodulized to drive off the excess moitsure before being taken to the smelter nearby.

The plant of the Braden Copper Company is one of the best seen in South America and the operation is second only to that of Chuquicamata in the list of Chilean copper mines.

Province of Curico.—In the Department of Vichuquen, Province of Curico, copper has been mined at El Cobre.

Province of Talca.—Copper has been mined on a small scale in several places in the Coast Mountains near Talca and Colin.

Territory of Magallanes.—Copper ores have been prospected at Cutter Cove on a small island in Lat. 49° 30′ S. in the Territory of Magallanes.

THE FUTURE OF COPPER MINING IN CHILE

The development of the Braden Copper Co. near Rancagua and the Chile Copper Co. at Chuquicamata has shown the possibility of working the low-grade copper deposits of the country with profit even in the face of seemingly great obstacles. Neither the inaccessibility due to high altitudes in precipitous mountain gorges nor the adverse conditions prevailing in the desert have prevented these companies from opening mines, and their examples will, no doubt, be followed by others. The Anaconda Copper Co. is already developing their recently acquired extensive low-grade deposits at Potrerillos and no doubt we shall hear of more large establishments of this kind during the next decade.

But it is not alone in the development of the large deposits of low-grade copper ores that opportunities exist in Chile today. One of the best-informed mining men in that country asserts that there are hundreds of small vein mines, many of them abandoned years ago when the workings encountered hard rocks or sulphide ores, that would pay handsome dividends if reopened and properly equipped. It would not require nearly as much capital to put such a mine on a working basis as to equip a low-grade disseminated ore proposition, yet the fact that the old openings are now closed would mean considerable expenditure of money to determine their character. The building of numerous lines of railroad within the past few years has also increased the value of these old mines, and it might prove profitable to investigate the smaller and less important copper mines of Chile. The country's future production will probably come from three sources—the low grade disseminated deposits, the high-grade vein mines already abandoned or worked spasmodically with insufficient equipment, and from new deposits to be discovered. The former class will undoubtedly furnish the largest porportion of the output, yet the other two sources possess great possibilities, as yet undetermined.

IRON ORES

Chile is rich in iron ores, yet practically all the iron and steel used in the country is imported. Although important deposits of iron ores have been found in many of the provinces, in only a few places have they ever been mined, and, in most places, so little development work has been done that the extent and character of the deposits are not known. Up to the present time only one mine has been extensively worked, the Tofo Mine north of La Serena, and the ore from this operation is being shipped to the United States. In several places iron ores have been mined to a small extent for use as fluxes in silver and copper smelters.

There are several reasons for the slow development of the iron industry of Chile, among which the following may be mentioned: lack of adequate transportation facilities, lack of fuel of any kind in proximity to the best iron-ore deposits, the entire absence of coking coal in the country, lack of capital for the development of the mines and erection of furnaces, and the ease with which iron could be imported from other countries in vessels coming to the country for supplies of nitrates. Since the opening of the Panama Canal, the Chilean iron ores have assumed much greater importance because of their greater accessibility for the North American and European steel industries.

The most elaborate attempt to establish the iron industry of Chile was made by a French Company that acquired the Tofo deposits and under an extremely favorable Government subsidy built blast furnaces at Corral in the Province of Valdivia. The plan was to use wood instead of charcoal in the furnaces, but after operating from February 1910 to April 1911, during which only 4,793 tons of pig iron were produced and that at a total loss of about $300,000, the furnaces were closed down and have been idle ever since. In 1913 the Tofo iron mines were leased to the Bethlehem Steel Company and there now seems to be little likelihood of the Corral project being taken up again, at least not by the original company. In the vicinity of Corral there is an abundant supply of wood that might furnish an adequate supply of charcoal, so that it seems feasible to establish an iron industry there using charcoal.

The abundance of available water power in southern Chile and the improvement of the electric furnace offer another possibility of supplying the nation's requirements for iron and steel by a domestic industry. It is highly probable that, at no distant day, the country may have an active and profitable iron industry.

The iron ores of Chile belong to several different types. (1) The most important are the magnetite and hematite deposits that were apparently formed by magmatic segregation. (2) In many places veins of magnetite and hematite are present in the igneous and metamorphic rocks, suggesting true fissure veins or metamorphosed ferruginous sediments. Copper ores are found in association with these ores in many places and some of them have been utilized in copper smelters. (3) Throughout the central provinces where extensive pyrites and cupriferous pyrite deposits have been deeply oxidized great masses of limonite gossan have accumulated, some of which are believed to contain thousands of tons of good ore. In some cases they contain appreciable amounts of copper and workable copper deposits are found underlying them.

The deposits of magmatic origin are mainly confined to the coast ranges of the provinces of Atacama and Coquimbo. They include the important deposits of Tofo, Algarrobo, Chañar Quemada, Cristales, Romeral and Juan Soldado, Dorado, Ojos de Agua, Pleito y Zapallo, and numerous smaller ones. The ore bodies are everywhere associated with igneous rocks and are mainly found at the contact of intrusives and older igneous rocks. In a few cases the older rocks are of sedimentary origin. Syenites, monzonites, and diorities are the most common types of igneous rocks.

The ores occur in lenses extending, in some cases, several kilometers in length with varying widths up to 500 meters. The lenses occur singly or in groups in which case the ore bodies are not everywhere in parallel orientation. Harder states that "they appear to be the after-effects of igneous intrusions filling fractures that have developed locally within intrusive masses upon cooling."

The ores consist of mixtures of magnetite of remarkable purity and occur in practically solid masses containing millions of tons. The phosphorus content varies, only part of the ores being of Bessemer grade.

In the résumé of the known iron ore resources that follows it will be observed that, although a number of provinces are mentioned, the great proportion of the deposits are found in Coquimbo, Atacama, and Antofagasta. The descriptions are taken mainly from the writings of the late Charles Vattier (201–206), but supplemented by data from a manuscript report by E. C. Harder and by the writers' observations.

Province of Tarapacá.—Some veins of iron ore are found near the Cordillera Mountains and also near the coast south of Junin, but, as they have not been developed, little information is available regarding their character and extent.

Province of Antofagasta.—Iron ores in which there are some copper and manganese minerals have been worked at Cerro Gordo between Mejillones and Antofagasta for use as fluxes in the smelting of Bolivian silver ores in smelters located near Antofagasta.

There are a number of promising iron ore deposits in the vicinity of Taltal. To the north of Taltal and adjoining the cove of Hueso Parado are the Potrero Mines, and 3 miles away is the Norte Magnetico deposit. In these places the ores consist of magnetite, specular hematite, and amorphous hematite. In some of the ores there is considerable apatite and also copper minerals, but in others the ore is free of objectionable minerals and contains from 60 to 63 per cent iron with low sulphur and phosphorus. Several ore bodies more than 30 feet in width have been uncovered, and in the Norte Magnetico there is an exposure of ore 162 feet in length and 325 feet wide.

About 4 miles to the east of Taltal are the Cachina iron deposits near Breas railway station where there are beds of high-grade red hematite ores as much as 10 feet in thickness. Analyses show a range from 55 to 59 per cent iron with medium to low sulphur and phosphorus.

Several veins of good iron ore have been prospected about 7 miles from the port of Cifunchos. In some of them there is a calcite gangue with traces of galena, chlorides, and bromides.

Province of Atacama.—About 18 miles from the port of Pan de Azucar are several surface deposits of iron ore one of which yielded ore containing from 45 to 50 per cent iron.

Ore bodies of magnetite and hematite have been prospected about 8 miles to the northeast of Chañaral. They are believed to average about 68 per cent iron. They are closely associated with copper ores, but are, in the main, free of copper near the surface though probably cupriferous in depth. Similar iron ore deposits are found in a number of places in the vicinity of Pueblo Hundido and Carmen, some of which are the gossan of chalcopyrite ore bodies.

In the Department of Copiapó, promising iron ore deposits have been discovered 18 miles north of Copiapó in the Galleguillos Mountains, where numerous blocks of iron ore strew the surface. In the vicinity of Tierra Amarilla a body of iron ore 10 feet in thickness outcrops for a distance of about 1,300 feet. It consists of high-grade specularite and amorphous hematite, in places containing some copper. Analyses show 64 per cent iron. Near Monte Amargo station veins of calcite and iron oxide containing 1½ to 2½ per cent copper have been worked for fluxes for copper smelters. Close to Copiapó and also near Potrero Seco are outcrops of magnetite and specular hematite of unknown extent.

Magnetite and limonite deposits are known to the north and northwest of Vallenar. Several of these outcrops have been worked to obtain fluxes for use in the copper and silver smelters at Antofagasta. A few miles southwest of Vallenar are the Ojos de Agua deposits which, from surface indications, appear to be extensive (Fig. 27). The Algarrobo deposits are situated about 24 miles southwest of Vallenar and cover a large area. They are believed to contain several million tons of ore and some claim for them a larger tonnage than the Tofo mines. The Algarrobo and Ojos de Agua deposits consist of lenses of iron ore within dark-colored intrusive igneous rocks which have cut through monzonite rocks of earlier age. One of the largest lenses at Algarrobo is 80 meters wide and several hundred meters long. The Algarrobo ore carries about 68 per cent iron, 0.025–0.064 per cent phosphorus, and 0.028 per cent sulphur. The Ojos de Agua ore contains apatite and is higher in phosphorus.

There are a number of deposits of iron ore between Carrizal and Freirina. They consist of magnetite, specular and amorphous hematite, and limonite but, because of little prospecting having been done, their extent is not known. The Chañar Quemada deposits, about 25 km. northwest of Vallenar, consist of ore bodies lying at the contact of monzonite and sedimentary rocks. In the extreme southeast corner of the Department of Freirina is the Cristales district where blocks of magnetite and limonite cover several square miles. The ore lenses occur in a light to dark greenish-gray porphyritic diorite containing abundant phenocrysts of feldspar and hornblende. Dikes of dark amphibole rock are associated with the ore bodies.

Province of Coquimbo.—By far the most important iron mines of the country are those of the Bethlehem Steel Company at Tofo in the Department of La Serena. The deposits are the most favorably situated of any of the important ones known and probably contain the largest tonnage of high-grade iron ore of any of the iron districts of Chile. The deposits form the tops of two hills about 2,000 feet above sea level and located at a distance of 4½ miles from the coast.

The deposits were first claimed by two Chileans who, however, mined no ore and finally sold the concessions to the French Company that built the unsuccessful blast furnaces at Corral in the Province of Valdivia. In 1913 the Bethlehem Steel Company obtained possession of the property on a long term lease and at once began elaborate improvements that when completed will permit of the mining of 1,000,000 tons of ore a year. The concessions cover an area of 215 acres.

FIG. 30.—Iron ore deposits of Tofo. Practically solid iron ore above lowest lines of track.

The ore is extremely compact and consists mainly of hematite with a small amount of magnetite. The only visible impurities are small yellow flakes of altered hornblende. The country rocks are greenish-gray to dark-colored diorites, which in many places have been greatly altered. Considerable epidote is present in the rocks. Several dikes of igneous rocks cut through the ore body and also a thin vein of copper ore has been encountered in the ore body of one of the hills. The ore body caps two hills and forms a rather sharp contact with the dark-colored igneous rocks. Near the contact there are occasional masses of dark-colored rocks within the ore body and likewise some bunches of ore within the rocks. To determine the thickness of the ore body in the center of the larger hill a tunnel was run into the hill 180 meters below the summit and encountered ore.

The ore body is estimated to contain about 100,000,000 tons of ore as determined by explorations thus far carried on. Portions of the ore body contain Bessemer ores, but other parts are higher in phosphorus.

The following analysis is typical:

	Per cent.
Fe	67.500
Mn	.200
P	.011 to .050
S	.010
SiO_2	2.500
TiO_2	.80

Up to the present time about 250,000 tons of ore have been shipped to the United States.

The origin of the Tofo deposits has been explained differently by geologists who have examined the property. Vattier (205) believed the ore bodies were metamorphosed sediments.

Opposed to this view are the relations of the ore bodies to the country rocks described above and the igneous character of all the associated rocks. The authors believe that the ore bodies are the result of magmatic differentiation from a dioritic igneous magma. No doubt there have been several stages during which the deposits have undergone transformations, but detailed studies in the adjoining regions are necessary to determine what these are.

The mining of the Tofo ore body is very simple as it is merely a question of quarrying. A small amount of soil supporting a sparse vegetation of cactus and allied plants is present between the ore boulders of the surface but never in large amounts. The rocks from the few dikes of barren igneous rocks must be discarded in mining, but the greater portion of the ore body is entirely free of these so that everything quarried can be shipped.

The ore as mined is passed through a crusher to reduce the size of the larger blocks and then sent to loading bins. The French company built an aerial tramway for transporting the ore to the port of Cruz Grande about 4½ miles distant, but the present company has built a railroad 15½ miles in length with a 3 per cent grade to replace the tramway and permit of a larger tonnage. Electric locomotives will be used. At Cruz Grande a basin 900 feet long, 240 feet wide, and 40 feet deep has been excavated in solid rock in which the vessels can lie while being loaded, effectively protected from the heavy storm waves which might otherwise delay the loading at times.

While the Tofo deposits may not prove to be the largest and richest ores in Chile and are in size very much smaller than those of Minas Geraes in Brazil, it is fairly certain that for some years to come the Tofo mines will remain the foremost iron mines of the South American continent.

North of the Tofo district are the deposits of Pleito y Zapallo in which there are several lenses of mixed hematite and magnetite ore in a light-gray porphyritic diorite.

Between La Higuera and La Serena there are a number of places where fairly thick lenses of hematite and magnetite have been found similar in character to the Tofo deposits although less extensive. The most important are the deposits of Juan Soldado and Romeral. At the latter place, about 15 miles north of La Serena, iron ores have been mined at different times and hauled by cart to La Serena and thence by railway to Coquimbo where they were shipped to Antofagasta for use as fluxes in the Bella Vista silver smelter. The ore bodies are similar to the Tofo deposits except the lenses are within monzonite rocks.

A short distance from Coquimbo and near Pan de Azucar Mountain are several veins of iron ore containing from 68 to 70 per cent iron but as yet none has been properly prospected.

The Aguas Buenas iron mines near Pejerreyes, 42 miles south of Coquimbo, have been worked for a number of years to secure fluxes for Antofagasta silver smelters. The ores which carry 55 to 63 per cent iron, are high in phosphorus and contain some copper.

About 5 miles from Ovalle are the Dorado iron ore deposits where Vattier says "millions of tons of high-class ore could be obtained by only loading up the débris strewn over the surface and by working by open-cast methods and at but little depth the ore which lies in sight." The ore consisting of magnetite and hematite lies within syenite rocks. Analyses show from 61 to 68 per cent iron and from 0.015 to 0.344 per cent phosphorus.

Several deposits of iron ore have been discovered in the departments of Combarbala and Illapel, many of which contain copper.

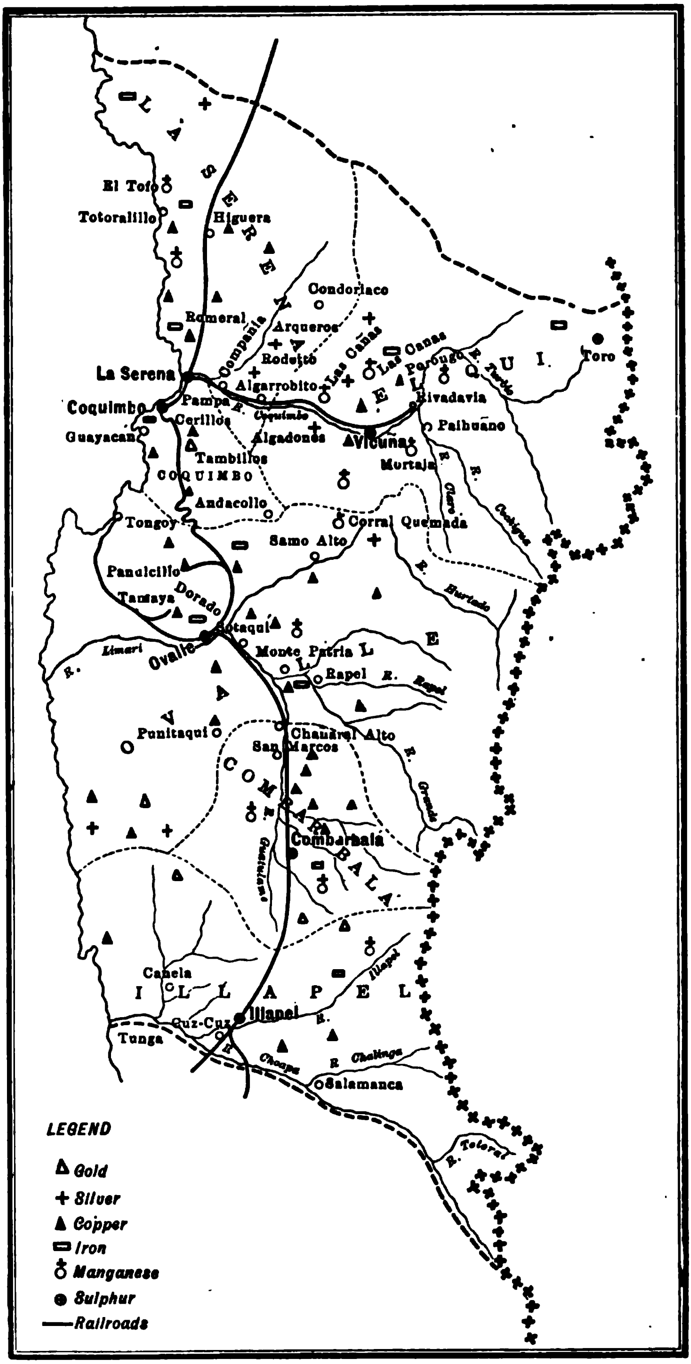

FIG. 31.—Province of Coquimbo showing location of important mineral deposits.

Near the latter place some veins of hematite have been worked to secure fluxes for the nearby copper smelter.

Province of Aconcagua.—Near Tilama in the Department of Petorca are the Iman iron ore deposits. The deposits of magnetite occur in large masses intruded by barren dikes. They have not been worked. Outcrops of similar ores are found to the south of the Iman region.

Province of Valparaiso.—Near Calera, iron ores have been worked for fluxes for silver smelters. Outcrops of iron are known near Limache and also at Domuño near Nogales.

Province of Santiago.—Iron ore deposits are known at a number of places in the Province of Santiago, but the cost of transportation forbids them being utilized for the manufacture of iron. At Pelvin, near Penaflor, to the southwest of Santiago, iron ores have been mined for fluxes for the copper smelters of Maitenes. At Lampa and Batuco are iron ores in which small amounts of copper are found.

Province of Linares.—At San Manuel about 30 miles southeast of Parral an iron ore deposit has been discovered in the top of a mountain in which high-grade magnetite ores are present. Vattier considers it a fissure vein and thinks that there are others in the same region. Much timber nearby, from which charcoal could be obtained, and also water power from the Longavi River during part of the year make it seem possible that iron might be produced at that place.

Province of Concepción.—Near Coronel several outcrops of iron ore have been reported to occur, but little is known in regard to them.

Province of Valdivia.—Near La Union deposits of limonite containing from 35 to 39 per cent iron have been observed.

Territory of Magallanes.—Near Punta Arenas are some outcrops of iron ore containing appreciable amounts of copper.

GOLD AND SILVER

Gold and silver ores are found widespread throughout Chile, but for some years gold and silver mining has been on the decline. Under Spanish rule diligent search was made for the precious metals while other mineral products received little attention, a situation which has now been reversed. Indeed a considerable part of the gold and silver production of recent years has come from ores worked primarily for their copper content. There are also many mines throughout the country in which high values in gold and silver were obtained in the upper oxidized levels, but beneath, in the sulphide ores, the copper content increased and the gold and silver decreased.

Altogether Chile has produced about $315,000,000 in silver and $225,000,000 in gold. Within recent years the annual silver production has been about $500,000 and the annual gold output between $200,000 and $300,000.

Chile has had some of the richest silver mines ever discovered. The Chañarcillo mines, about 60 miles south of Copiapó, and the Huantajaya mines, near Iquique, furnish ideal illustrations of bonanza mines. The latter were extensively worked to the close of the 18th century and were later allowed to remain idle until 1873, but are again being operated. They are said to have produced more than $22,000,000 in silver. The Chañarcillo mines were discovered in 1832 and up to 1859 produced $60,000,000 in silver. The Caracoles district, 110 miles east of Antofagasta, was another famous silver district and also Los Tres Puntos, near Copiapó. The principal silver output now comes from the Huantajaya mines and some others near Taltal. Although the production has been steadily decreasing for many years until now it is of minor importance, there are many mining men in the country who firmly believe it would be profitable to re-open some of the abandoned mines.

Gold placers are widespread throughout Chile and in the early history of the country produced much gold. The Madre de Dios, near Valdivia, and the Malga Malga, between Santiago and Valparaiso, were two of the earliest deposits worked and also the richest. Placers in the southern part of the country continue to produce some gold, but the chief productive gold area, containing both placer and lode workings, lies between Santiago and Coquimbo. The most important mines are located near San Felipe, Los Valos, Talca, Ovalle, and Cachinal.

The gold and silver deposits of Chile are found in different kinds of rocks, but in almost every case closely associated with intrusive igneous rocks of Cretaceous or Tertiary age. The most abundant intrusive rocks are granites, granite porphyries, diorites, and quartz diorites, while the rocks containing the ore veins are granites, gneisses, schists, rhyolites, andesites, and limestones. In most of the mines the veins carry both gold and silver values, but in the case of those in the limestones, where extremely rich silver ores were worked in the middle of the last century, the gold values were insignificant. These mines yielded great masses of native silver and ruby silver in a calcite gangue. At Chañarcillo near Copiapó, a mass of practically pure silver weighing more than 200 pounds was found and another mass of chloro-bromide of silver and native silver weighing 45,000 pounds yielded 75 per cent silver.

It is generally believed that the gold and silver veins decrease in values with depth, and few mines have been worked to a greater depth than 500 feet. Although this has been definitely proved in several districts, there are other regions where high values have been found at depths exceeding 1,000 feet. The abandonment of many mines at comparatively shallow depths has been due perhaps to difficulties of working with poor equipment as much or more than to impoverishment of the ores.

The gold of Chile is mainly found as native gold in quartz veins or in chalcopyrite or pyrite. The silver ores are much more varied. Of greatest importance are the arsenical and antimonial silver minerals, proustite and pyrargyrite, of which many mines contain enormous masses, and also cerargyrite. Probably no other country in the world has furnished such quantities of ores of these minerals. In addition many mines have yielded considerable native silver, bromyrite (AgBr), embolite (AgBrCl), and iodyrite (AgI). In many copper mines, argentiferous copper ores have been found. Argentiferous lead ores are known in many places, but are much less abundant than in most countries.

Province of Tarapacá.—Silver mines have been worked in several places in the Province of Tarapacá. The most important are the Huantajaya mines, in the Coast Mountains, a short distance east of Iquique. These mines are among the oldest in Chile and have yielded enormous quantities of high-grade ore. It is stated that at one time a mass of native silver weighing 725 pounds was taken from these mines. The country rocks are metamorphosed limestones and argillaceous schists, which are cut by many veins carrying high values in silver. Although the veins cut different kinds of rocks, practically all the workable portions are within the limestone strata. Native silver, cerargyrite, and embolite are especially abundant. In the upper levels and in the partially cemented surficial débris a new

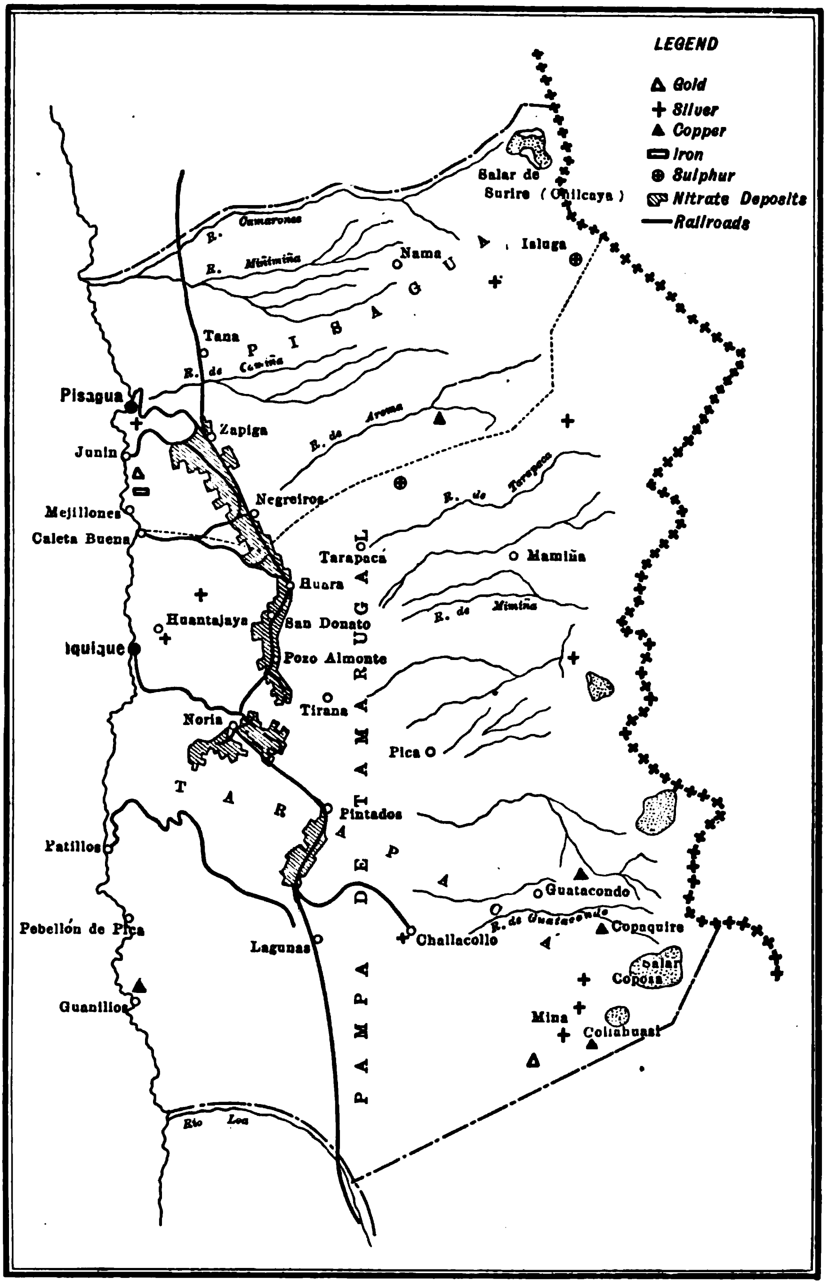

FIG. 32.—Province of Tarapacá showing location of important mineral deposits.

mineral was found which has received the name of huantajayite. It is an argentiferous variety of halite with the approximate composition of 20 NaCl + AgCl.

The Cordillera Mountains, east of the great Tamarugal Pampa, contain numerous gold and silver mines. About 65 miles east of Iquique are the silver mining districts of Jauja, Pila, and Yabricoya. The veins, in the main, carry argentiferous galena and sphalerite in a quartz gangue.

A number of silver and gold mines, in most of which the silver values predominated, have been worked near Challucollo between Collahuasi and Mino. At the latter place the ore-bearing quartz veins are in diorite which has been intruded by dikes of porphyry, gabbro, and basalt. The ore carries 80 ounces of silver and 0.1 ounce of gold to the ton.

Province of Antofagasta.—The Province of Antofagasta contains a number of gold and silver mining districts in both the Coast and Cordillera Mountains (Fig. 26). The most important is the Caracoles silver district in the Department of El Loa northeast of Antofagasta. These mines were discovered in 1870 and were extensively worked for many years. The rich silver veins were found in black shales which had been intruded by dikes of felsite and porphyry. The bonanza lodes encountered in the upper levels were exhausted and for a number of years practically no mining has been done in the district.

Another silver district is the El Inca about 20 miles north of Calama. In some of the veins the silver chlorides extend to a depth of 500 feet, in others argentiferous galena is found near the surface.

The Guanaco district, adjoining the nitrate fields, about 80 miles northeast of Taltal, contains the most important gold mines of the province. The country rock is dacite and andesite in the former of which there has been much propylitization, alunitization, and silicification. Upper levels carry gold and silver in a gangue of quartz, barite, and iron oxide. From 200 to 400 feet the ores consist of auriferous and argentiferous enargite and chalcocite. Below the depth of about 400 feet the gold and silver values became negligible and the mine was worked for copper. There are many such examples in Chile.

Province of Atacama.—The Province of Atacama is the most important gold and silver province of the country (Fig. 28), particularly the Department of Copiapó where hundreds of silver and many gold mines have been worked from the beginning of Spanish rule to the present.

About 65 miles east of Chañaral is the Vicuña district where, in a region of syenite and porphyry, quartz veins carry argentiferous ores of copper and lead.

So numerous are the silver mines of the Department of Copiapó that it is difficult to determine those most worthy of mention. In many of them silver was the only metal obtained but in others considerable gold was found and, in a number, argentiferous and auriferous copper ores have been worked.

The following districts contain valuable mines which have been extensively worked in the past although most are now idle: Chañarcillo, Tres Puntas, San Antonio, Cachiyuyo, Chanchoquin, Bandurrias, Lomas Bayas, Ladrillos, Chamonate, and Los Sapos.

The Chañarcillo mines are typical of the richest ores of the section. The country rocks consist of interbedded Mesozoic limestones and shales which have been considerably, in places intensely, metamorphosed by the intrusion of igneous dikes. The veins cut the various kinds of rocks, but the values are almost entirely confined to the limestones. The silver minerals found were native silver, cerargyrite, proustite, pyrargyrite, embolite, bromyrite, and iodyrite. The chloride of silver extended to a depth of 20 m., below which a zone of chloro-bromide of silver with some silver iodide was encountered, and at a depth of from 70 m. to 100 m. the ore contained only silver iodide. In the richest parts there was a strong odor of bromine, possibly chlorine. The values decreased with depth and the mines were closed yet, with improved equipment, it is probable that many might be worked with profit.

The Canutillo gold district, about 15 miles south of Freirina, is believed to have been worked by the Incas before the Spanish Conquest and at intervals from 1700 to the present. The lodes which vary in width up to 10 feet are contained in diorite. The highest values in gold were found near fault planes in the zone of secondary sulphide enrichment.

The principal gold and silver districts of the Department of Vallenar are the Algarrobo, the San Felix, and the Agua Marga, where very rich veins containing much native silver and some gold and copper were discovered in the beginning of the last century.

Province of Coquimbo.—Numerous very rich silver mines were formerly operated in the Department of La Serena and also some gold mines, but, at present, practically all are idle with the richest ores exhausted. In the southern part of the province, along the line of the Longitudinal Railroad from Coquimbo to Illapel and between the railroad and the coast several gold mines have been worked recently and some are still in operation.

Probably the most impórtant silver mines of the province (Fig. 31) were the Arqueros located about 20 miles northeast of La Serena. The rich ore deposits were discovered in 1825 and actively worked for many years. They yielded much native silver, silver amalgam, and cerargyrite.

The Rodeito silver mines, somewhat nearer La Serena, have also been highly productive as well as those of the Algodones district in the Department of El Qui.

South of Coquimbo are several gold deposits of promise near Punitaqui, Talca, Illapel, etc., and placers along the Caren River.

Province of Aconcagua.—In the northern part of the Province of Aconcagua are several gold mines. Near Los Vilos are the placers of Casuto Creek and the Las Vacas mine which has been worked for more than a century. The veins are richest near the contact of andesite dikes that have cut and slightly displaced the veins. They have been worked to a depth exceeding 1,000 feet, and although lower in gold content than at higher levels are still worked with profit. The ore averages somewhat less than an ounce of gold to the ton. Quartz and pyrite are the gangue minerals.

Other Gold Mining Districts.—In the Province of Valparaiso both gold lodes and placers have been found in the Marga-Marga Mountains. The Province of Santiago has important gold lodes at Alhue in the Department of Melipilla, lodes and placers at Tiltil, and auriferous copper veins at Caleo in the Department of Santiago. The El Chivate gold mine near Maule in the Province of Talca has produced rich ores. At Niblinto in the Province of Ñuble gold mines and placers have been worked; and at Putu in the Province of Talca some unusually rich gold ore was discovered in 1911, but only a small amount was obtained.

Southward, gold placer deposits have been located in many places but seldom have the lodes been found. The most important known are the following: the Quilacoya River placers between the departments of Rere and Concepcion in the Province of Concepcion, the Tucapel placers in the Department of Lebu of the Province of Arauco, those of the Damas and Repocura rivers in the Department of Imperial of the Province of Cautin, the Tolten River placers at Villa Rica and those of the San Jose de Valdivia River in the Department of Valdivia of the Province of Valdivia, the Ponzuelo placers in the Department of Osorno of the Province of Llanquihue, and the placers of Tierra del Fuego of the Territory of Magallanes.

The last named merit especial attention as attempts have been made to work these by means of steam dredges during the past few years. Gold has been found in many places in the Magellan region but particularly on both sides of the Strait of Magellan near Punta Arenas, on Navarino, Lennox, New, New Year, Picton and Terhalten islands. At Porvenir, across the Strait from Punta Arenas the most dredging has been done. The gold-bearing gravels there vary from 10 to 30 feet in thickness with an average of 25 to 50 cents per cubic yard. The difficulties encountered in that bleak region have interfered with the success of most of the operations, yet the district has a considerable annual gold production.

MANGANESE

Manganese ores are known to occur in many different places in Chile, although most of the deposits have received little attention. From 1886 to 1903, a number of mines were operated in the provinces of Atacama and Coquimbo, the ore being shipped from the ports of Carrizal and Coquimbo. The maximum production was reached in 1892, when 50,871 tons were exported. From 1885 to 1905 inclusive, 549,716 tons (97) were produced. Since that time most of the mines have been closed.

It is difficult to predict the future of the manganese industry of Chile, and yet the scant information available indicates the probable occurrence of extensive deposits of both high- and low-grade manganese ores.

The following descriptions are taken largely from Harder's article (97).

Province of Atacama.—The Carrizal district lies between Carrizal and Huasco in the Department of Freirina. The ore occurs in parallel beds varying in thickness from 1 to 5 feet and interbedded with chert, limestone, and shale, with occasional sills of dark green basic igneous rocks. The beds, which are continuous for several miles in places, dip steeply to the east in the northern part and to the northwest in the southern portion of the district. Beds of pink or dark-red jasper occur in immediate contact with the ore beds.

In the northern part of the district there are from 1 to 3 beds, and the ore consists of a dense, hard, black psilomelane with conchoidal fracture. In the southern part where there is less continuity there are four beds. The ore consists of hard, bluish-black braunite with some psilomelane and soft black oxides.

Analyses of the ores are as follows:

	Coquimbana Mine Per cent.	Huasquina Mine Per cent.
Manganese	45.82	37.08
Iron	2.74	3.21
Silica	5.42	11.97
Phosphorus	0.093	0.116
Water (combined)	3.78	3.48

Manganese ores have also been reported from the Pajonal Hills about 10 miles east of Caleta de Totoral, and in association with other ores where gold, silver, and copper mines have been operated.

Province of Coquimbo.—The Las Canas, La Liga, Arrayan, and Corral Quemada districts lie to the east and southeast of La Serena at a distance of 25 to 35 miles. They are all similar both in the character of the ores and the associated rocks.

The rocks of the region consist of flows of volcanic rocks, chiefly trachyte, with which sandstone, shales, limestones, and some jaspers are interbedded. The ore beds are generally closely associated with the limestones and range in thickness from thin seams to 4.5 feet. Including impure beds of limestone and manganese ore, a total thickness of 10 feet has been observed. In general the ore consists of compact, but soft, granular to finely crystalline, bluish-gray to bluish-black pyrolusite.

Several mines in the Corral Quemada district have been extensively worked.

Analyses of the ore are as follows:

	Mina Alta Las Canas, per cent.	Mina Potosi Las Canas, per cent.	Mina Estrella La Liga per cent.	Elsie Cut Corral Quemada, per cent.
Manganese	40.31	52.85	49.54	50.00
Iron	3.38	1.09	1.29	0.78
Silica	11.20	7.74	5.00	9.43
Phosphorus	0.022	0.007	0.010	0.013
Water (combined)	1.15	0.90	1.00	1.18

Northeast of Totoralillo is the Los Chorros district where veins of manganese ores are found in the volcanic rocks.

Other Provinces.—Manganese ores are also reported from the northeast part of the Province of Santiago and from Aculeo, in the Province of O'Higgins.

COBALT

In the Province of Atacama cobalt ores have been found in a number of mines but have been worked on a small scale only, and the mines have been alternately abandoned and reopened. The most important mines are those of San Juan, located about 20 miles south of Freirina and 30 miles from the port of Huasco. Extensive lodes from 1 to 6½ feet in width have been worked to a depth of 250 feet. They carry cobalt oxide, cobalt arseniate, and cobalt sulfo-arsenide. Some of the lodes carry considerable copper and also tourmaline. The ore averages 4 per cent cobalt. The veins are in schist.

Other mines containing cobalt ores of promise are the Caminada mines 12 miles northwest of Vallenar, the Cobriza mine 5 miles from Molle and about 38 miles south of Copiapó, the Matecitos and Cerro de los Carros mines near Locos 40 miles south of Copiapó, the Petacas mines 12 miles from Nantoco and 15 miles south of Copiapó, and the Pabellon mines about 23 miles from Copiapó.

Many of the silver mines of the Province of Atacama carry rich veins of cobalt ore and several mines in the provinces of Coquimbo and Santiago report the presence of similar ore.

MERCURY

Mercury ores have long been worked in Chile but never on an extensive scale. The principal lodes known have been found in the gold mines of Punitaqui in the Department of Ovalle, Province of Coquimbo; the Los Frailes mines located near the Rosilla silver mine, southern part of the Department of Copiapó, Province of Atacama; and in the Department of Petorca, Province of Aconcagua.

In the Punitaqui mines (93) veins of mercury ore are found in a diabase dike that cuts through syenite and diorite, the principal country rocks. The veins carry some mercurial tetrahedrite in addition to the cinnabar and quartz gangue. Other veins in which copper or copper and tin are the principal ores are found in the same body of diabase.

LEAD AND ZINC

Lead and zinc ores, both the sulphides and the oxidized minerals, have been encountered in numerous districts but, as yet have received practically no attention, especially the zinc ores. The lead ores worked are those carrying silver.

BISMUTH

Bismuth, both in the native state and as the sulphide, has been reported from mines near Juan Godoy and San Antonio in the Department of Copiapó, Province of Atacama.

NICKEL

Nickel ores have been worked to a slight extent in several mines in the Departments of Vallenar and Copiapó, Province of Atacama, and in the Province of Coquimbo, but information is lacking in regard to the character or extent of the deposits.

ANTIMONY

Native antimony is reported from mines near Alto del Carmen, in the Department of Vallenar, Province of Atacama. Many veins of stibnite ore are present in the silver mining camp of Pampa Larga, not far from the port of Totoralillo, also in the Province of Atacama. They have been worked to a slight extent.

MOLYBDENUM

Molybdenum ores are reported to occur at La Punta, 10 miles northeast of the City of Santiago, and in some mines in the

Department of Coquimbo. Little or no work has been done to determine the value of the lodes. Ores of molybdenum have been worked on a small scale near Cupane, along the Lluta River about 54 miles east of Arica, in the Department of Tacna.

VANADIUM

Vanadates of lead and copper have been found in the silver mines of Arqueros in the Department of La Serena, Province of Coquimbo.

THE NITRATE DEPOSITS AND THEIR UTILIZATION

The most important and unique of all the mineral deposits of Chile are the extensive bodies of sodium nitrate of the desert regions of Northern Chile. Although sodium nitrate (Chile saltpeter) is known from many regions in the world, Chile is the only country, up to the present, where workable deposits have been found. The possession of such quantities of this useful product of the mineral kingdom has been the most influential cause in the development of the country. No other country possesses such a complete monopoly of any equally important mineral product, and every civilized country in the world has long paid tribute to this greatly favored nation whose revenues are largely derived from the export tax on the nitrate.

History of the Nitrate Industry.—The localities where the nitrate deposits occur were in the early days prospected for gold, silver, and copper, and a number of valuable ore bodies were discovered; but not until the beginning of the nineteenth century was much attention given to the saline products of the desert, although it is said that the miners working the silver mines of Huantajaya, near Iquique, did use some of the nitrate for the manufacture of blasting powder during the eighteenth century. According to report, by accident a small handful of the white crystals was thrown about some growing plants whereupon they produced a remarkable growth. Efforts were then made to obtain additional amounts of the material, and in 1812 several small *oficinas* were established for the commercial production of sodium nitrate for fertilizing purposes. In 1830, the first year for which export figures are available, 8,348 tons of crude material were shipped. Since then operations have been carried on continuously and production has steadily increased until it now occupies first place in the industrial activities of the country, which place it is destined to retain for many years in the future. There are few such striking instances known elsewhere in which a seemingly worthless desert waste has become a region of wealth, with permanent cities of importance, railroads, and other industrial improvements. It is even more striking that a substance derived from a region absolutely devoid of all plant growth should be in demand in all parts of the world for fertilizing purposes.

To the close of 1917 there have been more than 56,000,000 tons of sodium nitrate shipped from the Chilean nitrate fields. For 1913, the last year of normal production before the war, the statistics (18) are as follows:

Name of district	Number of *oficinas* in operation	Production in tons	Exports in tons	Number of workmen employed
Tarapacá	82	1,099,343	1,050,855	23,102
Tocopilla	10	359,037	360,956	5,643
Antofagasta	25	825,560	832,282	12,964
Taltal	13	323,326	328,030	8,040
Aguas Blancas	7	164,988	166,216	3,412
Total	137	2,772,254	2,738,339	53,161

In 1916 the nitrate industry had fully recovered from the slump brought about at the beginning of the war, and a total of 3,270,000 tons was exported during the year.

During the first half of 1917 the production is estimated to have been 1,463,900 tons with 1,205,000 tons exported during the same period. There were 122 *oficinas* in operation and 52 idle.

Location of the Nitrate Fields.—The principal nitrate fields are found in a narrow zone extending from about Lat. 19° 11′ S. to 27° S., a distance of about 450 miles. The workable deposits are not continuous but occur as disconnected areas of variable extent. In the northern portion of the nitrate belt some deposits are only about 13 miles from the coast but in the southern part some are as much as 93 miles inland.

The nitrate fields are commonly divided into five districts, separated by barren or low-grade nitrate areas. These are designated as the Tarapacá, Tocopilla, Antofagasta, Aguas Blancas, and Taltal districts. They are included within the provinces of Tarapacá and Antofagasta.

In addition, nitrate-bearing ground has been discovered in the Province of Tacna, although not thoroughly prospected as yet, and important deposits have been located to the south of the Taltal District in the Province of Atacama. The latter are sometimes referred to as the Chañaral-Copiapó District.

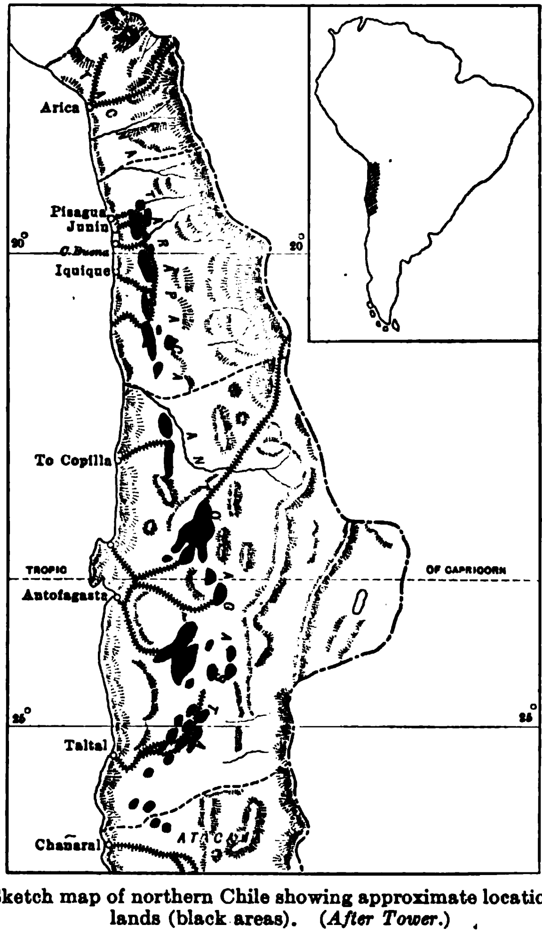

FIG. 33.—Sketch map of northern Chile showing approximate location of nitrate lands (black areas). (*After Tower.*)

The Tarapacá District lies entirely within the province of the same name and occupies the western part of the Tamarugal Pampa. This was the first district to be developed and it still retains its preëminence. The developed nitrate deposits occur in a narrow band seldom more than 2 or 3 miles in width. The elevation of the fields averages about 3,500 feet above sea level. In the northern portion, the nitrate deposits are only about 13 miles from the coast, but the southern fields are 30 miles inland. The district is well supplied with railroads. The Nitrate Railways Co. with a mileage of somewhat more than 350 miles traverses the district from north to south and connects most of the *oficinas* with the ports of Pisagua and Iquique. The Junin Railway with 60 miles of track, affords an outlet to the port of Junin; and the Caleta Buena and Agua Santa Railway, with approximately the same mileage, connects with the shipping port of Caleta Buena. In addition the Longitudinal Railway has been built into the district as far as Pintados and will ultimately be extended to Arica.

The Tocopilla, or Toco, District, is located a short distance west of the Loa River, which here flows north. It is on the west side of the Tamarugal Pampa, near the southern extremity, in the Department of Tocopilla, Province of Antofagasta. The deposits which form a narrow north-south band lie 30 to 35 miles from the coast at an elevation averaging about 4,000 feet above sea level. The Anglo-Chilean Nitrate Railway with about 75 miles of track connects the different *oficinas* with the port of Tocopilla.

The Antofagasta District lies northeast of Antofagasta along the line of the Antofagasta and Bolivia Railroad and its branches, over which the nitrate is shipped to the ports of Mejillones and Antofagasta. The fields of this district are scattered irregularly over a large area. Some of the deposits being worked lie over 90 miles from the coast. The elevation above sea level varies from 3,500 to 6,000 feet.

The Aguas Blancas District lies southeast of Antofagasta about 35 miles inland and consists of a number of separate deposits irregularly distributed. The elevation is about 3,500 to 4,000 feet above sea level. The nitrate is shipped to the port of Caleta Caloso over the Caleta Coloso-Aguas Blancas Railway.

The Taltal District is located in the southern part of the Province of Antofagasta. The fields cover a wide area extending from 30 to 50 miles inland. Some of the deposits worked in this region are more than 7,500 feet above sea level and, some undeveloped deposits occur above 9,000 feet. The Taltal Railway starting at the port of Taltal, reaches the various *oficinas*. Its mileage is about 180 miles.

General Description of the Nitrate Fields.—As the observations of the authors are limited to the Tarapacá District, the descriptions which follow are not equally applicable to all the nitrate fields. In the general features all of the fields are much alike, however, even though differing in some of the less important characteristics.

Throughout northern Chile the topographic features, described on a previous page, are especially well-marked, viz., the Coast Mountains rising precipitously from the shore, the high Cordillera forming the eastern boundary of the country, and a central alluvial-filled valley lying between. The nitrate fields lie toward the western margin of this interior valley and in places extend up the slopes of the adjoining Coast Mountains.

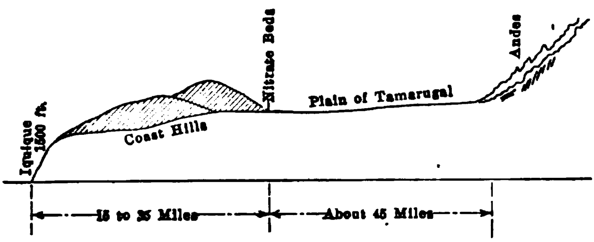

Fig. 34.—General east and west section of the nitrate district of Chile; vertical scale greatly exaggerated. (*After Cuevas.*)

This longitudinal valley between the two mountain ranges has been converted into a flat featureless plateau in parts, but elsewhere there are occasional hills, the tops of much larger hills whose bases are buried beneath the accumulation of débris from the neighboring mountains. The slope of the surface of this valley is toward the west, thus indicating the source of the bulk of the alluvium. At intervals, even yet, considerable material is brought down from the high Cordilleras after violent rains and dry water courses exist in many localities.

The nitrate fields are thus limited to the lower-lying portions of the longitudinal valley, but the nitrate deposits do not occupy the lowest depressions. Instead these places are encrusted with layers of common salt, with here and there an admixture of borates and other salts, whereas the nitrate deposits are located about the margin of these salt-encrusted areas known as *salares*. Small eminences rising above the general level of a *salar* as islands may also contain nitrates.

Not all of the nitrate deposits are associated with *salares*. In some sections where there are broad stretches of flat pampa bordering the hills the nitrate is absent from the flat places but occurs on the slopes of the hills to a height of several hundred feet. Where the slopes are very steep, nitrates are apt to be absent, as is also the case on the most gentle slopes. Medium gentle slopes, probably 5° to 15°, seem to be the most favorable places for the accumulation of these valuable salts. The reasons for this phenomenon will be considered in a discussion of the origin of the materials.

In spite of the fact that the region is so extremely arid, the ground water level lies close to the surface throughout the nitrate fields. Beneath the *salares* it is very shallow. At the Oficina Central Lagunas the water table is only 3 feet below the surface and at the Oficina Paposa near La Noria 18 feet. The water of the nitrate pampas is sheet water filling the alluvial-filled valleys and is inexhaustible. It comes from the high Cordilleras and makes its way slowly to the west through the loose débris and comes close to the surface near the Coast Mountains. As will be shown later this shallow ground water is responsible for the concentration of the nitrates and other salts in the places where we now find them.

The climatic conditions of the nitrate fields are of prime importance, as they have made possible the accumulation of these easily soluble salts. The nitrate regions are probably as desert as any portion of the globe. In some places rain has never been known to occur, but in most sections occasional showers may be expected every two or three years, and in a few cases heavy downpours of short duration have occurred. At Agua Santa, near the northern portion of the Tarapacá District, the desert was flooded a few years ago due to unusually heavy rains in the Cordillera, lying to the east.

The rapid radiation of heat during the night causes fogs (*camanchacas*) to collect frequently, but these disappear soon after the sun rises. MacCoy (133) says that

"the relative humidity of the desert air, as observed in the Aguas Blancas Pampa over a period of several months, ranges from 8 per cent to 50 per cent with a daily average of near 30 per cent."

Throughout the nitrate fields no trace of vegetation of any kind can be observed. In part, however, this is due to the salt in the soil and not entirely on account of the absence of rainfall.

In many places the ground water is close enough to the surface to support plant life, and in a few localities adjoining nitrate fields there are some coarse grasses and low shrubs.

Most of the nitrate fields lie within the tropics and consequently high temperatures prevail during the middle of the day. With no clouds to intercept the sun's rays, the temperature becomes so high during the summer that most of the work on the pampas must be done in the mornings and late afternoons. Owing to the elevation of the fields and also the low humidity, the nights are cool, and in winter freezing temperatures are experienced. Sea breezes of unusual intensity drive great clouds of dust over the pampa during the early afternoon, and evidences of wind erosion can be seen in abundance.

The earthquakes of the nitrate regions should also be mentioned as they are responsible for the shattering of the hard rocks in many places, thus affording openings for the accumulation of the nitrate. They also have determined the low type of buildings everywhere seen. In some places, perceptible shocks, which accomplish little damage, occur once or twice a week on an average with occasional ones severe enough to destroy property. Only a few years ago the incline of the Agua Santa Railway, 2,250 feet in height, leading down to the port of Caleta Buena, was broken and displaced by an earthquake.

Description of the Nitrate Deposits.—The nitrate deposits are usually spoken of as surface deposits, but actually seldom is the nitrate immediately at the surface. In the nitrate fields several layers of materials are recognized, all of which have received distinctive names. From the surface downward these are (1) *chuca* or *chusca*, (2) *panqueque* (*pancake*), (3) *costra*, (4) *caliche*, (5) *tapa*, (6) *congelo* or *conjelo*, (7) *coba* or *gova*. These seven layers are not everywhere recognizable, and in certain localities there are still other layers. The *chuca*, *costra*, *caliche*, and *coba* layers are the most persistent and are recognized in almost every nitrate working. Of these the *caliche* is the one of greatest value as in most localities it alone contains nitrate in commercial quantities. The thickness of all vary greatly, even within a few yards.

(1) The surface layer, *chuca*, consists of the loose surface soil, sand, and fine pebbles, in places feebly cemented by various salts but elsewhere so loose that it is shifted from place to place by the wind. In thickness it varies from zero up to several feet. In

color it varies from dark-gray to dark-brown. Deliquescent salts are present in the *chuca* in some localities, and, in the morning following a night of heavy fog, the surface of the earth will appear damp as though rain had fallen.

Semper and Michels (184) give the following analyses of *chuca* from the southern Tarapacá District. It will be noticed that the bulk of the material consists of insoluble rock mineral.

	Per cent.	Per cent.	Per cent.
Silicic acid	54.85	62.15	46.70
Iron oxide	1.92	2.96	2.00
Aluminium oxide	14.83	14.04	12.42
Manganese oxide	0.45	0.78	0.45
Calcium oxide	7.26	9.35	9.26
Magnesium oxide	3.04	3.20	2.88
Potassium	1.29	1.52	1.02
Sodium	5.29	4.37	1.99
Sulphuric acid	6.46	9.72	13.23
Nitric acid	1.25	.....	1.14
Carbonic acid	.....	.....	Trace
Phosphoric acid	0.61	0.81	0.85
Iodic acid	0.06	.....	0.25
Chlorine	2.24	0.88	1.24
Moisture	1.00	0.45	0.85

(2) Beneath the *chuca* is a hard layer well developed in some sections but entirely absent in others, commonly termed *panqueque*. Near Laguna it consists of separate masses of concretionary shape lying on top of the *costra* and varying in size up to 1 foot in diameter. At Oficina Paposa near La Noria the separate masses are several feet in diameter, and at Oficina Agua Santa they form a solid layer resembling a chalky limestone and ranging in thickness up to 2 feet. It consists mainly of gypsum and sodium sulphate.

(3) The *costra* consists of rock fragments, commonly pebbles, sand and clay, but in certain places fragmental rock material feebly cemented by different salts. In places the line of separation between the *costra* and *caliche* is not a sharp one and there is a difference of opinion as to what should be called *costra*. At present some *costra* is utilized in places, and with improved methods of extraction considerable quantities may be used.

The average thickness of the *costra* is probably from 2 to 3 feet, but in some sections is as much as 18 feet or even more. The thickness varies greatly even within short distances. In color it is dark-brown, gray, or reddish.

Semper and Michels (184) give the following analyses of costra from the Oficina Alianza, Tarapacá.

	Per cent.	Per cent.
Sodium nitrate	14.6	13.6
Potassium nitrate	1.7	1.3
Sodium chloride	27.2	19.3
Sodium sulphate	......	6.7
Calcium sulphate (gypsum)	3.8	2.7
Magnesium sulphate	7.5	9.7
Magnesium chloride	0.4	......
Sodium iodate	0.1	0.11
Insoluble	42.2	44.0
Moisture	2.6	2.4

(4) Occasionally a thin layer of sand and clay containing much common salt and gypsum is noticed immediately above the *caliche*. This is known as the *tapa*. It seldom forms a persistent and distinct layer.

(5) The *caliche* is the high-grade nitrate-bearing material. In composition, thickness, color, etc., it shows marked differences. One sometimes observes layers of practically pure salts from 6 to 10 inches thick where the material in crystallizing has lifted the overlying débris. The more common occurrence, however, is that of alluvial débris in which the interstices have been filled with the soluble salts. When large cobbles are present there is apt to be a layer of the salts coating them to a thickness of ⅛ to ¼ inch. In one place near Negreiros, Tarapacá, *caliche* was seen consisting of shattered limestone, the cracks of which contained the salts.

The *caliche* is normally white or gray but bright yellow, violet, purple, red, green, and brown colors are not uncommon, the colors being due to mineral impurities. The thickness of the *caliche* is seldom more than 6 feet as a maximum and the average thickness is probably about 1 foot.

The composition of the *caliche* varies so much that it is difficult to select typical analyses. In the following list Nos. 1 and 2 are furnished by the Central Lagunas Oficina and 3 to 9 are taken from Penrose (164).

	1	2	3	4	5	6	7	8	9
Sodium nitrate....	25.00	30.62	28.54	53.50	41.12	61.97	22.73	24.90	27.08
Potassium nitrate..	.....	.....	Trace	17.25	3.43	5.15	1.65	2.50	1.34
Sodium chloride...	21.22	23.80	17.20	21.28	3.58	27.55	41.90	24.50	8.95
Calcium chloride...	.....	.....	.....	.....	.....	.....	.....	.....	5.25
Magnesium chloride............	0.47	0.00	.....	.....	.....	.....	.....	.....	0.18
Potassium perchlorate...........	0.17	0.26	Trace	0.78	0.75	0.21	Trace	Trace	Trace
Sodium sulphate...	0.00	1.56	5.40	1.93	Trace	2.13	0.94	6.50	0.00
Magnesium sulphate..........	0.00	3.24	3.43	1.35	10.05	0.15	3.13	6.50	0.00
Calcium sulphate..	3.63	1.86	2.67	0.48	3.86	0.41	4.80	4.50	2.89
Sodium bi-borate..	.....	.....	0.49	0.56	0.20	0.43	0.53	0.15	0.52
Sodium iodide.....	.....	.....	0.47	.....	.....	.....	.....	.....	.....
Sodium iodate.....	0.13	0.10	0.43	0.01	0.05	0.94	0.07	0.054	0.08
Ammonium salts...	.....	.....	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Sodium chromate..	.....	.....	.....	Trace	.....	Trace	Trace	.....	.....
Insoluble matter...	47.58	37.22	40.30	2.07	31.86	0.39	22.50	28.40	47.34
Moisture..........	1.80	1.34	1.88	0.79	5.00	0.67	1.75	2.00	6.37

At the present time there are few if any places where *caliche* averaging as high as Nos. 4, 5 and 6 is being worked. It is now the common practice to make use of all materials containing as much as 17 per cent of nitrate and in one plant the *caliche* does not average over 13 per cent.

(6) Beneath the *caliche*, and not sharply separated from it, is a thin layer, not everywhere distinguishable, in which there are commonly many small selenite crystals. It is the *congelo* layer and consists mainly of sand, pebbles, and clay, containing a considerable quantity of different kinds of salts, especially sodium, magnesium, and calcium sulphates.

(7) Beneath the *caliche* and *congelo* is the loose uncemented alluvial débris, or, in a few places, shattered rock in which there are few salts observable. This is the *coba* or *gova*. Analyses, however, usually show the presence of more saline matter than one would expect from a casual observation.

Semper and Michels (184) give the following analyses:

Silicic acid	35.30	25.05
Iron oxide	1.92	1.64
Aluminium hydroxide	8.58	7.96
Manganese dioxide	Trace	0.65
Calcium	10.16	6.82
Magnesium	1.90	1.92
Potassium	.....	Trace
Sodium	14.73	19.93
Sulphuric acid	26.15	20.09
Nitric acid	.....	2.49
Carbonic acid	.....	1.75
Iodic acid	Trace	0.13
Chlorine	0.78	12.98
Moisture	0.65	0.95

GENESIS OF THE NITRATE DEPOSITS (186)

Most of the theories that are or have been in vogue to account for the Chilean nitrate deposits may be grouped under four headings, according to the manner in which the nitrate is supposed to have been formed. These are:

1. The seaweed theories.
2. The guano theories.
3. The bacterial theories.
4. The electrical theories.

The seaweed theory was proposed in 1867 by Dr. C. N. Noellner (151). He believed that great quantities of seaweed collected along the portion of the west coast paralleled by the nitrate fields, due to the prevailing westerly winds, and that occasional hurricanes piled this up. An uplift of the land or a recession of the sea followed. The sea water that remained behind evaporated and furnished the sodium chloride, and the nitrates resulted from the slow oxidation of the seaweed.

In 1860, C. G. Hillinger advanced the theory that the nitrates are due to extensive deposits of guano that covered the banks of a large saline sea. The saline waters flooded the guano and reacted with the nitrogen to finally form sodium nitrate. Very similar is the theory proposed in 1894 by A. Gautier. He derives the nitrates from bird guano in the form of calcium nitrate. This was then liquefied little by little by the night dews, and thus brought into contact with the salt of the *salares*, basin-like depressions in the pampa characterized by an abundance of sodium chloride, where it was converted into sodium nitrate. The most detailed presentation of this theory was made in 1910 by R. A. F. Penrose, Jr. (164). He believes the nitrate region was once part of the ocean bottom, and finally an interior basin occupied by salt lakes. Guano beds deposited about the borders of these lakes furnished nitrates that were carried down into their waters.

The way for the bacterial theory was paved in 1862, when Pasteur suggested that the oxidation of the nitrogen compounds in the soil is accomplished by living organisms. The best presentation of this theory is that by Dr. William Newton, in 1896 (149). He ascribes the genesis of the nitrate to the action of the nitrifying organisms on ancient vegetable matter in the soil of the region. The nitrates thus formed, he says, have been collected by the drainage waters of the entire region, and gathered and evaporated at the site of the present nitrate deposits, which is the point where these waters are stopped by the coast line of hills. As thus developed, this is one of the most plausible theories that have been advanced.

The electrical theory was advocated in 1903 by Dr. Semper, and in the following year, by Semper and Michels (184) in their paper on the nitrate deposits. According to the more prevalent form of this theory, the nitrates are formed by the oxidation of the nitrogen of the air through the electrostatic tension that is such a marked accompaniment of the frequent coast fogs, or *camanchacas*, that roll in over the nitrate pampa at night.

An atmospheric source of nitrates that has received less attention, is that formed during electrical storms in the Andes. This has certainly been at least a contributing factor to the nitrate supply of the region.

Sundt (198) believes that the nitrates have been formed *in situ* by the decomposition of feldspathic porphyries which yielded sodium carbonate, later transformed into sodium nitrate by the action of nitric acid contained in the atmosphere. He states that the deposits are only found where these high sodium rocks occur.

Briefly put, the authors believe that the nitrate deposits have resulted from the accumulation, by means of evaporation, of the minute nitrate content of the underground waters of the region. In other words, they represent a sort of efflorescence of soluble salts out of the ground-water. This accumulation has been made possible through the remarkable relations of ground-water and climate existing in the region of the nitrate deposits.

The pampa has been built up with loose detrital material washed down mainly from the slopes of the Andes on the east. Through such material, capillarity is very effectively feeding the shallow ground-water in enormous quantity to the atmosphere through evaporation. Whatever soluble salts this ground-water is carrying are left behind to accumulate in the soil between the surface and the ground-water level.

There is a constant flow of ground-water from the regions of more abundant precipitation in the higher slopes of the Andes on the east, westward beneath the pampa, toward the sea. The pampa has a gentle westward slope to the foot of the Coast Range, where the presence of these mountains causes an abrupt rise in the topography. Since the surface of ground water follows in its general outlines the overlying topography but is less accentuated than the latter, the ground water level should lie nearest the surface on this western edge of the pampa; and consequently here should take place the maximum evaporation, and for that reason, the maximum accumulation of soluble salts.

The richest nitrate ground is frequently that immediately contiguous to the *salares*, and the nitrate tends to decrease in quantity with increasing distance and elevation above the *salar*. There are often small knolls within a *salar* and these also carry nitrate above its level.

The fact that the nitrate occurs around and not in the *salares* is easily understood, in view of the deliquescent nature of this substance. Suppose that salt and nitrate had accumulated in these depressions. When a rain did come, or when the pampa was deluged, as it occasionally is, by torrents bursting down from the Andes, these would be the places for the waters to collect before they had been completely dissipated through seeping into the soil and by evaporation. They would be the wettest places and the last places to remain wet. Whatever nitrate existed there would be taken into solution, and it would at once begin to effloresce out of the boundaries of the *salar*, as, for instance, sal ammoniac crawls out of its solution in the La Clanche cell, and accumulate in the dry ground surrounding it. This process repeated at intervals would keep the *salar* free of nitrate, and leave the accumulation of salt behind.

If there is or has been an unusual activity in the generation of nitrates in this region, as the authors of the older theories have felt it necessary to assume, it merely means that it has taken less time to accumulate the present deposits than if there had been no such unusual activity.

The only feature in which this region might be unique in the generation of nitrates is that apparently more processes have been active here than is generally the case in other places. There is no evidence to show that any one of the possible sources would be adequate to account for all of the nitrate, and we believe that all combined would be inadequate, if it were not for the all important remarkable conditions of climate, underground waters, and geologic structure existing in the region.

Former attempts to satisfactorily explain these deposits have failed, because undue emphasis has been laid on the mode of generation of the nitrates, whereas the fundamental explanation lies in the conditions that have made possible their accumulation.

Statistics of Nitrate Reserves.—According to the report of the Inspector General of the Nitrate Deposits issued in 1916, the zone where nitrate deposits may be expected to occur comprises 200,000 square kilometers of which only 5,811 square kilometers have been carefully surveyed and the character and extent of the deposits determined. Most of these surveyed portions are now owned by private firms.

In the 5,811 square kilometers the Government inspectors estimated nitrate still remaining in the different districts as follows:

	Tons
Tarapacá District	33,000,000
Tocopilla District	27,000,000
Antofagasta District	31,000,000
Aguas Blancas District	48,000,000
Taltal District	93,000,000
Chañaral and Copiapó District	8,300,000
	240,300,000

In the above calculation *caliche* containing less than 17 per cent of nitrates has not been included nor have those deposits where the *caliche* is less than 1 foot thick, unless it is rich (more than 25 per cent nitrates) when an 8-inch layer is included. An allowance of 40 per cent for loss in mining and refining is also made.

As improved methods for extracting the nitrate are now coming into use *caliche* with less than 17 per cent nitrate is commercially available and the 40 per cent loss is extreme. Consequently the surveyed areas should yield more than the calculated estimate.

The areas surveyed are believed to be the best ones, yet in the unsurveyed 194,000 square kilometers, it is believed that, at a minimum, as much more available nitrate will be found as in those already calculated, or a total of 600,000,000 tons. Up to the present time only about 56,000,000 tons have been removed and the maximum for one year is less than 3,000,000. At that rate the Chilean nitrate deposits should not be exhausted for nearly 200 years. As all the estimates seem to be conservative, it is not improbable that they may last 300 years as claimed by some.

In some places ground has already been worked three times, lower-grade *caliche* and *costra* being taken each time, and this may be expected to continue; consequently, much nitrate earth now discarded may be utilized in the future.

For some time before the outbreak of the Great War the demand for nitrate increased about 10 per cent during each five years. Should this continue, the exhaustion of the Chilean fields will naturally come much earlier but, with the increased production of artificial nitrates, it is doubtful whether the same rate of increase will continue although the demand, likewise the production, will probably become somewhat greater than at present.

Government Regulations of the Nitrate Industry.—Before the Peruvian War practically all the then known nitrate fields belonged to Peru, and individuals and firms obtained absolute title to large tracts under extremely lax conditions. Since Chile has obtained control of the fields new methods of acquisition have been inaugurated although the former Peruvian titles have been recognized.

The present method is for the Government inspectors to first examine the land and estimate the amount of nitrate which it should yield. A minimum price per quintal (101.44 lbs.) is set by the Government and the land sold at auction to the highest bidder. In recent sales a price of 4 to 6 pence a quintal was asked. The Government carefully scrutinizes the sales to prevent the lands from passing into possession of unreliable parties.

In addition an export tax of 28 pence ($0.56) a quintal or $12.36 a long ton is levied on the finished nitrate when sold. In 1913 this amounted to over $33,000,000 and this tax constitutes the major portion of the Government revenue. Without this source of wealth Chile could not have made the great advance which it has in public improvements, building of railroads, etc.

Foreign companies from the beginning of the industry have been permitted to operate under exactly the same conditions as local companies. English capital was largely responsible for the early development of the industry and even yet is only slightly exceeded by Chilean capital. German firms own a number of properties, and French and North American capital is also interested. Recent estimates of the amount of capital invested in the nitrate fields are as follows:

Chile	$55,000,000
England	50,000,000
Germany	20,000,000
Other nationalities	25,000,000

Altogether about 170 companies are represented, a number of which produce more than 1,000,000 quintals a year.

Uses of Chilean Nitrate.—Two grades of nitrate are marketed, one 95 per cent pure mainly used for fertilizing purposes and the other 96+ per cent pure for use in manufacturing. It is employed in the manufacture of explosives, fireworks, glass, fusing mixtures, nitric acid, nitrate of potash, arsenate of soda, etc., and is also used for making chlorine, in the purification of caustic soda, etc.

Methods of Working the Nitrate Deposits.—In the nitrate fields the mining or quarrying of the nitrate earth is called "extraction" and the refining is called "elaboration."

In a few places the surface *chuca* and *costra* are removed by drag-line excavator, but in most cases holes dug by means of iron bars to the base of the *caliche* are charged with black powder. After blasting, the workmen sort the material, breaking up the largest lumps with sledges, and load the *caliche* into carts or directly into small cars. In many places a long working face is developed; tracks running along the face are moved as the work advances. The material low in nitrate is thrown into the old workings. As only lump *caliche* is taken to the refining plant there is a large loss of high-grade material on account of the friable character of the salts. Each *oficina* makes its own blasting powder from coal dust, sodium nitrate, and sulphur brought from the volcanic sulphur regions of the high Cordilleras.

Where the *chuca* and *costra* are more than 10 to 15 feet thick, which is unusual, a system of underground mining by caving is employed. No timber is used, but pillars are left where necessary; in general, the *costra* forms a good roof.

Methods of Refining the Nitrate.—The refining or "elaboration" of the nitrate has passed through several different stages since the beginning of the industry. In the earliest operations the *caliche* was put into great copper vessels of boiling water which dissolved the nitrate. The solution was then poured into wooden tanks where the nitrate crystallized.

Fig. 35.—Refining plant (Maquina) of North Lagunas Oficina, typical of the nitrate establishments.

About 1855 the method of heating the water by means of steam was first employed and with some modifications still continues. The process of refining is a simple one. The *caliche* is treated with boiling water to dissolve the sodium nitrate. Other salts, particularly NaCl, are also dissolved and these are separated by precipitation at different temperatures. In practice, the mechanical processes vary somewhat in the different *oficinas* but the description which follows is typical.

The *caliche* (and high-grade *costra*) is brought to the refining plant, called a *maquina* where it is dumped from the cars into bins. It is fed into crushers of the Blake type which are adjusted to suit the character of the material. If it is compact, it is necessary to crush finer in order to have a good extraction. In common practice the earth is crushed to the size of 2 to 4 inches, but on account of the friable character of the material most of it is much finer.

From the crushers the product goes to bins from which it is taken on belts or in cars to the boiling vats, called *fondados.* At Oficina Paposo these are 34 feet long, 7 feet wide and 9 feet deep. The *caliche,* covered with a solution, is boiled by means of steam passed through iron pipes about the walls of the vat. The *caliche* is treated in turn with several solutions, the first fairly well saturated with the soluble salts, and successively weaker and weaker ones until the last one is practically fresh water. By this method the largest amount of recovery is accomplished and also solutions of the requisite density are obtained.

The waste material, that which remains after the boiling has been completed, termed *ripio,* is emptied out of the vats into cars, by removing the plates of the false bottoms, and hauled to the dumps nearby.

The solution from the vats, called *caldo,* is tested at all stages to determine its density. Practice varies as to the most desirable density. It is found that the fresh liquid will take up a great amount of NaCl; but, as it nears the saturation point in successive vats, some of the NaCl will be precipitated and additional amounts of $NaNO_3$ taken into solution. At Oficina Agua Santa the liquor passes through 8 vats and reaches the density of 82° Twaddell. It is then boiled in great closed tanks until the density is more than 90° Twaddell.

From the boiling vats direct, or from the secondary boiling tanks, the *caldo* goes to large tanks, *chullagores,* where the solution cools to about 90° C. In these tanks the sediment and most of the NaCl are precipitated. The liquor is then drawn off into shallow tanks, the *bateas.* At Oficina Paposa these are 15 feet square, 2½ feet deep at upper end, and 3½ feet deep at lower end. In the *bateas* the liquor remains about 5 days and cools to the air temperature of 16° to 20° C., causing the precipitation of most of the nitrate. The liquid, known as the *agua vieja,* is pumped from the *batea* back to the boiling vats for use again; the nitrate is shoveled into cars and hauled on a trestle to the drying floors where it is dumped. After several days it is ready for sacking for shipment.

At Oficina Agua Santa Butters' filters have been installed and a new process devised by which it is claimed that an extraction can be obtained that will make it profitable to work *caliche* and *costra* containing a minimum of 8 per cent nitrate.

In this process the material from the crusher passes over shaking screens to separate the coarse and fine products. The coarse goes to the boiling vats and is treated as described above. The fines go to a Hardinge mill in which there is a solution of $NaNO_3$ of about 53° Twaddell. The product from the mill is heated in a tank to 95° C., the mixture being kept in motion by a mechanical stirrer meanwhile. Here the solution is raised to 80° Twaddell. The mixture is then filtered in Butters' filters. The solutions are further treated in the usual way. The advantage of the process is due to the separate treatment of the fine materials which seriously interfere with the circulation of the liquids through the *caliche* in the boiling vats when mixed with the coarse materials.

In general there is much waste in both the methods of mining and refining as carried on at the present time, a fact that is freely admitted by most operators. The question which confronts them, however, is whether it will pay to change their methods for more efficient but more costly processes.

The fuel most commonly used is Peruvian or Californian petroleum.

IODINE

Iodine is a by-product in the refining of the nitrate. At the present time nearly the entire world's supply comes from Chile where it can be produced at small cost. A combine, which includes practically all the nitrate companies, regulates the amount which each *oficina* can market. From 1879 to 1913 inclusive, Chile produced 10,890 tons of iodine valued at £11,197,886. In 1913, 436,971 kilograms of iodine were exported.

Sodium iodate is present in small amounts in almost all the nitrate *caliche* and is taken into solution in the boiling tanks together with the nitrate. It is not precipitated by cooling as is the nitrate, consequently the *agua vieja*, after being used several times, contains an appreciable amount of iodine. It is pumped from the *bateas*, or crystallizing tanks, to "cutting" tanks in an adjoining building where a solution of sodium acid sulphite ($NaHSO_3$) is added. The mixture is allowed to remain for several days during which time the iodine is precipitated. The clear liquid is then decanted and either pumped back to the boiling tanks or to evaporators where the potassium nitrate is obtained. The iodine precipitate is flushed into washing tanks and again allowed to settle. It then goes into sacks which strain the water from it. The sacks are compressed in a small press, resembling a cheese press, to still further free it from moisture. After several cakes, or "cheeses," have been made, the iodine is refined by being put into a retort connected with cooling chambers constructed of tile pipes. The iodine is volatilized and precipitated in these pipes which are then taken apart and the iodine scraped from them. The iodine is packed in small kegs for shipment.

The sodium sulphite is manufactured at the *oficina*. Sodium bicarbonate is first obtained by burning a mixture of 6 parts of coal and 50 parts of sodium nitrate and treating the fused mass or residue with water. The sulphite is produced by passing sulphur fumes (SO_2) through the bicarbonate solution.

POTASH (89, 178, 212)

Potash in small quantities has been found in many places in the nitrate fields and elsewhere in the deserts of northern Chile but the production has been insignificant. Up to 1914, concessions for potash-bearing lands granted by the Government totaled 298. There is reason to believe that the potash industry may develop into an important one if capital can be induced to support it as has been done in the case of the nitrate industry. Germany's preëminent position with regard to potash deposits in former years has tended to discourage the investigation of new fields and consequently Chile's possibilities in this line have failed to receive sufficient consideration.

As a large part of the potassium chloride from the Stassfurt deposits of Germany is used in making potassium nitrate from the sodium nitrate of Chile, it would seem that the Chilean deposits should have a decided advantage over those of Germany on account of their proximity to the nitrate fields.

The best known potash deposits are those of the Salar de Pintados and Salar de Bella Vista in the Province of Tarapacá. The salts occur at the surface forming a crust which when removed is renewed in 8 to 12 years by evaporation of underground waters brought to the surface by capillarity. Chemists from the University of Chile examined these deposits and estimated that they contained over 2,037,948 tons of potash.

Investigations by Gale (89) have shown that the salt crust of the Pintados Salar over an area of 20 square miles contains appreciable amounts of potassium. He gives the following typical analyses:

ANALYSES OF HARD SALAR CRUST FROM THE PINTADOS DEPOSIT
Chemical Determinations

	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
K	5.8	6.7	5.1	4.9	2.8
Na (calc.)	25.2	28.8	31.9	32.1	35.3
Ca	2.4	0.9	0.5	0.4	....
Mg	1.0	0.7	0.1	0.2	....
Cl	45.7	41.4	40.6	45.8	47.1
SO_4	7.5	17.1	19.4	12.3	13.1
H_2O	9.8	2.4	0.7	0.8	1.3
Insoluble	2.0	1.9	0.8	3.1	Trace
	99.4	99.9	99.1	99.6	99.6

Calculated Salts

K_2SO_4	....	14.9	11.3	10.9	6.3
KCl	11.0	....	....	....	....
Na_2SO_4	....	5.9	17.2	6.8	14.4
NaCl	64.3	68.2	66.9	75.5	77.6
$CaSO_4$	8.0	3.1	1.7	1.5	....
$MgSO_4$	2.3	3.5	0.5	1.0	....
$MgCl_2$	2.0	....	....	....	....
H_2O	9.8	2.4	0.7	0.8	1.3
Insoluble	2.0	1.9	0.8	3.1	Trace
	99.4	99.9	99.1	99.6	99.6

Whether these low-grade potassium salts, which occur in such great quantities in the *salares* of northern Chile, can be worked with profit is still undecided but, no doubt, will be determined before many years.

SALT

Vast deposits of salt are found widely distributed throughout the arid portion of northern Chile in the *salares*, which represent dessicated lakes or salt deposits formed by the evaporation of the ascending shallow ground waters. Nevertheless, up to

1902 the country imported a large part of its salt supply. Since then, however, it has entered the export field itself. This is largely the result of the building of an aerial tramway from the Salar Grande, which lies in the southern part of the Province of Tarapacá and about 11 miles inland, to the port of Caleta Pescadores. The Salar Grande covers about 80,000 acres and contains practically pure sodium chloride in enormous quantities. Much of it analyzed 99.99 per cent. pure. The thickness of the deposit is not known, but a shaft 82 feet in depth failed to reach the underlying rock stratum.

Although the single deposit at Salar Grande could easily supply the entire country, and the world besides, yet on account of the high cost of transportation many other deposits are worked on a smaller scale to supply the immediate vicinity.

Throughout the western part of the Province of Tarapacá the lowest portions of the *salares* are covered with thick layers of common salt. These *salares* present an interesting appearance with their glistening white salt crystals. The surface is not flat but, instead, everywhere roughened by hummocks or fissured compression ridges up to 3 feet in height. Where railroads cross the *salares* the track is very rough, due probably to changes in the surface produced by upheaval as the result of growing crystals obtaining new supplies of material from the ascending ground water.

In a *salar* near Lagunas (186*a*), salt is being obtained in a unique manner. Ditches are cut in the surface of the *salar* to a depth of 8 inches below the level of ground water, which here lies at a depth of 3 to 3½ feet. The ditches, exposed to the hot, dry sunshine and parched winds, act as very efficient evaporating pans; and the saline water underlying the *salar*, exposed in the ditches, is evaporated to the point of saturation when salt begins to crystallize. Since the level of ground water is maintained in the ditches by the constant seeping in of the ground water, the salt continues to accumulate until it reaches the height of ground water, or a thickness of 8 inches, when the ditch has dried up. The salt is shoveled out by hand, and as it is removed the water again comes in. After a ditch has its salt removed, the same process is gone through again. The rate at which the salt forms is 1 inch in 15 days, or at the rate of three crops of salt a year.

The salt is shoveled out on the ground between the ditches to drain and dry, and is then packed in sacks holding 2 quintals each, or about 200 pounds. Most of it is of a beautiful snowy white color and pure enough for table use. Occasionally, however, the violent wind storms which sweep across the pampa blow enough of the yellow pampa dust into the ditches to give the salt a dirty color. Such salt is kept separate from the rest and sold for cheaper uses. A branch of the Nitrate Railways to the South Lagunas Nitrate Oficina runs between the salt ditches and affords very convenient shipping facilities.

This salt industry was established on a very small scale about 10 years ago and has proved to be such an inexpensive method that it has grown rapidly, until now there are 150 of these evaporating ditches. Each ditch covers an area ranging from about 40 by 40 feet to 40 by 100 feet. The output is about 16,000 quintals a month, which is roughly equivalent to about 10,000 tons annually.

BORATES

Borates are other desert products which Chile possesses in abundance. It is no exaggeration to state that Chile could furnish the entire world with the needed supply of borax for several centuries. It is found in the dessicated lakes, which throughout the section are generally known as *salares*. In some instances there are open bodies of water in these *salares*, although in most cases they contain no water except for a short time after heavy rains such as occasionally occur. *Salares* are found here and there all over the arid portions of Northern Chile and probably everywhere contain some borate but only a small proportion contain it in sufficiently concentrated form to render them workable.

The first borate deposit worked was in the Pampa of Tamarugal near the nitrate Oficina Virginia in 1852. The material, however, was quite impure and it became necessary to refine it chemically. In 1852 the Salar de Ascotan near the present Chile-Bolivia border was found to contain much richer deposits; but, in the absence of railroads, it proved to be very expensive to transport the material to the coast at Antofagasta, a distance of more than 200 miles through the desert.

In 1873 some borates were obtained from the Salar de Maricunga, to the northeast of Copiapó, and shortly after a deposit was developed at Pintados which has produced considerable.

Since 1883, however, almost all work has been confined to the Salar de Ascotan, although numerous other deposits have been worked from time to time. One can gain some idea of the wide-spread occurrence of the borate deposits by naming those that have been reported to contain workable material. In the Province of Tarapacá the chief localities are Chilcaya, Cariquima, Pocopoconi, and Pintados; Carcote, Pajonales, Gorbea, Parinas, Ascotan, Dioloque, Ceres, Calartoco, Tiloposo, Vegas de Carvajal, Aguas Calientes, Punta Negra, Chacanse, Chiu Chiu, and Toco in the Province of Antofagasta; and La Isla, Infieles, Pedernales, and Maricunga in the Province of Atacama.

Among those named many contain large quantities. It is estimated (157) that the Salar de Chilcaya will yield 8,250,000 tons of borates containing .44 per cent boracic acid, and the deposits of the *salares* of Ascotan and Pedernales contain many times as much.

The deposits mentioned above extend from about 25 miles from the coast at the western edge of the interior valley close to the Coast Range to the Bolivian and Argentinian borders and beyond. The richest *salares* are those of the valleys of the high Andes in the vicinity of the recent volcanoes, many of which still have active fumaroles. Chilcaya and Ascotan contain much richer deposits of borates than are to be found in the western *salares*, such as those of the Tamarugal Pampa.

Since the Antofagasta-LaPaz railroad has been built, practically all the borate mining of Chile has been confined to the operations at the Salar de Ascotan. The railroad passes through Cebollar on the western border of the *salar* where the plant of the Borax Consolidated Co., Ltd., is located. This company not only owns this deposit but 10 other important ones, but for several years has operated at the one point only. The annual production averages about 40,000 tons, but the amount could be increased if the market demands increased. As this company dominates the borax industry of the entire world, there is little likelihood of any other company with deposits less favorably situated with respect to transportation facilities entering the field.

The Salar de Ascotan is about 24 miles in length and at the broadest part about 6 miles wide. At present it is the main source of the world's supply of borax. The *salar* presents in the bright sunshine a most dazzling appearance. Here and there are small pools of water, but, for the greater part, the entire area is covered with glistening white crystals of various salts. The railroad passes along the western border of the *salar*, and close to the eastern margin are several volcanoes with well-preserved craters, some of which have active fumaroles. The *salar* lies at an elevation of 12,220 feet above sea level, and the adjoining volcanic mountains have elevations ranging from 18,000 to 19,600 feet.

The only borate that has been found in Ascotan is the boronatrocalcite, ulexite ($NaCaB_5O_9.8H_2O$). In some parts of the *salar* it is found practically free from all impurities, but elsewhere it is associated with interbedded strata containing much NaCl, Na_2SO_4, and $CaSO_4$, besides some terrigenous material probably blown from the adjoining land as strong winds are prevalent in the region. The top of the borate deposit, especially, contains considerable dirt. The ulexite occurs either in nodules or in compact fibrous masses. The thickness of the rich stratum is, in most places, less than a foot, but a thickness of almost 4 feet has been reported at one place, and at the Salar de Chilcaya a thickness of 5 feet was found.

Del Campo (46) gives the following analyses of the ulexite as mined:

	Per cent	Per cent
Boric acid	24.16	32.38
Calcium	7.64	10.20
Sodium	4.69	5.91
Water	42.53	28.68
Sodium chloride	15.64	16.38
Calcium sulphate	1.16	1.82
Magnesia	0.43	0.35
Iron and aluminium	0.28	0.26
Insoluble	3.44	4.02
	99.97	100.00

The surface layer contains less borate than the underlying stratum so is removed by means of spades or pickaxes, occasionally by light blasts. The richer material is then shoveled into cars and taken to the plant. As the richest portions of the *salar* are several miles distant from Cebollar, a narrow-gauge railroad has been constructed across the *salar* for hauling the material to the drying plant. There it is first dried in the sun to remove part of the moisture after which it is further dried by artificial heat. The drying plant contains both reverberatory ovens and rotary dryers. For some time the only fuel used was *yareta*, a description of which is given on page 312. The company constructed an aerial tramway to a locality about 8 miles away and at an elevation of about 14,000 feet where it was plentiful. The plant is, however, of slow growth and the supply is now insufficient so that coal has to be shipped in to meet the deficiency.

After drying, the borate is bagged and shipped to Antofagasta 232 miles distant, or occasionally to Mejillones, whence it goes to Europe for further refining and for marketing.

Origin of the Borate Deposits.—The source of the boric acid of the *salares* is undoubtedly the recent volcanoes that are so prominent in northeastern Chile and southwestern Bolivia. The aridity of the climate is such that there is no complete drainage system and the scant precipitation that falls in the region, particularly on the top of the mountains, finds its way very quickly into the enclosed valleys where it evaporates leaving its dissolved salts as a residue. Volcanic gases in other regions have been shown to contain boron so that it seems probable that the ulexite has been so derived in the Chilean deposits, although as yet these volcanoes have not been studied to show the exact origin of the boron.

The volcanoes are so situated that almost all their drainage enters nearby *salares*, which accounts for the richer deposits found in the high Andes in comparison with those lying farther west, although some of it travels by underground circulation to the nitrate pampas lying near the Coast Mountains.

SULPHUR

In the Cordilleras forming the boundary between Chile on the west and Bolivia and Argentina on the east are numerous volcanic peaks rising far above the surrounding country. They are composed of volcanic materials of different kinds—layers of lava flows alternating with beds of pumice, tuff, and volcanic ashes. Many of them still retain well-preserved craters with fumaroles and hot mineral springs along their flanks. Whether these volcanoes are extinct or only dormant is conjectural, but none of them has been in active eruption within recent years.

Lava flows which have undergone very little alteration furnish indications of the relatively short period of quiescence. Their summits are from 15,000 to 20,000 feet above sea level, and it is on their slopes and within the craters of these volcanoes that the sulphur deposits are found.

Owing to the inaccessibility of the sulphur-bearing mountains, occurring as they do in the highest portions of the Cordilleras and remote from the centers of population, exact information concerning most of them is not available and only the richest and most accessible ones have been exploited. So far as known the deposits that have been worked are found in the eastern portions of the province of Tacna, Tarapacá, Antofagasta, Atacama, and Coquimbo.

The Tacora district, in the Province of Tacna, is the most important of all the sulphur regions of the country from the standpoint of production. In the Province of Tarapacá the chief deposits are in the northeastern part in Lat. 19° 5′ S. In the Province of Antofagasta sulphur deposits have been worked in several places both to the north and to the south of Ollagüe, adjacent to the line of the Antofagasta and Bolivia Railroad, and also close to the Argentina border directly east of Taltal. The best known deposits of the Province of Atacama are those of the Cerro Azufre (5080 m.) located close to the eastern boundary of the country in Lat. 27° 18′ S. The Toro Sulphur mines in Lat. 29° 50′ S., near the Argentina border, are the best known ones of the Province of Coquimbo.

The above mentioned localities are by no means the only places where sulphur deposits occur, but they comprise the principal districts where, up to the present time, it has been profitable to work the deposits.

The sulphur industry of Chile dates back to the early days of the nitrate workings about 100 years ago, as the sulphur required for the manufacture of the blasting powder needed to break up the nitrate ground has been supplied from the native sulphur deposits from the beginning of the nitrate industry. Those deposits lying directly east of the nitrate fields and closest at hand have been the ones worked to supply the necessary sulphur which was taken to the nitrate *oficinas* on the backs of pack mules.

The building of the Antofagasta and Bolivia Railroad and later the Arica-La Paz Railroad, both of which pass near important sulphur deposits, stimulated the sulphur industry as nothing else could have done and has made it possible within recent years to meet the country's needs. The chief uses of sulphur in Chile are in the manufacture of black blasting powder and for use in the flourishing vineyards of the agricultural section of the country. With the increase of the sulphur industry foreign markets must be sought.

The Tacora District, Province of Tacna.—The Tacora sulphur deposits are located in Mt. Tacora and Mt. Chupiquiña, about 9 miles from Ancara, the nearest station on the Arica-La Paz Railroad. The station of Ancara has an elevation of about 13,500 feet and the summit of Mt. Tacora is almost 20,000 feet above sea level. Mt. Chupiquiña is not so high.

The mountains are composed of andesitic lavas, tuffs, and ashes. The sulphur deposits are found at many places on the slopes of these two mountains, practically to their summits, although the largest deposits thus far developed are about 16,000 to 17,000 feet above sea level and in or close to the saddle that connects the two mountains. Although the climate is semi-arid, enough snow collects during the winter months to seriously interfere with the working of some of the sulphur deposits. One of the best deposits of Mt. Chupiquiña can be worked only about 3 months of the year.

Solfataras are present in many of the places where the sulphur occurs, and the deposits are still in process of formation. Steam, hydrogen sulphide, sulphur dioxide, and other gases are being given off in many places. In some of the solfataras the noise of the escaping gases can be heard to a considerable distance; while even where the gases cannot be readily detected, they may still be given off in small amounts from the loose cavernous rocks so that it is unsafe to work the deposits by shafts or deep pits on account of the gases collecting in them. Hot springs with highly charged mineral waters are present on the north side of Mt. Tacora and furnish the name "Aguas Calientes," to a locality where one of the companies has its refining establishment.

The sulphur, formed by the precipitation from the sulphurous gases of the solfataras, occurs in irregular patches of variable size on the sides of the mountain. In some cases these yellow spots on the mountains can be seen several miles away and present a most pleasing appearance. The sulphur, in crystalline form, occurs mainly as cavity fillings in the fragmental and vesicular volcanic materials near the surface. In some places where large masses of practically pure sulphur, several feet in diameter, are found, it seems that some of the rock minerals have been removed by the dissolving action of the steam and other gases and sulphur deposited in their stead. All of the rock minerals have been greatly altered, particularly the feldspars, so that the rock fragments can be crumbled in the fingers. How deep the deposits extend has not been determined but information obtained indicates a maximum depth of 50 to 75 feet of workable material. The depth is as irregular and variable as the distribution.

The rock with the contained sulphur is termed *caliche* and the rock fragments themselves are called *costra,* the same terms used in the nitrate fields but with somewhat different significance. The *caliche* worked varies in sulphur content up to practically pure sulphur. Under present conditions it does not pay to save *caliche* containing less than 60 per cent sulphur.

The deposits thus far worked were located by the sulphur observed at the surface, but here and there the operations have been continued beneath a covering of ashes, cinders, and talus, which leads one to believe in the probable presence of other deposits not yet discovered. The *caliche* is almost everywhere easily obtained because of the soft friable character of the sulphur and the decomposed rock fragments Crowbars, picks, and shovels are the only tools needed. Occasionally, a little blasting is done to loosen the rock.

The usual method is to dig shallow, irregular holes in those places where the *caliche* is richest with no attempt to work the deposit systematically. One company is working the entire deposit in a series of benches, which has the advantage of obtaining all available material; but, as about two-thirds of the *caliche* dug in this manner is discarded as too low in sulphur content, the advantage is largely offset.

The *caliche* dug in some of the operations is almost too hot to be handled by the men and it is said that their hands frequently become sore on account of the corrosive action of the hot gases still escaping.

Where the sulphur deposits are far down on the slopes of the mountains, the refining plants, or *oficinas,* are located close by, but in other cases the *caliche* is transported on the backs of llamas or by means of aerial trams to the *oficinas.*

At the *oficina* two methods are employed to separate the sulphur from the rock. The oldest method, now seldom employed, is by *calderas;* the modern method is in retorts.

The *calderas* are large iron vessels holding about 25 tons of *caliche*. A strong fire beneath the *caldera* for about 48 hours melts the sulphur which is then run into shallow rectangular stone basins to cool. As the mass cools it separates into three well-defined layers. The top layer, which is decidedly vesicular, contains sulphur with many impurities, such as very fine pieces of the volcanic ash or weathered rock fragments; the middle layer is almost pure sulphur; and the bottom layer is mainly rock fragments with some sulphur. After cooling, the mass is broken, and the sulphur layer is separated from the impure bottom and upper layers, called *borra*. The *borra* is then remelted and cooled and the resulting *borra* again melted. On an average 500 pounds of 60 per cent sulphur caliche should yield about 100 pounds of sulphur on the first melt, 65 pounds on the second, and 35 pounds on the third, or a total recovery of 66⅔ per cent. In this method the loss is great and the cost of fuel is also excessive. In the retort method the sulphur is separated from the rock impurities by sublimation.

The fuel used in the Tacora region is entirely *yareta*, a plant belonging to the genus *Azorella*. It grows on the rocky slopes of the mountains up to 16,000 feet above sea level. In general shape it suggests heads of coral growing upon and conforming to the configuration of the rocks. Some of the masses are as much as 4 feet in diameter and 1½ feet thick. After being detached from the rocks it is piled up to dry for a short time before being used. On account of a large amount of resinous material it burns readily.

The quantity of sulphur available in the Tacora region has not been definitely determined, but it is certainly large and the production can be greatly increased. Salcedo (177) estimates the reserves at 9,000,000 metric tons of 70-per cent caliche. Whether production increases or not will no doubt depend almost entirely upon whether the product is able to compete in foreign markets with the sulphur from the United States and Japan. The outlook is promising. Some of the people interested in the district are looking for North American capital to properly develop the region. Four companies own deposits and refining establishments in the Tacora District.

The Ollagüe District, Province of Antofagasta.—Along the main line of the Antofagasta and Bolivia Railroad as it passes through the Cordilleras near the Bolivian border and also along the Collahuasi branch are a number of sulphur deposits that have been worked from time to time. So far as known no establishments for the refining of the sulphur have ever been built in this region. The production, which is small in comparison with the Tacora district, consists entirely of the richest portions of the *caliche*, which are sorted out by hand and shipped without refining.

FIG. 36.—Llamas in the Tacora sulphur district loaded with yareta, the common fuel of the region.

The bulk of the sulphur of this district comes from Mt. Ollagüe and Mt. Olca, both of which form part of the boundary line between Bolivia and Chile. Numerous other volcanic mountains in the vicinity contain sulphur, among which are Mt. Uruputunga, Mt. Anca Quelicha, and Mt. Jardin, while further to the south is Mt. San Pedro. The writers visited the workings of Mt. Ollagüe and Mt. Olca but were unable to obtain much information concerning the deposits on the other mountains.

Mt. Ollagüe is a beautiful symmetrical mountain about 19,000 feet high, approximately 10 miles south of Ollagüe Station. It contains probably the largest and most active fumarole of any of the Chilean volcanoes. The column of steam and sulphurous gases from this fumarole, located some distance below the summit of the mountain, can be seen at a distance of thirty miles on a clear day.

Large areas of sulphur deposits are visible on the upper part of the mountain, and undoubtedly others exist beneath a covering of talus. The most extensive sulphur area lies on the southwest slope of the mountain not far below the giant fumarole. The dimensions of this deposit are said by the owner to be 3,000 m. long and 2,800 m. wide, with an average thickness of 2 m. Some work is being done in this district by a company that digs small holes in the richest portions. Only those pieces of *caliche* containing upwards of 90 per cent sulphur are taken, while the remainder is thrown aside as waste. The sulphur is put in bags and carried on the backs of llamas to Ollagüe station for shipment to Antofagasta.

The Mt. Ollagüe deposits are of high grade and seem to be sufficiently extensive to warrant the construction of an aerial tram to take the *caliche* down the mountain where a refining plant could be built. *Yareta* or *taquia* (the dung of the llama) could be obtained for fuel.

Mt. Olca, with an altitude of 18,330 feet, lies about 5½ miles northeast of Yuma, a station on the Collahuasi branch of the Antofagasta and Bolivia Railroad. The mountain is composed of various kinds of lava and fragmental volcanic materials, with a well-preserved crater at the summit about 1,200 feet long, 300 feet wide, and 150 feet deep. The only solfataras observed are on one side of the crater.

All of the sulphur deposits are near the summit of the mountain where four companies are working on a small scale. The deposits of two companies lie on the Chilean side of the mountain, and the other two own properties on the Bolivian side. The occurrence of the sulphur is as at Tacora, except that there are much larger masses of practically pure sulphur.

The Compañía Olca Michincha is working in a deposit that is visible as a continuous yellow band from 25 to 50 feet wide extending for a distance of about a mile. It seems to have an average depth of about 25 feet. When visited an adit had been run into the deposit to a distance of about 20 feet where a chamber 18 feet in diameter had been excavated in almost pure sulphur. A narrow passageway led to another similar chamber about 10 feet below. Few sights could be more beautiful than this opening with all sides covered with beautiful sparkling sulphur crystals.

In working the deposit the material is dug out by means of picks and shovels and sorted into three piles. The ground containing less than 70 per cent sulphur is thrown aside as waste; the 70 to 90 per cent grade is put into a pile for possible later use; and the 90 + per cent material is put in bags and carried down to the railroad. Naturally only the richest portions of the deposit have been worked as yet; these seem to contain material averaging nearly 80 per cent sulphur.

COAL

In general the South American countries are deficient in their coal resources and those in which there are ample supplies are almost equally dependent upon foreign countries because of the inaccessible location of most of the deposits. In Chile the situation is different from that which prevails in the other South American countries in that the deposits are in the low-lying lands bordering the ocean and hence easily obtained. Nevertheless, the coal industry has never attained much prominence, and the coal mines of Chile do not supply half of the coal consumed in the country.

PRODUCTION AND IMPORTATION OF COAL IN CHILE

	Production in metric tons	Importation in metric tons
1909	898,971	1,342,649
1910	1,074,174	1,493,073
1911	1,188,063	1,407,299
1912	1,334,407	1,577,221
1913	1,283,450	1,587,084
1914	1,086,946	1,304,470
1915	1,171,564	461,468

Coal is said to have been discovered by Mendoza on Quiriquina Island in Concepción Bay in 1557. The first coal mined was in 1821 near Concepción, but not until about 1840 was there any mining of consequence. Since then coal mining has been carried on continuously.

Distribution of the Coal Deposits.—The coal deposits of Chile are found in separate basins in the provinces of Concepción, Arauco, Bio-Bio, Malleco, Cautin, Valdivia, and Atacama, and in the Territorio de Magallanes. With the exception of small amounts mined for local purposes, coal mining is confined to the provinces of Concepción, Arauco, and Valdivia, and to a small area near Punta Arenas in the Territorio de Magallanes.

FIG. 37.—Province of Concepcion, Arauco, Malleco, and Bio-Bio, showing location of the principal coal deposits of Chile.

Geology of the Coal Regions of Chile.—The coal measures of the provinces of Concepción and Arauco where the leading mines are located have been studied in greatest detail. The generalized descriptions which follow more particularly apply to these regions. The classification is that proposed by Brüggen (40).

STRATIGRAPHIC COLUMN OF THE PROVINCE OF CONCEPCION AND ARAUCO

Quaternary—Sand and fossiliferous sandy clays.

Tertiary { Pliocene—Fossiliferous sandy clays.
Oligocene-Miocene { Upper—Non-coal-bearing marine fossiliferous strata.
Middle—Coal measures.
Lower—Non-coal-bearing fresh water and fossiliferous marine sediments.

Unconformity.

Upper Cretaceous—Arenaceous and calcareous fossiliferous shales, sandstones, and conglomerates.

Unconformity.

Jurassic(?)—Black schists, arkosic quartzites, anthracite coal.

Pre-Cretaceous crystallines—Mica schists, phyllite, graywacke, granite, diorite, etc.

Pre-Cretaceous Crystallines.—The metamorphic crystalline rocks form the basal complex of the coal-bearing regions of Chile and are exposed in many places. These rocks also intervene between the different coal basins. They are of indeterminate age.

Jurassic(?).—In the valley of the Bio-Bio River, between Concepción and San Rosenda, Russell (176) describes a series of black schists and arkosic quartzites to which he gives the name of the Quilacoya formation. In the black schists are thin beds of anthracitic coal which have been worked to a slight extent but are of little economic importance. Russell states that the schist is of marine origin as "fossil remains have been found in it, and these have been recognized as similar to the Paleozoic type." Brügger (176) obtained both fossil plants and animal remains from these beds north of Talcamavida and considers them of probable Jurassic age similar to forms described from Siberia.

Upper Cretaceous.—Cretaceous sediments have been found on Quiriquina Island, about the Bay of San Vicente, near Tomé, Lirquen, and Colico. They consist of basal conglomerates resting unconformably on the crystalline rocks and overlain by arenaceous and calcareous shales and sandstones containing many fossils of Upper Cretaceous age. A thickness of about 40 feet is exposed on Quiriquina Island.

Tertiary.—Earlier writers have stated that there was a transition between the Cretaceous and Tertiary in the coal regions of Chile, but the work of Brüggen disproves this belief. Instead he shows that a great unconformity exists and that no species of fossils are common to the sediments of the two periods.

The Tertiary strata of the region aggregating from 1,300 to 1,600 feet in thickness, are divisible into three parts, a lower non-coal-bearing member, a middle coal measures member, and an upper marine non-coal-bearing member. The exact age of the various parts is still in question, but they seem to represent Oligocene-Miocene strata. They may prove to be entirely Miocene. Russell included these strata in his Arauco formation, which he considered of Lower Miocene age.

The lower member contains a basal conglomerate resting unconformably upon Cretaceous sediments or upon the pre-Cretaceous crystallines. The sandstones and shales which comprise this member are mainly of fresh water origin and vary in thickness up to 300 feet. Near Lebu the member contains some fossiliferous marine strata.

The middle or coal measures member of the Tertiary is the most important one as it contains all the known coal beds of any consequence. It is also the thickest member, including the greater portion of the Tertiary strata. It consists almost altogether of arenaceous shales and sandstones, but in it are numerous coal beds and in a few places some beds containing marine fossils. Within short distances marked differences in the character of the strata may be found and correlations of the beds represented in the various districts are difficult to make. It seems that the deposits of coal were accumulated in detached basins of small size, as the number of coal beds and also their position in the stratigraphic column present striking dissimilarities even in the same region.

The upper member of the Tertiary is composed mainly of marine sediments in which are many fossiliferous beds and some glauconitic sands. The fossils obtained from a number of places indicate late Miocene age.

A typical section from Brüggen's report (39) is given to indicate the lithologic characteristics of the Tertiary strata.

Columnar Section at Colico

	Thickness in meters
Quaternary:	
Superficial earth	2.00
Clay	2.00
Sand with fossils	2.00
Coarse-grained sand	1.50

Tertiary:

Bluish sandstones with plant and shell fossils	47.50
Sandstones of various classes	60.00
Various sandstones with plant and shell fossils	39.00
Sandstones and conglomerates	30.80
Bluish clay	0.30
Coal (Mora Bed)	0.80
Various colored sandstones	20.00
Coal (Fortuna Bed)	0.50
Fireclay	1.50
Bluish shales and white sandstones	7.50
Coal	0.10
Fireclay	0.75
Bluish shale	3.50
Coal (Mezcla Bed)	1.25
Fireclay	0.75
Black shale and coal	0.20
Bluish shale	7.50
Coal	0.05
Conglomerate	0.50
Hard fine-grained sandstones	53.80
Bluish-gray sandstones with thin irregular beds of coal and fossil shells	25.50
Shale and sandstone	5.55
Fireclay	1.26
Coal (Chico Bed)	0.40
Sandstones	8.50
Coal (Alto Bed)	0.75
Shale and sandstone	17.75
Coal (Arbol Bed)	0.10
White sandstone	4.50(?)
Various kinds of sandstones, no coal beds	110.00

Pliocene.—In the northern part of the province of Arauco between the city of Arauco and the Tubul River are some sandstones containing fossils of Pliocene Age.

In the Longitudinal Valley to the east of Nahuelbuta Cordillera, coal-bearing strata have been found in many places between Nacimiento and Temuco. Russell includes these strata in his Malleco group, which he describes as composed principally of sandstones and fireclays. He refers the group to the Upper Miocene, whereas Brüggen considers the beds as Pliocene. Although coal beds have been prospected in many places, in this region no deposits of importance have been found.

Quaternary.—The coal region of Chile has only recently been elevated from beneath the sea as indicated by numerous beds of fossiliferous marine sands found in many places. In the vicinity of Colico, Quaternary deposits 100 feet in thickness are found at an elevation of 500 feet above sea level. The fauna contained in these beds seems to be identical with that now inhabiting the coastal waters of the Province of Arauco.

Structures of the Chile Coal Fields.—The various coal fields of Chile present striking similarities in the structures encountered. In general the beds dip to the west at angles of 15° to 18°, although in a few cases the dip is southerly or even southeasterly. Folds are practically absent, but faults are numerous in every region. Most of the faults are normal with an approximate north-south

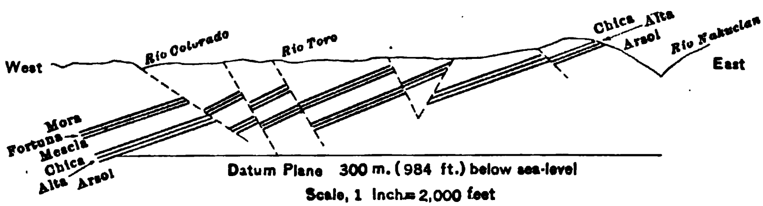

FIG. 38.—Longitudinal section of Colico colliery. (*After Russell.*)

trend and an easterly dip of the fault plane. The displacement is seldom more than 20 feet although several faults have been located with throws of 200 to 400 feet. In some instances the faulting has materially aided in the working of the coal as the repeated uplift of the westerly dipping beds has obviated the necessity of deep mining. In many places the faults can be easily located on the surface by gullies developed along the fault planes. A typical section showing the structure of the beds is shown in the sketch by Russell (Fig. 38).

Quality of the Coal.—In general the coal is soft and inferior to the imported coals with which it must compete. The following analyses are taken from a report by Javier Gandarillas M. (89*b*).

	1	2	3	4	5	6	7	8	9
Moisture.........	13.76	14 00	3.89	2.29	3.31	4.25	3.15	2.81	17.75
Volatile materials..	34.52	42.00	36.22	41.27	38.50	38.13	42.26	34.04	42.15
Fixed carbon......	48.27	39.35	56.68	47.68	53.14	52.54	44.48	57.38	30.60
Sulphur...........	.411	.50							
Ash..............	3.45	4.75	3.21	8.76	5.19	5.07	9.97	5.75	9.50
Calories (Berthier)	6307	6000	7397	7390	7225	7404	6902	7324	5160

1. Region of Lirquen.
2. Region of Millahuillin, near Valdivia.
3. Region of Lota and Coronel.
4. Region of Colico.
5. Region of Curanilahue.
6. Region of Pilpilco.
7. Region of Los Alamos and Cullinco.
8. Region of Lebu.
9. Mina Loreta de Magallanes near Punta Arenas.

Chilean coal has long been used by the steamship companies of the West Coast of South America, by the Government railroads, for domestic uses, and to a limited extent for the manufacture of gas. For all these uses it is fairly satisfactory. Unfortunately it is not suitable for the production of metallurgical coke which is the chief obstacle in the development of the iron industry of the country. The coke, while satisfactory for domestic purposes, is too friable for blast furnace use. A mixture, in about equal proportions, of foreign coking coal and the better grades of Chilean coal yields a coke of fair quality.

Probable Coal Reserve.—J. del Fuenzalida (85*a*) estimates the coal reserves of Concepción and Arauco provinces as follows:

	Area in sq. kils.	Reserves in tons.
Penco District, Province of Concepción..........	150	150,000,000
Lota and Coronel District, Province of Concepción	30	60,000,000
Province of Arauco...........................	1,600	1,872,000,000
		2,082,000,000

Mining Operations.—Most of the coal deposits of importance thus far developed lie very close to the shore, and as the beds dip to the westward, the operations are carried on mainly under the sea by means of inclines following the beds. Some of the workings extend for a distance of about 1½ miles along the dip which, as mentioned above, is seldom more than 15°. There have been several mines in which the ocean waters have broken in and flooded the workings, but in most cases the mines are comparatively free from water even though faults are present.

In the upper portions of both shafts and inclines the water in the loose sediments has necessitated the construction of brick walls, but in the lower portions the usual methods of timbering are employed.

Considerable attention must be given to ventilation as the mines are gaseous and disastrous explosions have occurred. Bands of fireclay containing much pyrite have been found within some of the coal beds and also beneath them. In some mines it is necessary to remove this material in order to prevent mine fires resulting from spontaneous combustion.

The descriptions of the coal-mining districts which follow are taken mainly from published reports by Brüggen and Russell.

Province of Concepción.—The Bio-Bio River divides the coal fields of the Province of Concepción into two districts. Those lying to the north constitute the Penco district and those to the south comprise the Coronel and Lota district.

The most northerly coal deposits worked are on the shores of Coliumo Bay, near the village of Dichato, about 18½ miles north of Concepción. Beds 18 and 24 inches thick occur there, but several attempts to mine at this place have been failures. The region is greatly faulted. About 1¼ miles north of Tomé, a bed of coal from 20 to 30 inches thick has been worked to a small extent. In the immediate vicinity are the Lirquen, Cerro Verde, and Rosal mines. In the Lirquen mine, which has been worked to only a slight extent, three beds of 20 inches, 40 inches, and 24 inches in thickness were cut. In the Cerro Verde mine a single bed 42 inches in thickness has been worked although two others, somewhat thinner, have been cut. In the Rosal mine several similar beds have been worked. Here a great fault with a displacement of about 210 feet has brought the thicker, deeper-lying beds closer to the surface, thereby making their mining less expensive. Several small mines have been worked in the region of Talcahuano, but are now closed.

The Coronel and Lota district produces the bulk of the coal production of the country. The Compañía de Lota i Coronel and the Compañía Carbonifera i de Fundicion Schwager control the larger part of the district, and each produces about 300,000 tons of coal annually. Practically all the workings are under the sea, extending to a distance of 1½ miles. A few mines have been lost, due to flooding by the ocean waters. In the mines of the latter company 9 coal seams are present, but only two, having thicknesses of 45 and 55 inches, are being worked. The long-wall system of mining is employed. There are numerous faults, one of which has a throw of 328 feet. The coal of the Coronel and Lota district is used mainly by the coast vessels and the railroads, but some is used in the manufacture of coke for the copper smelters located near by.

Province of Arauco.—The chief mining operations of the Province of Arauco are confined to the Colico district, in the departments of Arauco and Lebu, between Laraquete and Cullinco, and the Lebu district, in the Department of Lebu. Coal outcrops have been found in other parts of the province, especially along the coast between the cities of Lebu and Arauco.

The mines of the Colico district are all inland and consequently less accessible to shipping ports although a line of railroad traverses the district. Mines have been opened in many places but chiefly in the vicinity of Peumo, Colico, Curanilahue, Pilpilco, and Cullinco.

The mines of the Compañía Carbonifera de los Rios de Curanilahue are near Curanilahue. There are 9 beds of coal known to exist in the property ranging in thickness from 14 inches to more than 6 feet. The thickest veins are less persistent than some others from 3 to 4 feet in thickness. The company has an annual production of about 250,000 tons and owns property supposed to contain about 33,000,000 tons.

A number of mines have been worked in the vicinity of Lebu, both to the north and to the south of the Lebu River. The workable beds, 7 in number, average about 3 feet in thickness with a maximum of 6½ feet. In the Errazuriz mines shafts have been sunk to a depth of more than 1,000 feet.

Provinces of Bio-Bio, Malleco, and Cautín.—In the Longitudinal Valley thin beds of coal have been discovered and worked to a small extent for local consumption in the provinces of Bio-Bio, Malleco, and Cautín, between Nacimiento and Temuco, but the meager information regarding them does not seem to indicate the presence of any valuable coal deposits.

Province of Valdivia.—Coal-bearing strata near Valdivia have been worked to a small extent in the Millahuillin mines, which have an annual production of about 1,600 tons.

Territory of Magallanes.—Coal has been found in several places near the Straits of Magellan; but the only place where it has been mined in quantity is 5½ miles from Punta Arenas, where the Loreta Mine has had an annual production of about 10,000 tons for several years. The coal is believed by

Hatcher (99) to be of Middle or Upper Oligocene age. It is a lignite and is of little use except when made into briquettes by mixing with Welsh coal and pitch. The beds, of which there are several, range in thickness up to 16 feet. The greater portion of the coal thus far mined in this section has been used by the gold dredges.

Province of Atacama.—At Ternera, in the Province of Atacama, about 62 miles east of Caldera, a little coal of very poor quality has been mined at intervals since 1851. It contains about 50 per cent ash but, mixed with other coal, has been used in small amounts by blacksmiths.

PETROLEUM AND NATURAL GAS

Although reports of the discovery of petroleum and natural gas in various parts of the country have been circulated from time to time, Government inspectors have usually found no evidence whatever of the existence of either of these products except in the vicinity of the Straits of Magellan. Volcanic rocks have been mistaken for asphalt and swamp gases for natural gas.

In general, geologic conditions seem unfavorable for the occurrence of either petroleum or natural gas in all regions except the extreme southern part of the country, mainly because of the shallow depth at which the basement crystalline rocks are encountered in almost all sections.

Indications of petroleum and natural gas have been reported south of Patillos in Tarapacá Province, near Copacoya in the Province of Antofagasta, close to the Bolivian border in Lat. 22° 10 'S., and south of the Maullin River near Puerto Montt, Province of Llanquihue.

In the region of the Straits of Magellan emanations of natural gas and rocks filled with petroleum have been encountered in Miocene and Upper Cretaceous strata in many places on the Brunswick Peninsula, especially near Punta Arenas, on Riesco Island, on Dawson Island, on Cambridge Island, and in two places on the northern part of Tierra del Fuego. These are all associated with pronounced anticlinal structures.

Several borings have been made, but as yet the amount of oil and gas obtainable has not been determined. The favorable indications seem to justify further investigation.

GRAPHITE

Valuable deposits of graphite are reported from the Gambos River, near Castro, on the Island of Chiloe; it is also known from Chehueque, northeast of Vallenar, Province of Atacama.

FELDSPAR

Promising deposits of feldspar are said to occur in large quantities in several places near Concepción on the Island of Chiloe, but as yet have received little attention.

APATITE

To the southeast of Freirina, Province of Atacama, are several apatite-bearing veins which have been described by Brüggen (43). The region is one of basic igneous rocks—diabase, gabbro, diorite, peridotite, etc.—belonging to different generations. The most important vein is the Veta Caracoles which runs N. 85° E., and dips 80° to the south. The vein has been traced for a distance of about 200 feet. A shallow excavation showed a thickness of about 5 feet of almost pure greenish-colored apatite. Associated with the apatite vein are sericite, magnetite, asbestos, quartz, and mica. Other veins, although less pure are also regarded as valuable because of the large amount of apatite present.

GUANO

The guano deposits of Chile cannot be adequately described for lack of space. Suffice it to say that in the Provinces of Antofagasta and Tarapacá there still remain important deposits of this useful fertilizing material. Some of the principal localities are near Mejillones, Guanillos, Pabellon de Pica, and Punta Pichalo. The government forbids the export of guano. Several literature references are given in the bibliography.

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117. Labastié, F.: Caracoles. *Boletín* de la Sociedad Nacional de Minería, Vol. 15, pp. 113–125, Santiago, 1903.

Review of district and the mines now active, geologic notes, and description of the Recuerdo mine.

118. Lamb, Mark R.: History and Review of the Niter Industry of Chile. *Eng. and Min. Jour.*, Vol. 90, pp. 18–22, Ill., 1910.

History of the industry, distribution, and occurrence of the nitrates; methods of mining and refining are treated.

119. Lamb, Mark R.: Gold Discovery at Putu, Chile. *Eng. and Min. Jour.*, Vol. 92, pp. 1078–1079, Ill., 1911.

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120. Lamb, Mark R.: The Chilean Nitrate Industry. *Eng. and Min. Jour.*, Vol. 99, pp. 811–815, Ill., 1915.

The deposits and the methods employed in refining the nitrates are described. Many views of different phases of the industry are shown.

121. Lamb, Mark R.: Gold and Silver in Chile. *Eng. and Min. Jour.*, Vol. 99, pp. 847–849, Ill., 1915.

Brief description of the various operating gold and silver mines.

122. Latrille, Francisco: Memoria Descriptiva de Ciertos Yacimientos Minerales del Desierto, Particularmente del Radio de Calama. *Boletín* de la Sociedad Nacional de Minería, 2d Ser., Vol. 1, 1888–1889, pp. 50–70, 86–105, Santiago.

Describes a great number of mining districts in northern Chile and also nitrate, borate and sulphur deposits.

123. Latrille, Francisco: Informe de los Minerales de Yabricoya i Jauja. *Boletín* de la Sociedad Nacional de Minería, 2d Ser., Vol. 8, pp. 55–58, 70–74, 81–83, 97–101, Santiago, 1896.

Yabricoya situated 31–34 leagues inland from Iquique. Divided into three sections of Jauja, Pila, and Yabricoya. Describes mines in each of these subdivisions.

124. Lebour, G. A. and Mundle, William: On the Coal-Bearing Rocks of Southern Chile. *Geol. Mag.*, Decade I, Vol. 7, pp. 499–509, Ill., 1870.

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125. Leith, C. K.: Iron Ores of the Americas. *Proc.* Second Pan American Scientific Congress, Vol. 8, pp. 954–959, Washington, 1917.

A summarized account of the kinds of ores and the ore reserves of North and South America.

126. Lemâitre, Eduardo: Sistema Carbonífera Chileno. Provincias de Concepcion y de Arauco. *Boletín* de la Inspección de Geografía y Minas, Ministerio de Industria y Obras Públicas, 1914, pp. 437–461; 1915, pp. 35–63. Santiago.

Gives topographic and geologic description of the region.

127. Lemétayer, Paul i Vasquez S., David: Informe sobre los Estudios practicados en las Guaneras de Punta Pichalo, Punta Gruesa, Chipana, Punta de Lobos, i Pabellon de Pica. Por orden del Señor Ministro de Hacienda, 68 pp., Santiago, 1902.

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128. Loram, Sidney H.: The Mines and Mills of the Atacama Mineral Co., Ltd., Taltal, Chile. *Trans.* Amer. Inst. Min. Eng., Vol. 29, pp. 488–502, Ill., 1899.

The mines described are the Guanaco located 80 miles northeast of Taltal, the Sierra Overa 63 miles southwest of Taltal, and the Parañao, 42 miles north of Taltal.

129. Loram, Sidney H.: Notes on the Gold District of Canutillo, Chile, S. A. *Trans.* Amer. Inst. Min. Eng., Vol. 35, pp. 696–711, Ill., 1904.

A history of mining in the region, which lies 15 miles south of the city of Freirina, is given and also a description of the geology, ore bodies, and methods of mining and milling.

130. Loram, Sidney H.: A Geological Cross-Section of the Western Cordillera along the Rio Huasco. *Trans.* Amer. Inst. Min. Eng., Vol. 35, pp. 879–886, Ill., 1904.

The section extends from the Argentine border to the Pacific and is of interest because of the evidence it offers regarding the formation of mineral deposits in that section.

131. Loram, Sidney H.: Placers of Tierra del Fuego. *Min. and Sci. Press*, Vol. 99, pp. 125–128, 1909.

Description of the geology, the placer deposits, and their working.

132. Loram, Sidney H.: Nitrate of Soda Industry of Chile. *Min. and Sci. Press*, Vol. 100, pp. 125–129, 180–184, Ill., 1910.

Detailed descriptions of the occurrence and character of the nitrates, their exploitation, the refining of the caliche, and a review of the various theories of origin.

133. MacCoy, Fred: "Caliche" Deposits of Atacama Desert, Chile. *Eng. and Min. Jour.*, Vol. 103, pp. 1059–1060, Ill., 1917.

A short account of the nitrate minerals and their occurrence.

134. Machado, Miguel R.: Distribución jeolójica i jeográfica del carbon en Chile. *Boletín* de la Sociedad Nacional de Minería, 3d Ser., Vol. 19, pp. 330–337, Santiago, 1907. Abst., *Trans.* Inst. Min. Eng., Vol 36, pp. 760–762, 1909.

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135. Machado, Miguel R.: Estudios de los Terranos Petrolíferos de Magallanes. *Boletín* del Museo Nacional de Chile, Vol. 3, No. 1, pp. 3–14, Santiago, 1911.

Brief sketch of the occurrence of oil and gas.

136. Machado, Miguel R.: El Carbon de Chile i su Distribucion Jeográfica. *Boletín* del Museo Nacional de Chile, Vol. 4, No. 1, pp. 114–130, Santiago, 1912.

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137. Michado, Miguel R.: Le Charbon du Chili et sa Distribution Géographique. Coal Resources of the World, Vol. 2, pp. 581–594, Toronto, 1913.

A summary of the country's coal deposits with an estimate of the reserves.

138. Mallard and Fuchs, Edmond: Notes sur quelques points de la Géologie du Chili. *Annales* des Mines, 7th Ser., Vol. 3, pp. 67–102, Paris, 1875.

139. Mieres, Meliton: Estudio sobre los Criaderos Minerales de la Placeta Seca (Cordillera de Rancagua), i sobre su explotacion. *Anales* de la Universidad de Chile, Vol. 35, pp. 197–275, Santiago, 1870.

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140. Miller, Benjamin L. and Singewald, Joseph T., Jr.: Exploitation of Chilean Mines. *Eng. and Min. Jour.*, Vol. 102, pp. 289–293, Ill., 1916.

A review of the mineral resources and mining industry of Chile.

141. Miller, Benjamin LeRoy and Singewald, Joseph T., Jr.: Some Andean Sulphur Deposits. *Bull.* Pan Amer. Union, Vol. 46, pp. 24–38, Ill., 1918.

Descriptions of the Tacora and Ollagüe sulphur regions.

142. Moesta, F. A.: Über das Vorkommen der Chlor-, Brom-, and Jodverbindungen des Silbers in der Natur. Ein Beitrag zur Kenntnis der geologischen und bergbaulichen Verhaltnisse von Nordchile. 47 pp., Marburg, 1870.

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143. Möricke, W.: Einige Beobachtungen über chilenische Erzlagerstätten

und ihre Beziehungen zu Eruptivgesteinen. Tschermak's Mineralogische und Petrographische Mittheilungen, Vol. 12, pp. 186–198, Vienna, 1891.

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144. Müntz, A.: Recherches sur la formation des gisements du nitrate de soude. Comptes Rendus de l'Academie des Sciences, Vol. 101, pp. 1265–1267, Paris, 1885.

145. Müntz, A.: Orijin de los Depositos del Nitrato de Soda. *Boletín* de la Sociedad Nacional de Minería, Año 4, pp. 719–720, 727–728, Santiago, 1887.

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146. Müntz, A. and Marcano, V.: Sur la Formation des terres nitrees dans las regions tropicales. Comptes Rendus de l'Academie des Sciences, Vol. 101, pp. 65–68, Paris, 1885.

147. Murdock, J. A. W.: A Curious Copper Deposit in Chile. *Eng. and Min. Jour.*, Vol. 71, pp. 587–588, Ill., 1901.

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148. Muro, José: Mineral de Collahuasi. *Boletín* de la Sociedad Nacional de Minería, 3d Ser., Vol. 18, pp. 129–137, 169–176, 201–208, Santiago, 1906.

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149. Newton, William: The Origin of Nitrate in Chili. *Geol. Mag.*, Decade IV, Vol. 3, pp. 339–342, London, 1896.

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150. Newton, William: The Nitrate of Soda Industry in Chile. *Jour.* Soc. Chem. Ind., pp. 408–416, London, 1900.

151. Noellner, C. N.: Ueber die Entstehung der Salpeter- und Boraxlager in Peru. *Jour.* für praktische Chemie, Vol. 102, pp. 459–464, Leipzig, 1867.

152. Nordenskjold, Otto. Ueber einige Erzlagerstätten der Atacamawüste. *Bull.* Geol. Inst. of Univ. Upsala, Vol. 3, pp. 343–351; Vol. 4, pp. 28–44, Ill., 1897–98. Abst. *Trans.* Inst. Min. Eng., Vol. 16, pp. 542–543, Vol. 18, pp. 512–514, London.

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153. Ochsenius, Carl: Einige Angaben über die Natronsalpeterlager landeinwärts von Taltal in der chilenischen Provinz Atacama. *Zeitschrift* der deut. geol. Gesell., Vol. 40, pp. 153–165, Berlin, 1888.

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154. Ochsenius, C.: Salpeterablagerungen in Chile. *Zeit.* der deut. geol. Gesell., Vol. 55, Briefliche Mitteilungen, pp. 35–40, Berlin, 1903.

155. Oehmichen, Hans: Eine Exkursion zur Kupfersulfat-Lagerstätte von Copaquiri im nördlichen Chile. *Zeitschrift* für praktische Geologie, pp. 147–151, Berlin, 1902.

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156. Olmeda, D. Palacios: Yacimientos de Fierro de la Serena. *Boletín* de la Inspección de Geografía y Minas, Dirección General de Obras Públicas, Año 9, pp. 258–279, Santiago, 1913.

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157. Ortuzar, Adolfo: Le Chile de nos Jours. Son Commerce, sa Production et sus Resources. Annuaire National (2° année 1905–1906). Publication subventionnée par le Gouvernment du Chile, Paris, 1906. Chile of To-day, 1907–1908 (English translation), New York, 1908.

Pages 397–535 describe the mineral deposits of Chile, metallic and non-metallic. Takes up in turn each of the products, giving a general résumé for the country, then by provinces.

158. Ossa, Belisario Diaz: La Industria del yodo en Chile. *Boletín* de la Sociedad Nacional de Minería, 3d Ser., Vol. 26, pp. 270–281, Santiago, 1914.

Statistics of production since 1879. Various methods of extraction that have been tried. Detailed account of methods actually used and costs of same.

159. Ossa, Belisario Díaz: The Nitrate of Soda Industry in Chile. Teniente Topics, Vol. 2, No. 4, pp. 1–11, Ill., 1917. (Translated from Agenda del Salitre, 1916.)

A good description with many details of methods employed in working the deposits and refining the nitrate.

160. Ossa, Ignacio Díaz: La Industria del Cobre, 1810–1910. *Boletín* de la Inspección de Jeografía i Minas, Ministerio de Industria i Obras Públicas, pp. 348–358, Santiago, 1910.

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161. Ossa, Ignacio Díaz: Monografia sobre el estado actual de la Minería en la provincia de Coquimbo i descripcion de sus yacimientos minerales más importantes. *Boletín* de la Sociedad Nacional de Minería, 3d Ser., Vol. 27, pp. 5–20, Santiago, 1915.

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162. Palache, Charles and Warren, C. H.: Kröhnkite, Natrochalcite (a new mineral), and other sulphates from Chile. *Amer. Jour. Sci.*, Vol. 26, pp. 342–348, Ill., 1908.

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163. Penrose, R. A. F., Jr.: The Gold Regions of the Strait of Magellan and Tierra del Fuego. *Jour. Geol.*, Vol. 16, pp. 683–697, Ill., Chicago, 1908. Abst. *Min. and Sci. Press*, Vol. 98, pp. 153–154, 1909.

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164. Penrose, R. A. F., Jr.: The Nitrate Deposits of Chile. *Jour. Geol.*, Vol. 18, pp. 1–32, Ill., 1910.

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165. Pepper, Charles M.: Chile as a Factor in Panama Canal Trade. *Iron Age*, Vol. 93, pp. 56–60, Ill., 1914.

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166. Pissis, A.: Descripcion Topográfica i Jeolójica de la Provincia de Aconcagua. *Anales* de la Universidad de Chile, Vol. 15, pp. 46–89, Santiago, 1858.

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167. Pissis, A.: Sur la Constitution Géologique de la Chaîne des Andes entre le 16° et le 53° degré de latitude sud. *Annales des Mines*, 7th Ser., Vol. 3, pp. 402–426, Paris, 1875.

Includes a geological map of Chile and a geologic section from Arica to La Paz and another from Talcahuano to the summit of the Andes.

168. Pissis, Amado: El Desierto de Atacama; su Jeolojía, sus Productos i Minerales. *Anales* de la Universidad de Chile, Vol. 51, pp. 573–597, Santiago, 1897.

Generalized account of geology and mineral resources, metallic and non-metallic.

169. Plagemann, A.: Sobre la formacion jeolojica del salitre bajo el punto de vista de la fermentacion quimica. *Boletín* de la Sociedad Nacional de Minería, 3d Ser., Vol. 9, 1897, pp. 88–93, 153–6, 245–8, 323–6, 409–12, 583–9; and Vol. 10, 1898, pp. 12–15, Santiago.

169*a*. Plagemann, A.: Der Chilesalpeter, 75 pp., Ill., Map, Berlin, 1905(?).

An excellent account of the entire nitrate industry.

170. Pöhlmann, R. and Schulze, Hans: Bemerkungen über die Golderze von Guanaco. *Verhandlungen* des deutschen wissenschaftlichen Vereines zu Santiago, Chile, Vol. 2, pp. 177–185, Santiago, 1893. *Boletín* de la Sociedad Nacional de Minería, 2d Ser., Vol. 8, pp. 202–205, Santiago, 1896.

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171. Pöhlmann, R.: Die Goldseifen bei Punta Arenas und im Nördlichen Feuerland. *Verhandlungen* des deutschen wissenschaftlichen Vereins zu Santiago de Chile, Vol. 4, 1898–1902, pp. 307–318, Santiago.

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172. Pope, E. David: Gold Mining in Chile. *Min. Mag.*, Vol. 13, pp. 33–36, Ill., London, 1915. Generalizations concerning the gold deposits of Chile with brief descriptions of the working mines accompanied by map showing their location.

173. Richard, Armando Rojas: La Rejion Salitrera de Chile Bajo Los

Puntos de Vista Jeográfico e Histórico. *Boletín* de la Inspección de Jeografía i Minas, Ministerio de Industria i Obras Públicas, 1909, pp. 27–61, 130–189. Santiago.

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173*a*. RODRIGUEZ, RAMÓN MONTERO: El Mineral del Tofo y las Instalaciones para su Explotación. *Anales* del Instituto de Ingenieros de Chile, Año 17, pp. 481–497, Ill., Santiago, 1917.

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174. ROGERS, ALLEN H. AND VAN WAGENEN, HUGH R.: The Chilean Nitrate Industry. *Bull.* 134, Amer. Inst. Min. Eng., pp. 505–522, Ill., 1918.

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175. ROSE, C. A.: Metallurgical Operations at the Chile Exploration Co. *Proc.* Second Pan American Scientific Congress, Vol. 8, pp. 818–826, Ill., Washington, 1917.

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176. RUSSELL, A.: The Coal Fields and Collieries of the Republic of Chile. *Trans.* Inst. Min. Eng., Vol. 38, pp. 29–82, London, 1909.

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177. SALCEDO, JORGE VÁRGAS: Estudio de las Azufreras del Tacora. *Boletín* de la Sociedad Nacional de Minería, 3d Ser., Vol. 14, pp. 275–282, Santiago, 1902.

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178. SALCEDO, SEVERO: Potash Deposits in Chile. *Eng. and Min. Jour.*, Vol. 100, p. 218, 1915.

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179. SÁNCHEZ, PEDRO O.: Caracoles. Su Descubrimiento. *Boletín* de la Inspección de Geografía y Minas, Dirección General de Obras Públicas, Año 9, pp. 137–143, Santiago, 1913.

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180. SAN ROMAN, FRANCISCO J.: Reseña Industrial e Histórica de la Minería i Metalurjia de Chile. Escrita por Encargo de la Comision Directiva de la Exposicion de Mineria i Metalurjia, 510 pp., Imprenta Nacional, Santiago de Chile, 1894.

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181. SAN ROMAN, FRANCISCO J.: Estudios Jeolójicos i Mineralójicos del Desierto i Cordillera de Atacama. Publicados bajo la vigilencia de la Sociedad Nacional de Minería, Vol. 2, 405 pp., Santiago, 1911.

Observations of Francisco J. San Roman, chief of the Comision Esploradora del Desierto, edited by Lorenzo Sundt. Contains many descriptions of mines and mineral deposits.

182. Schneider, Julio: Descubrimiento de la Hulla en Chile.—Mineral carbonífero de "Huimpil."—Lautaro,—Province de Cautin—Chile. *Boletín* de la Sociedad Nacional de Minería, 3d Ser., Vol. 17, 1905, pp. 165–175, Santiago.

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183. Schneider, Julio: Los Yacimientos carboniferos de Cobquecura, Department of Itata. *Boletín* de la Sociedad Nacional de Minería, Ser. 3, Vol. 19, pp. 409–412, 1907. Abst. *Trans.* Inst. Min. Eng., Vol. 36, p. 760, London, 1909.

184. Semper and Michels: Die Salpeterindustrie Chiles. *Zeitschrift* für das Berg-, Hütten- und Salinenwesen im preussischen Staate, Vol. 52, pp. 359–482, Ill., Berlin, 1904. Abst. *Trans.* Inst. Min. Eng., Vol. 27, pp. 737–739, London, 1905.

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185. Semper y Michels: La Industria del Salitre en Chile. Publicado bajo la Vigilancia de la Sociedad Nacional de Minería, 418 pp., maps, Santiago, 1908.

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186. Singewald, Joseph T., Jr., and Miller, Benjamin LeRoy: The Genesis of the Chilean Nitrate Deposits. *Econ. Geol.*, Vol. 11, pp. 103–114, 1916. Discussion by Lorenzo Sundt and authors, Vol. 12, pp. 89–96, 1917. *Proc.* Second Pan American Scientific Congress, Vol. 8, pp. 873–880, Washington, 1917.

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187. Stelzner, A. W.: Ueber die Turmalinführung der Kupfererzgänge von Chile. *Zeitschrift* für praktische Geologie, Vol. 5, pp. 41–53, Berlin, 1897.

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189. Strauss, Lester W.: The Mineral Industry of Chile. *Min. and Sci. Press*, Vol. 112, pp. 475–478, map, 1916.

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190. Streng, A.: Mineralogische Mittheilungen über die Erze von Chañar-

cillo in Nordchile. *Neues Jahrbuch* für Mineralogie, Geologie und Paleontologie, pp. 897–927, Stuttgart, 1878.

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191. Stutzer, O. Turmalin führende Kobalterzgange. *Zeitschrift* für praktische Geologie, Vol. 14, pp. 294–298, Berlin, 1906.

The Blanca mine near San Juan, Department Freirina, Prov. Atacama, Chile, has a vein in schist characterized by an abundance of tourmaline and cobaltite.

192. Stuven, Enrique: Memoria sobre los Yacimientos y Extraccion del Bórax en Chile. *Boletín* de la Sociedad Nacional de Minería, 2d Ser., Vol. 1, 1888–1889, pp. 146–154, Santiago. *Boletín* de Minas, Industria y Construcciones, Vol. 5, pp. 19–21, 26–29, 39, 46–47, Lima, 1889.

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193. Stuven Enrique: Una Visita al Distrito Minero Talca. *Boletín* de la Sociedad Nacional Minería, 2d Ser., Vol. 8, pp. 143–146, Santiago, 1896.

In department of Ovalle, province of Coquimbo. Auriferous quartz vein in amphibolites close to granite contact, into both of which diorite was later intruded. Description of mine and mill.

194. Sundt, F. A.: Mining and Metallurgy in Chili. *Mines and Minerals*, Vol. 30, pp. 646–647, map, 1910.

A review of the mineral resources and mineral industry of the country.

195. Sundt, F. A.: The Calama Copper District, Chile. *Mines and Minerals*, Vol. 31, pp. 473–475, 605–606, map, 1911.

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196. Sundt, Lorenzo: Estudios Jeolójicas i Topográficos del Desierto i Puna de Atacama. Publicados bajo la Vigilancia de la Sociedad Nacional de Minería, Vol. 1, 212 pp., Santiago, 1909.

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197. Sundt, L. A.: Monografías Mineras i Metalúrgicas. Sociedad Nacional Minería, 217 pp., Santiago, 1910.

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198. Sundt, Lorenzo: El Origen del Salitre Chileno y de Algunas Sales que lo Accompañan. Trabajos del Cuarto Congress Cientifico (1° Pan Americano), III Seccion, Tomo 1, pp. 512–520, Santiago, 1911.

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199. Theil, H. and Muller, H.: Die Goldkupferlagerstätte des Guanaco in Chile. *Zeitschrift* für praktische Geologie, Vol. 21, pp. 300–320, Berlin, 1913.

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200. TOWER, WALTER S.: The Nitrate Fields of Chile. *Pop. Sci. Month.*, Vol. 83, pp. 208–230, Ill., 1913. Abst. *Min. and Sci. Press*, Vol. 107, pp. 495–500, Ill., 1913.

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201. VATTIER, CH., Y OTROS: L'Avenir de la Metallurgie du Fer au Chile, Paris, 1890.

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202. VATTIER, M. CH.: Les Mines de Fer et la Sidérurgie dans l'Amerique du Sud et principalement au Chili. Soc. Ing. Civ. de France, *Bull.* for Aug., 1911, pp. 159–197, Paris. Abst. *Trans.* Inst. Min. Eng., Vol. 42, pp. 625–626, London, 1912. Abst. *Trans.* Inst. Min. Eng., Vol. 43, pp. 570–571, London, 1913.

203. VATTIER, CHARLES: The Iron Ore Resources of Chili with Note on the Corral Iron and Steel Works. *Jour. Iron and Steel Inst.*, Vol. 86, pp. 320–362, Ill., London, 1912. Abst. *Eng. and Min. Jour.*, Vol. 95, pp. 234–236 ,1913.

A complete account of the known iron deposits of Chile.

204 VATTIER, CARLOS: El Fierro en Chile. *Boletín* de la Sociedad Nacional de Minería, 3d Ser., Vol. 25, pp. 107–120, Santiago, 1913. Abst. *Min. and Sci. Press*, Vol. 107, pp. 893–896, map, 1913.

Brief notes on the iron deposits of the provinces of Coquimbo, Atacama, and Antofagasta.

205. VATTIER, CHARLES AND ECHEGARAI, NICOMEDES: Iron Ore Resources of Chile. *Jour. Iron and Steel Inst.*, Vol. 88, pp. 416–434, London, 1913.

Descriptions of the iron ore deposits of Chile supplementing an article by the senior author published the preceding year.

206. VATTIER, CARLOS y ECHEGARAI, NICOMEDES: Neuvos Reconocimientos de Algunos de los Principales Yacimientos de Minerales de Fierro de Chile. *Boletín* de la Inspección de Geografía y Minas, Direccion General de Obras Públicas, Año 9, pp. 159–178, Santiago, 1913.

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207. VALDÉS, SAMUEL: Informe sobre el Estudio Minero i Agricola de la Rejion Comprendida entre el Paralelo 23 i la Laguna de Ascotan, Presentado al Ministro de lo Interior. 196 pp. Imprenta Nacional, Santiago, 1886.

Sketch of the geography, geology, and meteorology of the region, followed by a description of the ore deposits by districts.

208. VICUÑA, MANUEL JOSÉ: El Mineral del Huanaco. *Boletín* de la Sociedad Nacional de Minería, Año 5, pp. 800–801, 805–810, 813–818, Santiago, 1888.

Located 128 km. east northeast of Taltal. Full account of discovery and history of the district. Numerous auriferous quartz veins occur, carrying also barite and iron oxide. Describes a number of the Mines.

209. VILLANUEVA, AUGUSTO: Guanos i Salitres del Desierto de Atacama. *Anales* de la Universidad de Chile, Vol. 53, pp. 403–445, Santiago, 1878.

Brief account of guano deposits along the coast and in the interior, and of the nitrate deposits. Also discusses the water problem and transportation.

210. WALKER: The Nitrate Deposits and Trade of Chili. *Eng. and Min. Jour.*, Vol. 50, pp. 164–165, 1890.

Good description abstracted from a consular report.

211. WALKER, EDWARD: The Copper Sulphate Deposits at Copaquire, Chile. *Eng. and Min. Jour.*, Vol. 75, p. 710, 1903.

A good description of the character of the deposits.

212. WELLS, ROGER C.: Extraction of Potassium Salts from the Pintados Salar. *Eng. and Min. Jour.*, Vol. 105, pp. 678–679, 1918.

A discussion of different methods for separating the potash from the other substances of the salar crust.

213. WILLIAMS, ERNESTO: El Mineral del Guanaco. *Boletín* de la Sociedad Nacional de Minería, Año 5, pp. 856–858, Santiago, 1888.

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214. WOLFF, FERDINAND VON: Beiträge zur Geologie und Petrographie Chile's, unter besonderer Berücksichtigung der beiden nördlichen Provinzen Atacama und Coquimbo. *Zeit.* der deut. geol. Gesel., Vol. 51, pp. 471–555, Berlin, 1899.

Detailed description of geology and petrography of Atacama and Coquimbo provinces.

215. G. Y.: Compañia Minera Aurífera de Alhué. *Boletín* de la Sociedad Nacional de Minería, 3d Ser., Vol. 10, pp. 145–148, 176–182, 189–194, Santiago, 1898.

Situated 55 km. northwest of Rancagua. Auriferous quartz veins. Description of the occurrence, mining operations and metallurgical practice, and economic considerations.

216. YEATMAN, POPE: The Braden Copper Company. *Eng. and Min. Jour.*, Vol. 92, pp. 1128–1132, 1186–1188, Ill., 1911. (Abst. from Annual Report of the Co.)

Describes in detail ore bodies and methods of mining and milling, costs, etc. Gives several maps.

217. YEATMAN, POPE: The Braden Copper Mines. *Min. and Sci. Press*, Vol. 103, pp. 769–772, 1911. (Abst. of a report to the Company.)

Detailed descriptions of ore bodies and methods of working and treating the ore.

218. YEATMAN, POPE: Mine of Chile Exploration Co., Chuquicamata, Chile. *Eng. and Min. Jour.*, Vol. 101, pp. 307–314, Ill., 1916. *Proc.* Second Pan American Scientific Congress, Vol. 8, pp. 992–1004, Ill., Washington, 1917.

Detailed descriptions of geologic conditions, character of ore body, and methods of mining.

219. YEME, G. PRIETO: Chilean Nitrate. *Pan-American Magazine*, Vol. 25, pp. 273–298, Ill., 1917.

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CHAPTER VI

COLOMBIA

RÉSUMÉ OF MINERAL PRODUCTION

From the time of its discovery to the present, mining in Colombia has been devoted almost exclusively to the production of the precious metals and preëminently to that of gold. In the sixteenth century it was the region toward which the paths of most of the Spanish adventurers and explorers converged in their quest for the *El Dorado* or land of gold. The total gold production of Colombia exceeds that of Brazil, its nearest rival among the South American countries; and on the basis of Restrepo's estimate of the production to 1886 (75, pp. 156–8)* now totals over $700,000,000, more than two-thirds of which was derived from the placers. In recent years there has been a gradual augmentation in production, and it now averages between $4,000,000 and $5,000,000 annually. The silver output has been very small in comparison and subject to far greater fluctuations. Restrepo (75, p. 156) estimates the amount produced to 1886 at $33,000,000, or one-twentieth that of the gold; and one-half of this was mined during the nineteenth century, whereas less than one-third of the gold production is credited to that century. The period from 1870 to 1890 was the most flourishing for the silver mining industry, and in 1884 the production had a value of one and a quarter million dollars (51, p. 264). In 1914 the production was 351,311 ounces with a value of $194,300, a little less than one-twentieth of the value of the gold output. The trend of present mining development in the country will likely lead to a greater relative production of gold in the next few years and the relegation of the silver production to a more inferior position. The platinum production has been steadily increasing, rising from 10,000 ounces in 1910 to 17,500 ounces in 1914, with a much greater increase in value due to the rapid rise in price of the metal. The relative importance of the country as a platinum

* Numbers in parentheses refer to articles in bibliography at close of chapter.

producer has also increased for the 1910 production represents 3.5 per cent and the 1914 production 6.6 per cent of the world's output. Further Colombia furnishes the only important supply of platinum aside from that which comes from Russia.

The base metals have been produced to a very limited extent. Small quantities of copper ores were worked by the Spaniards and some lead has been produced. Zinc ores have not been worked at all and except for the occurrence of sphalerite in association with the ores of other metals, no mention of zinc deposits is made in the literature. Iron ore has been worked in small amounts for the supply of several local iron-works. There has been no production of manganese ores within the present boundaries of the country.

The occurrence of the rarer metals is not mentioned except for those of the platinum group which are found in association with the platinum. Mercury deposits are known but there is no recorded output.

The emerald mines of Colombia, formerly accredited to Peru, have for three centuries been the world's most important source of this stone. The industry has in the course of its long history undergone many vicissitudes, and since 1912 there has been practically no output.

No statistics of fuel production are available. Coal for local use and for the railroads is mined. The petroleum production up to the present has been small. Asphalt is mined for domestic use and a small amount is exported.

Other non-metallic products of present importance are salt and kaolin. About 30,000 tons of salt are produced annually for domestic consumption. At Caldas and Carmen near Medellin kaolin is worked for use in local potteries.

TOPOGRAPHIC AND GEOLOGIC FEATURES

A brief outline of the topography and geology of the country will greatly facilitate the description of the distribution of its mineral resources.

The great backbone of the Andes, which in Ecuador consists of two ranges, in Colombia splits up into three ranges separated by the two great rivers of the country, the Magdalena and Cauca, and known respectively from east to west as the Cordillera Oriental, the Cordillera Central, and the Cordillera Occidental. Entering from Ecuador with a trend east of north, they gradually bend around to a nearly north-south direction.

The Cordillera Oriental has its steepest slopes on the west side

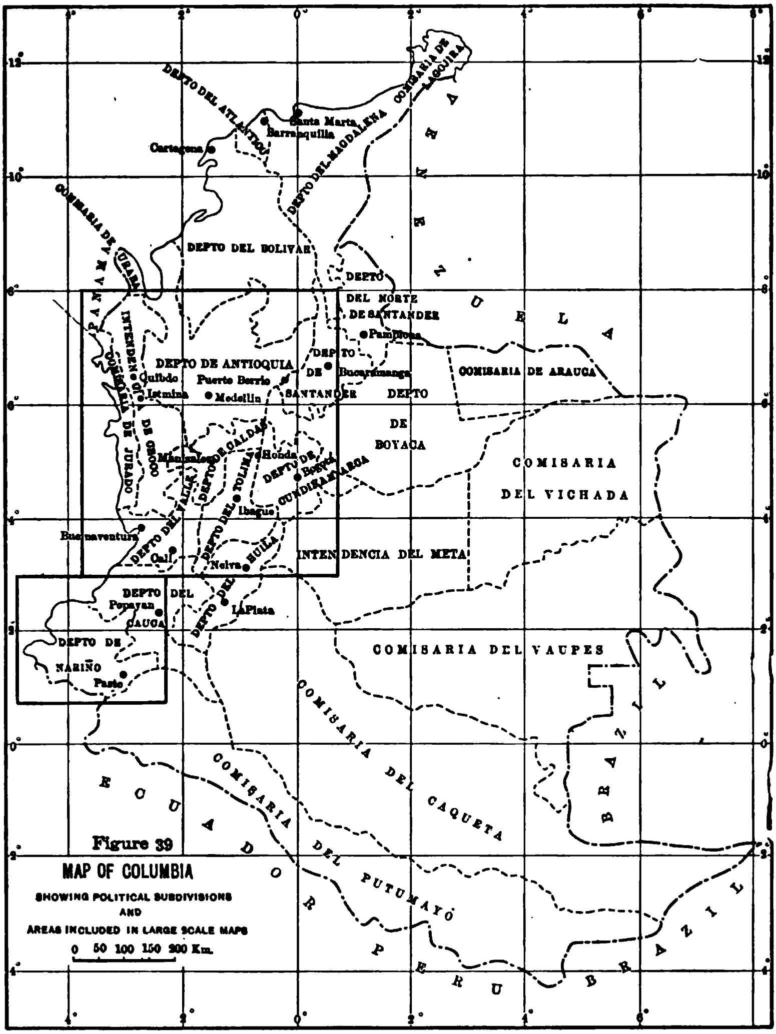

FIG. 39.

facing the Magdalena Valley, and on the east side gradully slopes off to the valleys of the tributaries of the Orinoco and Amazon rivers. At its northern end in the vicinity of Pamplona it splits into two branches, one continuing to the north and known as the Sierra de Perija makes connection with the group of mountains near the coast east of Santa Marta called the Sierra Nevada de Santa Marta, the other bends to the east and extends into Venezuela as the Sierra de Merida. The country just described includes two-thirds of the total area of Colombia, but except for a band adjoining the Magdalena River, including the departments of Magdalena, the Santanders, Boyacá, and Cundinamarca, is little known and almost entirely undeveloped.

The Cordillera Central lies between the Magdalena and Cauca rivers, and gradually decreases in elevation toward the north. Topographically in the departments of Caldas and Antioquia it is an extensive plateau cut by numerous valleys to depths of several thousand feet which gives rise to an extremely accentuated terrane. In central Caldas, the elevation is about 10,000 feet and it decreases to 6,000 to 8,000 feet in Antioquia. The number of prominent peaks is not large, but such as Ruiz, Santa Isabel, and the Nevada del Tolima rise to elevations of over 14,000 feet. This region includes the important mining departments of Antioquia, Caldas, and Tolima.

The Cordillera Occidental embraces the territory between the Cauca River and the San Juan-Atrato Valley. The average elevation of the range is lower than that of the other ranges and it also lacks their plateau-like character. The eastern slope is abrupt and the divide is close to the Cauca River so that there are few important tributaries from it to that river. The principal drainage is consequently on its western slope to the Atrato and San Juan rivers. The general elevation of the range is 5,000 to 8,000 feet, though some peaks reach elevations of 12,000. The area included within this range embraces the western part of the department of Antioquia, the southern part of the Intendencia de Chocó, and the greater portions of the departments of Valle, Cauca, and Nariño.

The San Juan-Atrato Valley is a marked depression with an elevation of only 450 feet at the divide between the two rivers. The Atrato, the longer of the two rivers, empties into the Caribbean; the San Juan flows to the south and empties into the Pacific to the north of Buenaventura. The strip of territory between the valley and the Pacific which includes the Comisaria de Jurado and the northern part of the Intendencia de Chocó consists of a low coast range called the Cordillera de Baudó.

The department of Bolivar except in the southern part consists of low comparatively flat country.

The geology of Colombia has been so little worked out that one can discuss it only in general terms. As regards age, the rocks fall into two major divisions, the pre-Cretaceous crystalline complex and the Cretaceous-Tertiary sediments and volcanic rocks. The crystalline complex is made up of a varied series of schistose rocks—amphibole and mica gneisses, amphibole, mica, and graphite schists, slates, and to a limited extent quartzites—granular igneous rocks of granitic and syenitic composition that locally outcrop over large areas, and numerous dikes of felsitic and fine-grained dioritic rocks. The dikes are probably of Tertiary age, but most writers on Colombian geology regard the complex as a whole of pre-Cambrian age. Ospina, on the other hand, (62, 63) divides it into three divisions which he assigns respectively to the Archean, Paleozoic, and Jura-Trias; but in view of the confessed absence of fossils, there is no certain evidence as the basis for the division. In the light of present knowledge, one can hardly do more than look upon these rocks as a single group separated by a great time interval from the earliest recognized Cretaceous and possibly of pre-Cambrian age.

Except for the region about the Sierra Nevada de Santa Marta and parts of the northern end of the Cordillera Oriental, the Magdalena Valley may be taken as marking approximately the eastern limit of the crystalline complex. The latter forms the backbone of both the Cordillera Central and the Cordillera Occidental, though it is more prominent in the former than in the latter as a result of the less extensive covering by the later volcanics. The core of the Cordillera Central is essentially granitic with the schists more prominent on the flanks.

Both Cretaceous and Tertiary sediments are well represented in the younger group of rocks. The rocks of accepted Cretaceous age are divided into lower and upper Cretaceous. The lower Cretaceous includes the Jiron and the Villeta series which have a combined thickness of about 13,000 feet. The Jiron series consists predominantly of coarse clastic sediments, whereas the Villeta series is made up of dark shales and bituminous limestones with only subordinate layers of sandstone. The passage into the upper Cretaceous Guadalupe series is gradual. It consists of about 3,000 feet of sandstone.

The next younger series are the Guaduas beds which Stille[1] says lie concordantly upon the Guadalupe but are discordantly overlain by the next younger rocks and which for that reason he likewise regards as Cretaceous. They consist of a thick series of red marls and clays, locally carrying salt and gypsum, and are further characterized by intercalations of eruptive rocks which occur as intrusions, flows, and tuffs, chiefly of andesitic composition. Ospina and others consider this series Tertiary.

The Cretaceous rocks are extensively developed east of the Magdalena River and make up the greater part of the Cordillera Oriental. They extend across the valley and are found on the lower eastern slopes of the Cordillera Central as a band of considerable width in places. Cretaceous sediments are likewise found up the valley of the Cauca to beyond Cali but are limited in occurrence to the lower slopes of the two ranges flanking this valley. The thickness of the series in this western area is considerably less and it is made up chiefly of sandstones, shales, and conglomerates.

The close of the Cretaceous and beginning of the Tertiary was marked by igneous intrusion and uplift and is probably the time of the principal uplift of the Cordillera Central. The most important intrusive rocks of this period are of acidic composition, and it is in the vicinity of them that most of the Colombian gold and silver deposits are found. They intrude both the pre-Cretaceous complex and the Cretaceous beds.

The principal areas of Tertiary strata are the lower slopes of the western side of the Cordillera Occidental and the Sierra de Chocó where ferruginous conglomerates and sandstones predominate, an inland belt parallel to the Caribbean coast where limestones are a prominent facies, and eastward from the lower eastern slopes of the Cordillera Oriental. Tertiary beds also occur in the Magdalena and Cauca valleys, those in the former known as the Honda series consist of coarse and fine clastic material with much of it of volcanic origin and in places of tuffaceous character.

The late Tertiary was marked by extensive volcanic activity in both the central and western ranges which continued to comparatively recent time. In fact the active volcanoes of today

[1] HANS STILLE: Geologische studien im Gebiete des Rio Magdalena. *Festschrift* Adolf von Koenen, pp. 294–5, Stuttgart, 1907.

represent a continuation of that volcanism. These youngest volcanics have their greatest areal distribution in the western range and in the southern part of the country toward the Ecuadorean boundary where agglomerates, tuffs, and ash cover extensive areas.

In addition to the volcanic material, the Quaternary is represented by the river terraces which are particularly well developed along the Magdalena and its tributaries, the sediments along the lower courses of the rivers, and the beds of pebbles, sands, and clays of marine origin along the Caribbean coast.

DISTRIBUTION OF MINERAL DEPOSITS

The areal distribution of the geological formations has naturally determined to a very large extent the distribution of the mineral deposits, and this will be discussed from both the geographic and geologic standpoint. Accompanying the text are three maps that will be useful for reference. The first is a small scale map of Colombia showing the principal political divisions and for purposes of more ready orientation a few of the most important places, the second is a large scale map of that part of the country in which most of the mineral deposits occur, the third a similar map of the department of Nariño.

GOLD AND SILVER

Primary gold and silver deposits are confined to the rocks of the pre-Cretaceous complex and the later intrusives that have cut them. The greatest number are consequently found in the Cordillera Central. A much smaller number are known in the Cordillera Occidental, due in part possibly to less mineralization in that range but certainly to a large extent to the fact that most of the range has been little explored. The great and widespread occurrence of placer gold in the San Juan-Atrato river valleys is strong evidence of an abundant mineralization of this region, but whether it has been sufficiently localized to form primary deposits of importance is still unknown. Mineralization has also occurred in the vicinity of Bucaramanga in the Cordillera Oriental and to a slight extent in the Sierra Nevada de Santa Marta. The most important producing regions of lode gold and silver are, therefore, the departments of Antioquia, Caldas, and Tolima. Of less importance are those of Valle, Cauca, Nariño, and Huila in the southwestern part of the country and the Santanders, Bolivar, and Magdalena in the northern. The relative importance of the country west of the Magdalena River is even greater than this areal distribution indicates, for Restrepo (75, p. 156) estimates that to 1886, the production east of the Magdalena River amounted to $20,000,-000 and that west of the river $652,000,000.

The placer gold deposits are coextensive in areal distribution with the lode deposits, being found in all the gulches and rivers draining those areas, and in addition there is the important placer gold and platinum region of the Intendencia de Chocó which is so little explored beyond the very stream courses that but few deposits of lode ores have been located in it.

PLATINUM

The commercial occurrence of platinum is restricted practically to the south central part of the Intendencia de Chocó. It occurs in the same deposits as the gold, the relative quantities of the two metals varying greatly in different streams and in different parts of the same stream.

COPPER

Copper deposits have been reported from many localities in widely separated parts of the country, but no really important occurrence has been discovered. Copper mines were worked in the colonial days at Natagaima, Moniquirá, and Villeta, but these occurrences are of no present importance. At Natagaima, on the west side of the Magdalena River in the department of Tolima, the ores consist of native copper and chalcocite with smaller amounts of chalcopyrite (27, pp. 138-9) and occur as nests, veinlets, and impregnations of diabases and melaphyres or in metamorphosed sedimentaries which they have intruded. The amount of chalcopyrite is greatest in the sedimentaries. At Moniquirá in Boyacá, the mineralization is similar but has taken place in sandstones. In addition, Gamba (27, pp. 138-9) mentions the occurrence of strong lodes of chalcopyrite and bornite in quartz. Copper ores are also found in Cundinamarca. Further west they are reported from Antioquia, the Chocó, and Nariño. At El Plateado in Antioquia are veins of chalcopyrite in dacitic rocks, but they do not exceed 30 cm. in thickness; and during the last few years similar veins have been discovered on the western slopes of the Cordillera Occidental in the vicinity of the Rio Tigurido and Bagado which are reported to be from 30 cm. to 4 m. wide and to assay $8–$11 gold and 25 to 32 per cent copper (63).

LEAD AND ZINC

Transportation difficulties and the stage of development of the country as a whole exclude the possibility of a lead and zinc industry and for that reason little or no attention has been paid to ores of these metals. Nothing at all can be said in regard to the occurrence of zinc ores. Lead ores are known at a number of localities, of which may be cited Cucarachero near Rio Sucio in Caldas, the most important occurrence where considerable masses of galena are found filling cavities in calcareous rocks, Charalá and Zapatoca in Santander, Villa de Leiva in Boyacá, and near Anolaima in Cundinamarca.

IRON

No iron ore deposits are known in Colombia of such quality, size, or so located as to make the exportation of iron ore worthy of consideration. The utilization of the ores is, therefore, dependent entirely on the development of a local industry. Four domestic iron-works have been erected of which two are in successful operation, one located near Bogotá and the other near Medellin, the Pradera and Amagá works respectively. At Pradera is a small blast furnace with a capacity of 30 quintals in 24 hours (63), a small rolling mill, a foundry, and 20 coke ovens. It is located on the plateau, 30 km. from Bogotá, at an elevation of 3,000 m. The Amagá plant is of about the same size and supplies material for the Zancudo mines and Medellin. A second works on the plateau of Bogotá, called Pacho, 25 km. from Pradera and 55 from Bogotá has been shut down for twenty years. The fourth plant was erected at Samaca in Boyacá in 1860 and consisted of a blast furnace, a reverberatory furnace, and a puddling furnace. After several unsuccessful attempts involving considerable expenditures to put this enterprise upon its feet, it was finally abandoned about 1880, a complete failure.

Information in regard to the ore deposits upon which these enterprises were based is very scant and indefinite. At all of these localities the iron ores are closely associated with coal beds and limestone and occur in the Cretaceous rocks in the form of small layers and concretions of hematite, limonite, and siderite.

For upper Cundinamarca, Manning (53, p. 995) gives the following sequence of strata: fine-grained sandstone, shale, iron ore, shale, coal, limestone. The ores run 52 to 60 per cent iron and he says the ore in sight has been estimated at 480,000 cu. m. Less is known in regard to the Samaca deposits. There were two mines, located on what were supposed to be large deposits.[1] The poorer one being nearest the works furnished the ore actually used. At Amaga the ores are reported to be light brownish-yellow siderites (58, p. 143). They occur in the stream as nodules which have weathered out of Cretaceous sandstone. Other localities at which iron ores are known to occur are Subachoque and La Calera in Cundinamarca, Cali in Valle, and Rio Hacha in Magdalena, but there is no information as to their character. In the vicinity of San Luis in Antioquia (63) are veins more than one meter in width consisting of specularite and quartz.

MERCURY

Gamba (26, p. 194) states there is a discontinuous belt of cinnabar ores extending from Santa Rosa in Antioquia to Miraflores in Tolima, but Quindió on the western edge of Tolima at the head of the valley of the Vermellon is the only point at which exploitation has been attempted. Restrepo (75, p. 211) says that D. José Celestino Mutis opened up these veins in 1786. The deposits are again being developed. The ores occur in schist but related to a large dike of trachyte and andesite. In the fresh rock they form a stockwork of veinlets consisting of quartz and calcite gangue with compact and crystalline cinnabar, pyrite, and rarely galena and tetrahedrite. The crude ore is said to average ¼ to ½ per cent mercury and the sorted 10 per cent or more. Decomposed schists impregnated with finely powdered cinnabar also occur and doubtless represent oxidized products of the stockworks.

COAL

Coal deposits are of widespread occurrence in the Cretaceous and Tertiary strata of Colombia but have been worked at only a few points for local use and are practically unexplored. The principal coal producing localities are on the plateau of Bogotá

[1] 16th *Ann. Rept.*, U. S. G. S., Pt. III, pp. 63–64, Washington, D. C., 1895

near Bogotá and Zipaquirá, where coal is mined for use on the railroads, at the salt works, and for other industrial purposes, and at the Pradera iron works; and in the Titiribí district in southern Antioquia for use at the Zancudo smelter, the Amagá iron-works, and other local purposes. The highest grade coals are confined to the Cretaceous horizons and are found in two principal areas—in the eastern range in the departments of Cundinamarca, Boyacá, Santander, and Norte Santander; and in the valley of the Cauca in the departments of Cauca, Valle, and Antioquia. Gamba (31, p. 578) says there are in all probability large areas underlain by the coal-bearing formations in southern Colombia in the region of the Rio Putumayo. In the better known regions first mentioned he estimates the probable reserves at about 27 billion tons, but the knowledge of the area of coal involved and the number and thickness of the seams is so meager that the figure has little value.

Gamba states that the Cretaceous coal seams in the eastern area are usually three in number and vary in thickness from 0.6 m. to 1.2 m., aggregating 2 m. Ospina (63, p. 333), referring to the western area, says the number is variable and may be as high as six and that the thickness ranges from a few centimeters to three meters. Ordinarily the coal is a black hard compact lignite, but where it has been subjected to regional or igneous metamorphism it has been transformed into a good bituminous coal suitable for coking. Garrison (34, p. 220) describes several localities on the Taraza River near Caceres where there are a number of seams with a dip of N 10° E, the upper one having a thickness of 8 in., several lower ones 18 to 30 in., and the lowest 4 to 5 feet, and says the coal has a compact glossy appearance similar to cannel, but burns like punk and can be lighted with a match. The following analyses serve to indicate the character of the Cretaceous coals. The first two are from Ospina and the other two from Garrison, and all represent Antioquian coals.

	Palmichal	Sitioviejo	Rio Tarasa	
Moisture	11.02	1.40	13.60	15.36
Volatile carbon	44.03	35.58	38.10	47.41
Fixed carbon	43.75	58.54	44.40	32.67
Ash	1.20	4.48	3.80	4.56
Sulphur	.07	.46	.....	.547
B.t.u	9,608.00	14,145.00		

The Tertiary deposits are lignite of inferior grade. The best known occurrences are about Rio Hacha and the headwaters of the Rio Aracataca in Magdalena, the department of Atlantico, and the Comisaria de Lagoajira, Rio Sucio in Antioquia, and the vicinity of Quibdo in the Chocó.

PETROLEUM

The description of the oil fields is based largely on Arnold's account which is the most complete available (11, pp. 303–8). Petroleum occurs in both the Tertiary and Cretaceous series and ranges in grade from heavy oil of asphaltic type to a paraffin base oil of 41° Baumé. The oil-bearing series are commonly also coal-bearing. Tertiary oils are found in the regions contiguous to the two coasts of Colombia, the Caribbean and Pacific. The Cretaceous oils are found in the eastern range and at a number of places in the Magdalena Valley, though some of these occurrences may be in the Tertiary strata. Arnold estimates the areas included in the Colombian oil districts at 34,300 sq. mi., of which he classes 618 sq. mi. as possible oil territory and 2 sq. mi. as proved oil territory. He regards the showing as favorable enough, however, to warrant the conclusion that valuable deposits of petroleum exist, particularly in the Caribbean and Santander districts, and recent activity in oil prospecting by foreign capital indicates similar confidence on the part of others.

Caribbean District.—The Caribbean district extends from the eastern edge of the department of Magdalena southwestward along the coast to the Gulf of Uraba and inland for a distance of 30 to 50 miles except in the Atrato River valley which it ascends for 90 miles. In this area of about 15,000 sq. mi., Arnold estimates 300 sq. mi. contain oil possibilities and that less than one square mile has been proved commercially productive. The great bulk of the sediments are dark-colored shales with sandstone members and the oil occurs in the sandstones and probably in joints in the shale.

"The structure is that of broad to sharply folded and faulted anticlines, and the surface evidences of oil are usually, though not invariably, confined to the anticlinal areas."

The gravity of the oil ranges from 16° to 41° Baumé but usually falls between 20° and 30° Baumé. There are at least ten productive wells, the production of which is usually less than ten barrels daily. The greatest amount of development has been carried on in the Turbaco and Tubará fields, located 12 to 15 miles south and 20 miles east of Cartagena respectively. The principal surface evidence of oil in these fields consists of mud volcanoes, though in Tubará sulphur springs and oil seepages also occur. The Standard Oil Company is interested in the Turbaco field and with its associates, Diego Martinez & Co., has drilled a number of wells ranging from 500 to 2,200 feet in depth. In the Tubará field a Canadian company has put down wells to depths of 700 to 3,000 feet which yield an asphaltic oil with a gravity of 22° to 26° Baumé. Ospina (63, p. 334) gives the following results of fractional distillation of two samples of oil from the region about the Gulf of Uraba.

		I	II
150°C.,	Benzine..........	0% by volume	6% by volume
150°–300°C.,	Petroleum........	25% by volume	64% by volume
Above 300°C.,	Oils..............	64% by volume	24% by volume
	Residue	11% (contains paraffin)	6% (very little paraffin)

Pacific District.—The Pacific district includes a belt 60 or 70 miles long extending up the Pacific coast from Buenaventura to Baudo, and reaching inland to the Atrato River at Quibdo on the north and as far south as Cali. Out of an area of 1,800 sq. mi., Arnold estimates that 18 sq. mi. have possibilities of oil. The rocks of the region are predominantly sharply folded shale. Many hot springs and salt springs exist and a few emit gas of some sort. The oil on the Baudo River has a gravity of 31° to 37° Baumé.

Magdalena-Santander District.—A district of probably equal importance but more inaccessibly located than the Caribbean is the Magdalena-Santander district which includes the two departments of Santander, the western part of Boyacá, and the southeastern corner of Bolivar, an area of 200 miles by 50 miles of which Arnold thinks 200 sq. mi. contain oil possibilities. The proved territory is less than a square mile in extent and is located near Pamplona where a small refinery handles the high-grade product of a few wells for local consumption. The oil occurs in Cretaceous limestones and sandstones and lower Tertiary sandstones. The favorable structures for oil accumulation are long, well-defined, and even overturned anticlines and possibly fault zones. The grade of the oil is variable, the wells shallow, and the yield small; but conditions seem to be favorable for a greater yield at greater depth. A southwesterly extension of this district is represented by a line of seepages along the Magdalena flank of the eastern range to beyond Girardot and the oil-bearing area in Tolima along the Saldaña River. There are also indications of oil on the eastern slopes of the eastern range which are believed to extend from the eastern edge of Cundinamarca possibly as far as the Brazilian border. There is, however, little information in regard to this region which lies remote from transportation facilities.

ASPHALT

Asphalt deposits are found at a number of localities in the oil districts and have been reported from the departments of Atlantico, Antioquia, Norte de Santander, Santander, Boyacá, Tolima, and Huila. The Boyacá occurrences have been worked for asphalt for the streets of Bogotá, and from Chaparral in Tolima and some of the Santander occurrences small quantities are now exported.

EMERALDS

The emerald is the only precious stone of commercial importance in Colombia, though sapphires and rubies are found in the Rio Mayo an affluent of the Patía, and garnets in various parts of the country. With one exception the emerald deposits are confined to the department of Boyacá in which there are over 150 reported occurrences. The exception is a reported occurrence near Bolivar in Santander about 37 miles from Muzo along the line of strike of the emerald-bearing formations. Some of the more important localities are shown on the map, Fig. 42. Only three of these many localities have been of commercial importance—Muzo, 96 km. northwest of Bogotá, Coscuez, about 12 km. further northwest, and Somondoco or Chivor, about 80 km. north of east of Bogotá. The most productive has been Muzo which for nearly two centuries has been the sole commercial source of Colombian emeralds. There are no data as to the total emerald production of Muzo or of the country as a whole. The principal deposits were known and had been extensively worked by the Indians before the arrival of the Spaniards; since then the production has amounted to tens of millions of dollars in value and during many years was as high as one to two millions. Since January 1, 1913, production at Muzo has been suspended.

The first knowledge of the location of the emerald-bearing region was obtained by the Spaniards in 1537 and after a year's search they located the Somondoco deposits. In 1558 they began mining in the region about Muzo, but the present Muzo deposits were not found until later, possibly not until 1594. After a few years of considerable prosperity, the industry dwindled and was conducted in a more or less desultory fashion, even after reorganized under the Royal Treasury in the middle of the seventeenth century, until the War of Independence in 1816 caused a complete cessation of mining. The locations of the Somondoco and Coscuez mines were then completely lost and only in recent years have they been rediscovered. Since the War of Independence, the deposits have been the property of the Republic and from 1824 to 1848 they were leased to private companies under a 10 per cent royalty. In 1848 it was decreed by Congress that the deposits were to be worked by the nation but actually they have been worked by private parties in partnership with the government or even as concessions until the last agreement made in 1909 with the Colombian Emerald Mining Co., Ltd., was abrogated on January 1, 1913. Due to lack of sufficient appropriations, the government since that date has been able to do nothing more than maintenance work.

With the exception of the Muzo deposits which will be more fully described in a subsequent section of the chapter, little can be said in regard to the geology of the emerald occurrences. They appear to lie within a series of black carbonaceous shales and shaly limestones of Cretaceous age. A number of them were studied in 1915 by Prof. Robert Scheibe of Berlin, but the results have not been published. The Coscuez deposits are difficult of access and nothing is known concerning their geology. Latham (50, p. 212) says of the Somondoco occurrence that the country rock consists of dark-gray to black clay-slate and limestone and is cut in zig-zag form by veins of semi-decomposed quartz. Pogue thinks it likely that these are really calcite veins. The emeralds are found in these veins, either a few together or, occasionally, in pockets of contorted shapes and isolated in the rock formation; the latter stones are generally of the highest grade.

SALT

The salt industry is a government monopoly in Colombia and all salt deposits and saline springs whose waters exceed

6 per cent in saturation are its property. There are three commercial sources of salt, which arranged in the order of their importance are:

1. Rock salt found in the Cretaceous or Tertiary beds east of the Magdalena River in the departments of Cundinamarca and Boyacá and the Intendencia del Meta. The most important of these localities is Zipaquirá. Others producing salt are Nemocón, Tausa, and Sesquilé in Cundinamarca, and Cumaral and Upin in Meta. The deposits are worked either as rock salt or by leaching and evaporation of the concentrated brines. The Zipaquirá occurrence is briefly described by Armenta (10). It consists of a small hill about 2 km. in diameter and 250 m. high at the western edge of the town. The salt was worked in an open-cut at the summit by the Chibchas before the Spaniards came, but in later years underground mining has been used. Gonzalez Benito and Davison have calculated the available tonnage at one billion (63, p. 335). Armenta gives the annual production at 20,000 tons costing $150,000 and producing for the government a profit of over $350,000. The composition of the salt is stated to be similar to that of sea salt.

2. Salt derived from solar evaporation of sea water along the Caribbean coast. The production from this source is given at 6,000 tons annually.

3. Salt produced from saline springs west of the Magdalena River where transportation difficulties make the cost of salt from the other two sources excessive. The annual production from this source ten years ago was about 3,000 tons, but this is decreasing as improved transportation facilities make other salt more readily obtainable because much of it is of inferior quality, containing such salts as sodium sulphate, magnesium sulphate, and sodium bicarbonate in large quantity. The saline springs whose waters are utilized for salt production are located in the departments of Antioquia, Caldas, Cauca, Nariño, and Huila.

DESCRIPTION OF IMPORTANT DEPOSITS

The Gold and Silver Lode Deposits

The precious metal lodes in Colombia range in character from those in which gold is by far the most important constituent which constitute the vast majority to essentially silver veins. But in the case of the gold veins there is usually an appreciable amount of silver present so that the tenor of the lode gold is rather low. Restrepo (75, p. 37) gives fifty assays of lode gold from Antioquia which have an average fineness of 698. The veins occur principally in the schists and to a less extent in the igneous rocks of the pre-Cretaceous complex but are almost invariably closely associated with younger intrusive and extrusive rocks, that appear to include porphyries, monzonites, andesites, trachytes, and rhyolites. The veins are chiefly quartz veins carrying, in addition to free gold, auriferous sulphides which in their usual order of abundance are pyrite, sphalerite, arsenopyrite, galena, and chalcopyrite. Of less common and less abundant occurrence are sulphantimonides of copper and silver, argentite, and rarely molybdenite. In a few instances calcite and dolomite are important gangue minerals. The free gold is very minute and not always visible even in the quartz and rarely in the sulphides. Wire gold and dendritic forms are not common, but gold is often seen in thin flakes and leaves in the quartz. The veins in the schists are usually intercalated parallel to the schistosity and show a tendency to wedge out and re-appear and are often connected by minute stringers. In some instances the ore body is merely a network of narrow stringers and veinlets not over an inch or two wide, forming a veritable stockwork; and the oxidized outcrops of such deposits can often be worked in the same manner as placers, provided they are located in such a position that water can be brought to them. The veins in the igneous rocks are more generally fissure veins and average in width from 20 cm. to 200 cm. A further characteristic of most of the veins is the occurrence of the pay ore in shoots and pockets so that there is great variation in tenor of the ores; and according to Restrepo (75, p. 37) an impoverishment in depth is generally manifested. There seems to be no definite information on this latter point and the impoverishment referred to by Restrepo doubtless was in part at least apparent rather than real, due to decreasing recovery with the primitive treatment in vogue as the sulphide zone was penetrated. The chemical character of the vein filling and the extensive formation of placers do not make it probable that much enrichment by downward migration of gold has occurred. On account of the small scale of most of the operations, the imperfect recovery accompanied by inadequate assay control, and the great variability in tenor from place to place in even the same vein, it is difficult to give accurate figures of the average tenor of the ores mined. Posada (71, p. 827) states that on account of the usual low extraction ores must carry $16 gold per ton to be workable.

Department of Antioquia.—This department has been the mining region *par excellence* of Colombia. The total output since the conquest has been, based on Restrepo's figures to 1886, about $300,000,000, or nearly one-half of the estimated production for the entire country, and of this about one-third has come from the veins and two-thirds from the alluvial deposits. The ores of Antioquia are distinctly auriferous as the Zancudo mines at Titiribí are the only silver mines within its borders. Wright (87, p. 519) states that in 1909 there were over 600 mines in operation of which about 30 were being worked by foreign companies. These are grouped into a great number of mining districts, most of which lie in the Cordillera Central, that is, in the portion of Antioquia between the Magdalena and Cauca rivers. The relative importance of a number of these is shown by the following estimates of their 1914 production by Perry (67, p. 948): Remedios and Titiribí $400,000 each, Amalfi $120,000, Santa Rosa $80,000, Sonson and Puerto Berrio $70,000 each, and Anorí and San Roque $60,000 each. A number of the more important and geologically interesting districts will be briefly described.

Remedios.—This is one of the oldest and most important of the Colombian mining districts. Gold mining was commenced and the city founded in 1560. The early operations were placer and the site of the town was shifted several times as the location of mining activities changed before finally settling where it is at present, at an elevation of about 2,500 feet. Lode mining did not attain prominence until the advent of foreign capital in the first half of last century. The principal operator is the Frontino and Bolivia South American Gold Mining Company, Ltd., which entered the district in about 1864. Its reserves were estimated in 1916 at 42,200 tons averaging $20 gold, and the production during the fiscal year closing in 1916 was 22,358 tons with an average yield of $17.50. This company has recently been extending its holdings and improving its milling facilities, having erected a 50-ton counter-current decantation plant, an auxiliary pan-amalgamation mill for handling concentrates, and a new 1,050-lb stamp mill in addition to the old mill of thirty 450-lb. stamps that is to undergo remodeling. The Compañía Francesa de Segovia, re-organized in 1893 as a Franco-Belgian company, started in 1887 with a fine Fraser & Chalmers California mill which has thirty-five 750-lb. stamps

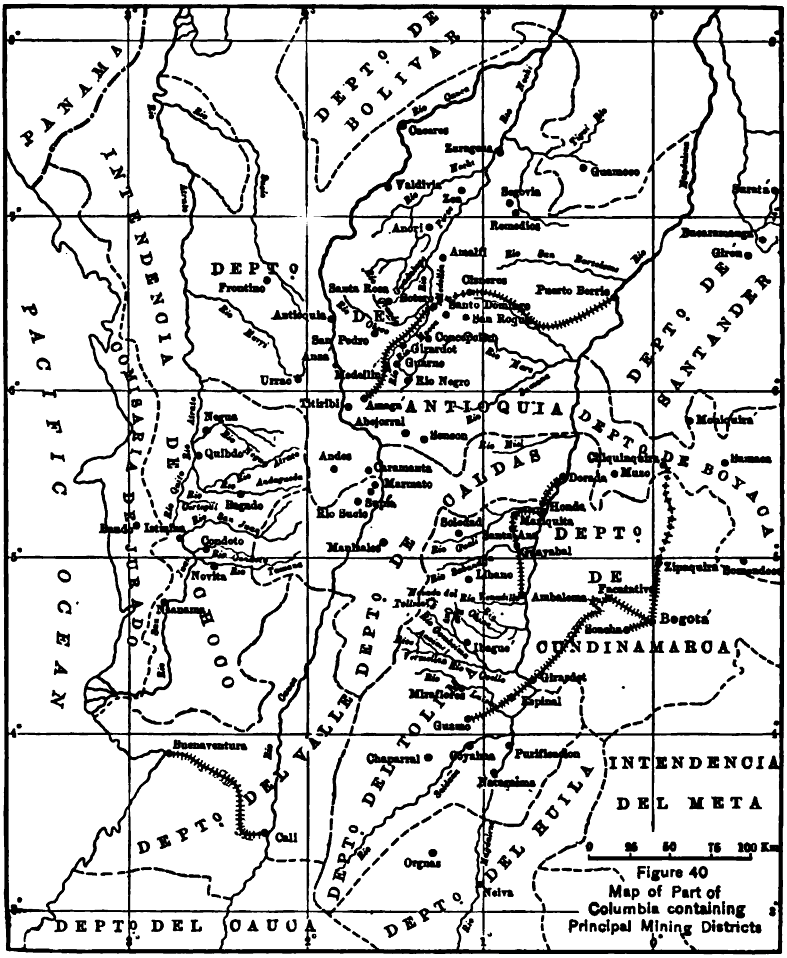

Fig. 40.

with a capacity of 70 tons daily and installed the first cyanide plant in Colombia (23, p. 21). The Colombian Mines Corporation, Ltd., started work on the Sucre and Providencia mines in 1887; and about a dozen years ago the South American Development Company of Chicago opened the Venecia, a few miles southwest of the town.

With the Remedios district are included the adjoining district of Segovia and several less important ones. The region is almost completely forest-covered and has an undulating topography with the hills 150 to 500 feet high. The prevailing rock of the mineralized area has been variously called syenite, andesite or trachyte, and granite, but appears to be a granular rock in composition between granite and syenite, and has been cut by dikes of porphyry or quartz porphyry. To the east of this area limestone is encountered, to the south gneiss, and to the west shales or slates. Overlying the granite are patches of schist.

There are a great number of quartz veins, most of them auriferous, and the important ones have a prevailing east-west strike with a dip of 20° to 60° usually to the south, and a width of 1 to 3 feet. The quantity of sulphides associated with the quartz is not large, ranging from 1 to 12 per cent and averaging about 3 per cent. Nichols and Farrington (58, p. 132) describe specimens of the ore as follows: "The ores are typical quartz-pyrite vein material. The quartz in the unoxidized specimens is hard and firm, and greatly exceeds in quantity the sulphide, which occurs as parallel bands of coarsely crystalline pyrite with very small quantities of galena and blende. Other sulphides appear to be absent." Other writers mention as occurring in small quantity marcasite, pyrrhotite, arsenopyrite, chalcopyrite, native bismuth, and lead molybdate. The tendency of the ore to occur in shoots is pronounced, but the shoots are persistent in depth, and the presence of galena seems to be an indication of rich ore. The oxidized ores extend to a depth of 50 feet or more and most of the mining, especially at the many native owned mines, has been confined to them.

The most important mines have been the Silencio and Salada, of the Frontino and Bolivia company, located west of the town of Segovia, the former with a depth of 600 feet being the deepest mine in Antioquia; the San Nicolas of the French company at Segovia which is supposed to be located on the same vein as the Silencio; and the Sucre also at Segovia. Halse (40) describes well developed vein conglomerates in the Sucre veins that were formed he thinks in part through a sliding of the hanging wall and in part by the solvent action of the thermal waters that deposited the ores.

Anori.—The district is a region of considerable relief and the town lies at an elevation of about 5,000 feet. The country rock consists of mica schist with a few granitic and dioritic intrusions. The veins have an east-west strike and a steep southerly to vertical dip. The main vein of the district has a width of as much as 6 m., or, including the hanging-wall and foot-wall branches which so frequently accompany it, even 13 m. The ore consists of quartz with considerable pyrite and chalcopyrite and averages ½ to 1 oz. gold per ton. The Constancia, the principal mine of the district, has reached a depth of 300 feet. For a number of years it accumulated its concentrates but is now provided with a 10-stamp mill and cyanide plant.

Amalfi.—The elevation is 5,500 feet. The country rock is mica schist intruded by several bosses and dikes. The igneous rock generally referred to as granite is stated by Nichols and Farrington (58, p. 137) to be pyroxene dacite with intrusions of chloritized andesite and trachyte. The veins are steeply dipping quartz veins with ores similar to those of Anorí except that arsenopyrite is a prominent constituent and pyrite is not abundant. The district, formerly an important one, has greatly declined; and in 1914 out of 150 mines with mills only 3 were in operation (67, p. 946). Perry thinks the decline is probably due to the refractory character of the ores since they carry considerable lead, copper, and zinc sulphide and may not have yielded readily to the simple methods of treatment in vogue. There are two mineralized zones, the Chuchero 9 miles northwest and the Vetilla 24 miles northwest of the town and close to the Porce River. The Clara de la Union is the only important mine at present in the first zone and treats an ore yielding $20 in free gold and concentrates per ton. The Comstock Antioqueño in the Vetilla zone has a large tonnage of $14 ore.

Santa Rosa.—The country about Santa Rosa is a high plateau at an elevation of between 9,000 and 10,000 feet and devoid of vegetation on account of its arid climate. The country rock is made up chiefly of igneous rocks with which are associated small patches of schist and gneiss. The granite and syenite of others is said by Nichols and Farrington (58, p. 139) to be trachyte and andesite and is cut by dikes of dioritic porphyry. The ores are very amenable to treatment, consisting of quartz and pyrite. The veins are numerous and in many places so closely spaced that the oxidized zone is a mineralized area that has been extensively worked by washing. The mines are all shallow, the Trinidad is the most important and has not reached a depth of over 60 feet. Nevertheless it has produced several millions and its present output is $2,500 to $5,000 monthly from 300 tons of ore. There are several leaching tanks for cyaniding, but not a modern plant in the district.

Santo Domingo and San Roque.—This region is more favorably situated with regard to transportation than the preceding on account of its proximity to the railroad from Puerto Berrio. There are a number of mines with small mills about San Roque and in the Nus Valley, including the Florida mines being developed by Americans. The Retiro and Las Animas mines are being worked by hydraulicking and milling the vein matter caught in the sluices. The veins are enclosed in granite and consist of quartz and pyrite. One small mine has yielded a little rich gold ore carrying a high percentage of copper (67, p. 946).

Titiribí.—The Titiribí district is one of the most notable, not only in Antioquia but in Colombia, and chiefly as a result of the Zancudo mine owned by the Empresa del Zancudo of Medellin. The output of this mine, discovered about 1793, amounts to about $30,000,000 and for many years has averaged about $300,000. Its favorable location with respect to coal supplies has made possible the smelting of the ores which has been done since 1851. The ores differ in character from those previously described in their heavy sulphide character and the predominance of silver values. The average grade is $15 per ton, of which two-thirds is silver.

Notwithstanding the great importance of the mine, it is practically impossible to give a reliable description of its geologic relations on account of the many conflicting statements regarding those features. The district is situated at the contact of the pre-Cretaceous complex and the Cretaceous sediments with their included coal beds. These rocks are cut by later porphyries and trachytes. The Zancudo ore body is a relatively flat, dome-shaped mass with a thickness of two meters or more. Granger and Treville (37, pp. 66–72) call it a contact vein between schist and an overlying conglomerate with a north-south strike and dip of 45° east. A number of branches from the foot-wall side unite to form a second lode dipping 14° west. These relations are shown in Fig. 41. To the west is a similar contact vein carrying free gold. The ores of the former carry free gold and silver 750 feet from the outcrop, where the sulphide ores appear and a diminution of the gold content takes place. They consist of pyrite, sphalerite, galena, arsenopyrite, pyrrhotite, chalcopyrite, tetrahedrite, bournonite, jamesonite, stibnite, etc., in a gangue of quartz and calcite. Other descriptions of the shape and content of the ore body are fairly concordant, but those of its geologic position are utterly discordant with the above. Gamba (26, p. 98) calls the wall rock hornblende schist. Nichols and Farrington (58, p. 144), on the basis of specimens examined by them, say the ores appear to be impregnations and replacements

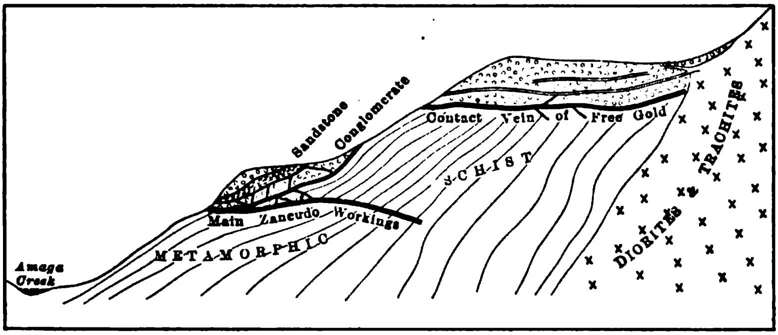

Fig. 41.—Profile of the Titiribí ore bodies, Colombia.

of a brecciated zone in trachyte. Demangeon (23, p. 42) considers the deposit of sedimentary origin laid down in the bed of a lake and analogous to the Witwatersrand deposits but on a small scale. Perry (67, p. 946) says the ore is at the contact of eruptive rock and schist.

In addition to the argentiferous ores described there are auriferous sulphides in veins usually only a few centimeters in width which cut the Cretaceous sandstones and conglomerates to the west of Zancudo in the immediate vicinity of eruptive rocks. Nichols and Farrington consider these rocks tuffs and agglomerates.

The Zancudo ores are sorted into smelting ore and milling ore. The milling ore yields free gold on blankets, sulphide concentrates, and tailings which are smelted to a matte. This matte is roasted and lixiviated for the recovery of silver sulphate; the residue is cyanided, and then given a chloridizing roast for additional recovery of gold and silver. A flotation plant is under construction.

Other Districts in Antioquia.—West of the Cauca River are several interesting though not commercially important districts. Caramanta has argentiferous veins in trachyte and trachyte tuffs consisting of pyrite, galena, and sphalerite with tetrahedrite and more rarely native silver, ruby silver, and argentite in a gangue of quartz and calcite. In the Andes district are auriferous quartz veins in shales closely related to dikes of diorite and felsite with a diorite mass west of the mines. At Anzá is the Quiuná mine on an auriferous vein in basic eruptive rocks with quartz and calcite gangue. The Frontino ores are auriferous and cupriferous, consisting of pyrrhotite and chalcopyrite with some tellurides and occur in veins with quartz and calcite gangue in a coarsely crystalline diorite. The region along the railroad west of Puerto Berrio is rapidly developing.

Department of Bolivar.—There is new activity in the old district of Guamoco. The mining here had been chiefly alluvial, but recently two Americans have developed a lode property from which with a 5-stamp mill and by saving only the free gold they have made a profit of $150,000. A larger mill and cyanide plant is being installed.

Department of Caldas.—The department of Caldas was created only recently and includes parts of what formerly belonged to Antioquia, Tolima, and Cauca. There are within its borders two mineralized areas of present importance—that about Marmato with a production of about $400,000 annually and the Manizales district which produces about $350,000 a year.

Marmato.—The region about Marmato includes the districts of Rio Sucio, Supía, Marmato, and Echandía, some of the mines of which are gold producers and others silver. The two best known mines, the Pava at Supía and the Echandía, are silver mines and each has had a production of several million dollars. The mineralized area as a whole is characterized by a predominance of volcanic rocks among which are represented apparently rhyolites, trachytes, andesites, and porphyrites. They are surrounded by schists and in places covered by the western edge of the Cretaceous sandstones of the Cauca Valley which are themselves in part intruded and covered by recent volcanics.

The Echandía mines are located on the southeast slope of the Cerro de Loaiza which is really a portion cut off by a steep valley from the Cerro de Marmato, an immense hill of rhyolite and porphyrite that rises 800 m. above the river. They are distant a few kilometers to the north of Marmato. On the opposite side of the same hill is the Chaburquia mine. The veins of this hill are in the igneous rock but near the schist contact, have a north-northwest strike and an easterly dip of 50° to vertical, and a width of 1 to 5 feet. The ore minerals are pyrite, sphalerite, galena, chalcopyrite, argentite, and some native silver and gold, and the gangue is either quartz or calcite with decomposed country rock. Granger and Treville (37, p. 51) give the average value of the ore as $30, of which 90 per cent is silver and 10 per cent gold. The ores are sorted into high-grade and concentrating ores and both are treated by amalgamation after a chloridizing roast. The Echandía mines have been worked for half a century by the Western Andes Mining Co., Ltd., of London, and Mr. Chavez, a Colombian.

The Marmato veins occur well within the volcanic rocks and are auriferous, though the fineness of the gold is only 350 to 600. Tulio Ospina says in this regard that veins distant from the schist contact carry gold only, those near and in the schist silver, but as they penetrate the schist they split up and die out. At Marmato there is a great series of parallel veins with east-west strike and vertical dip with numerous connecting stringers which have also been worked so that the underground workings form a veritable labyrinth. The veins are usually one or more feet wide and in some instances 15 to 20 feet. The wall rock is at many places altered and impregnated with auriferous cubical pyrite. Pyrite and the black sphalerite, marmatite, together with quartz constitute the chief filling, though a little galena is also found. The Marmato mines are worked by the Colombian Mining and Exploration Co., which has a locally built California stamp mill of 40 stamps treating 100 tons daily. The rest of the equipment is crude, consisting of the concentrators, burlap and blanket tables and grooved planks of the sort that have been in use for years. The treatment which was adequate for the oxidized ores is not suitable for the sulphides now worked and the losses are heavy. The natives collect the sulphides escaping from the mill and after allowing them to rust for a time regrind and pan them to recover additional gold. Every native is said to have his "gold garden" in which he has oxidizing sulphides (81, p. 422).

In the Supía district the volcanics are covered to a large extent by the sandstones, but the veins are encountered only in the former, and hence where the latter have been removed by erosion. The ores are pronouncedly argentiferous, though there are also some gold veins in the district. The most important vein is the Veta de la Pava which is narrow and irregular and nearly barren except in bonanzas, a single one of which yielded $2,000,000 (26, p. 134). The strike of the vein is east-west, and the filling principally pyrite and blende with argentite.

The silver mines of this region acquired considerable fame a century ago. Those at Quiebraloma in the Supía district were discovered before 1670; in 1825 Goldschmidt & Company leased a number and a second English company acquired others that were placed under the management of Juan B. Boussingault who introduced a number of improvements such as stamp mills and arrastres. Continued participation of English capital in the exploitation of these districts is represented by the Western Andes Mining Co., and the Colombian Mining and Exploration Company.

Manizales.—The town of Manizales was founded in 1848 and rapidly grew to be the most important commercial center in that part of Colombia. It is situated on the north bank of the Chinchina River, a tributary of the Cauca, at an elevation of about 7,000 feet, and lies on the great highway from the Magdalena to the Cauca. An aerial tram connecting the town with Mariquita 90 miles distant is partly completed. The Volcanes and Tolda Fria mines have each produced several million dollars. At present the Cascada is the largest producer, its output being about $20,000 monthly. It has an iron stamp mill of 20 stamps and a cyanide plant for the treatment of its tailings. Eighty per cent of the gold of the ores is free milling.

The country rock of the district consists of schists and igneous rocks that have been called syenite and granite but which Nichols and Farrington (58, p. 156) have determined to be rhyolites and trachytes. The ore deposits occur in both the schists and the volcanics, and are of two types—well defined veins and stockworks. The ores carry in a gangue of quartz and calcite and the common sulphides, pyrite, sphalerite, and galena, relatively large quantities of the sulphantimonides as tetrahedrite, stephanite, brogniardite, and pyrargyrite, which contain both silver and gold values.

The Volcanes vein is a north-south vein with steep westerly dip and average width of 60 cm. in wall rock of mica schist. The

Tolda Fria mine is situated about 10 miles southeast of Manizales at an elevation of 10,000 feet. It represents a stockwork in talcose schist with the main veins parallel to the laminations. They have an average width of about 1 cm. and direction of northeast strike and southeasterly dip of 23°. Granger and Treville (37, p. 55) state that the mine yields ore consisting of crystalline quartz with free gold and rich sulphurets worth $500 to $2,000 per ton and that it has produced 2,345 lbs. avoirdupois of gold 600 fine. The new Cascada mine is located near the Volcanes.

Department of Tolima.—The department of Tolima has always been known for its silver lodes rather than gold. In the Colonial days the region between Mariquita and Guayabal was famous for its silver mines. Another mineralized belt extends from north of the Rio Venadillo through Ibagué to Miraflores within which there are a number of more or less well-defined centers of production yielding both gold and silver, sometimes both and then again the one to the exclusion of the other.

Mariquita-Santa Ana-Guayabal.—These districts include a mineralized belt in the pre-Cretaceous schists and associated igneous rocks that lies a short distance west of the strip of Cretaceous sediments in the valley of the Magdalena. The ores are distinctly silver-bearing and characterized by the presence of ruby silver, argentite, and native silver associated with pyrite, sphalerite, and galena. The gangue consists of both quartz and carbonates. The veins are found chiefly in the schistose rocks but always in close association with trachytes, andesites, and other volcanics.

The mines of the Mariquita district lie north of the Guali River and west of the town. The most important, the Bocaneme and Plata-Vieja, worked veins with an east-west strike and vertical dip at and near the contact of schist and andesite. There were a number of important mines about Santa Ana of which the best known was the Santa Ana. They were on the decline in 1785 when the Viceroy placed them under the management of the European metallurgist D. Juan José D'Elhúyar, and in 1795 after the expenditure of an amount nearly ten times the production during the decade they were shut down and abandoned. From 1824 to 1874 they were successively leased by several English companies until finally abandoned in that year with a record of only a few profitable years and a net loss of over $1,000,000. The Santa Ana vein was worked to a depth of 780 feet, at which the ore became very poor. It seems to have been characterized throughout its extent by the irregular occurrence of shoots and pockets of limited extent which doubtless accounts for its checkered career. The only mine of importance in the belt at present is the Frias at Guayabal which after having been abandoned in the seventeenth century was reopened in 1871 and has been worked continuously since that date by an English company. Its production in 1914 amounted to 16,000 tons of ore which after hand picking and concentrating averaged 435 oz. silver and 15¾ per cent lead. The ore is shipped to England for extraction of the metals. In the Frias mine are two veins, the Frias with a direction N 30–35° E and dip of 20° E, and the Welton with an east-west strike and dip of 35–40°. The latter is a quartz vein 3 to 4 feet wide, whereas the width of the Frias is more variable. Almost all the pay ore has come from an ore shoot at the intersection of the two veins.

To the west of the area just described lie the less known districts of Sucre and Soledad in which there are no important mines. The Soledad ores appear to be both argentiferous and auriferous, the Sucre ores auriferous only.

Líbano-Venadillo.—The only mine of importance in this area was the now abandoned La Plata del Líbano, located in a well-wooded country at an altitude of 3,500 feet, 10 miles south of Líbano, in a region of mica schist cut by dikes of diorite and basalt (73, p. 65). The vein, which has a strike of N 20° E and vertical dip, is of variable width, pinching in places and at others widening to over 5 feet. The ore consists of quartz, pyrite, galena, sphalerite, and a little chalcopyrite, and averaged under 1 oz. gold, 3 to 21 oz. silver, and 15 per cent lead (26, p. 170).

Rio De La China.—On both sides of the Rio de la China are numerous parallel veins in a country rock of schists with numerous and important intrusions of andesite. The oxidized ores carry principally gold, but in depth pyrite, sphalerite, and galena appear and the silver values equal the gold. Nichols and Farrington (58, p. 165) describe specimens showing finely granular galena with disseminated pyrargyrite. Several Colombian companies operate here but there is no large mine, the San Sebastian probably being the most important.

Ibagué.—The mines of this district are all at some distance from the town and fall into two groups—those at the junction of the Combeima and Cay rivers about 6 miles northwest of Ibagué and those of the Anaime and Vermellon rivers about 25 miles to the west or southwest. The country rock at both localities consists of mica, quartz, and talc schists cut by eruptive rocks which according to Ospina are andesite and dacite (63). The veins are chiefly in the schists and parallel to the schistosity, and range in width from a few inches to several feet. Quartz is the most abundant filling, but carries with it pyrite and sphalerite. The richer ores also contain chalcopyrite and tetrahedrite and the values are gold.

Miraflores-Payandé.—The geologic relations of these ore deposits differ widely from those of the districts previously described as the Cretaceous sediments here form the enclosing rocks; in Miraflores they are sandstones and shales and at Payandé, some distance to the northeast, overlying fossiliferous limestones. Pyrite and cupriferous pyrite which on oxidation give rise to free gold represent the mineralization with some indications of lead and zinc at Miraflores. But little development has been done in these districts.

Department of Huila.—Within this department is the old silver district of La Plata which was a famous silver producer in Colonial times, but is of no present importance. The deposits are stockworks in sedimentary strata with a small quantity of cupriferous minerals which are said to assay ½ to 15 oz. silver (63).

The Organos district has also been a producer in years past. According to Halse, (39, p. 234) the district is made up of crystalline schists intruded by granophyre, felsite, and hornblende dolerite. The veins cut both types of rock but are more prominent in the schists. Most of them have an east-west strike and southerly dip. The ores carry free gold with manganese and iron oxides near the surface and pyrite and galena in depth. The average width of the filling is about 2 feet, but the thickness varies greatly horizontally and vertically. In the sulphides, the gold is associated with the pyrite rather than the galena.

Department of Nariño.—In the southeastern part of the department of Nariño are the two adjoining districts of Mallama and Samaniego that constitute a single mineralized belt. They first began to be actively developed about ten years ago and have been described by F. P. Gamba in several papers (27, 28, 29, 30, 33). The ore bodies occur along and near the contact of a large area of granite on the west and schists cut by and overlain by younger eruptives on the east. The latter form the Gualcalá range on the western slopes of which the mines are situated. The whole region is covered with recent volcanic ejectamenta to such an extent as to interfere with prospecting.

Mallama.—The Mallama district includes the sub-districts Mallama and Gualcalá. In the former is included the Porvenir group of mines at an elevation of 11,000 feet, belonging to the

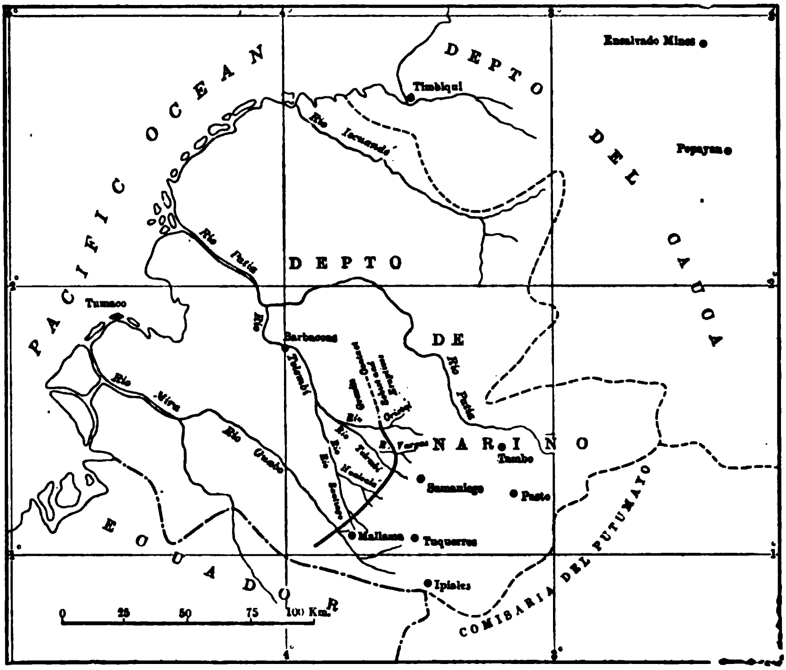

FIG. 42.—Map of Department of Nariño, Colombia.

Compañía Minera de Mallama, which are the most extensively developed. The ore body consists of a system of parallel veins and veinlets along the contact of granite and amphibole-augite andesite. The intervening country rock is impregnated with ore so as to constitute a lode or mineralized zone 100 m. wide, that has been prospected for 1,200 m. The ore minerals in order of abundance are arsenopyrite, pyrite, sphalerite, chalcopyrite, galena, and small amounts of tellurides, sulphides of silver, and native gold and silver. The average tenor of the vein material is $30 and of the mineralized rock $9. The ores are crushed and amalgamated in a stamp mill and the rich sands roasted and cyanided.

The Gualcalá mines are located west of the former in the granite area about 2,000 feet lower down the mountain slopes. They are the property of an American company, the Gualcalá Mines Company, and are equipped with a modern cyanide plant, the first in southern Colombia. The ore bodies are strong lodes of pyrite and chalcopyrite with quartz gangue and have an average width of 3 feet. They contain shoots of "black metal" which is a complex mixture of arsenopyrite, pyrite, galena, and sphalerite, rich in gold and silver and averaging as high as $30 per ton.

Samaniego.—The ores of this district are less sulphidic and more free-milling than those of the Mallama. The native mills, however, save only 40 per cent of the gold, recovering ½ to ¾ oz. and losing as high as 1 oz. in the tailings. The veins occur both in granite and schist. The Madroño mine which is located in the granite consists of a stockwork of quartz veinlets and where the granite is decomposed can be worked as an eluvial deposit. In the granite of the Rio Vargas are also auriferous aplitic dikes with ¼ to ½ oz. gold. The most important mine of the district, the Concordia, was producing in 1910 at the rate of $250,000 annually. The country rock is clay schist and slate in which there is a series of veins with north-south strike carrying free gold in quartz and a small amount of auriferous arsenopyrite and "black metal." Telluride minerals have not been recognized but the richer ores give the telluride reaction. The average tenor is 1.6 to 2.5 oz. gold and amalgamation recovers about 50 per cent. The Socorro mine, also in the schists, is working a *manto* by means of open-cut mining.

Tambo.—The Tambo district lies to the northeast of those just described. The ore body consists of a stockwork of quartz veinlets containing gold and auriferous pyrite in a dacite intrusion in slates and schists. The dacite is overlain by a completely altered rhyolite with coarse bipyramidal quartz crystals and is itself so strongly decomposed that the deposit can be worked as an eluvial.

Department of Norte De Santander.—To the west of the city of Pamplona are the three neighboring districts of Alta and Baja Montuosa and Vetas, constituting a single mineralized area.

Mines were worked here as early as the sixteenth century, but the industry was on the decline by the first quarter of the next, and since then the deposits have been worked only in a desultory manner at irregular intervals. In 1820 the completely abandoned mines were opened by the government and in 1824 leased to the Associacion Colombiana de Minas de Londres which opened up sixteen gold and silver mines but without success. The district was again abandoned in 1850 when the exportation of ore was prohibited because the local plant was not suited to the ores (13, p. 9). In 1886, the government made the veins denunciable again and they were taken over by Colombian companies.

The veins occur within an area of pre-Cretaceous schists and associated igneous rocks exposed in this part of the Cordillera Oriental and constitute the only important metalliferous deposits known in the range. Restrepo (75, p. 144) says of the country rock of the veins that it is essentially feldspar alternating with diorite except at the highest elevations where true granite bespattered with coarse granite is encountered. The veins are narrow, generally having a width of only a few centimeters. Most of the gangue consists of dark blue quartz though light-colored quartz also occurs. The ore minerals are pyrite, pyrrhotite, chalcopyrite, sphalerite, enargite, freibergite, malachite, azurite, and native gold and silver. The values were both gold and silver. The Pie de Gallo mine is said to have yielded in Colonial times a mass of gold weighing 64.4 kg., the largest recorded for the western hemisphere (75, p. 140).

THE GOLD PLACERS

As is naturally to be expected, the distribution of the gold placers is closely related to that of the gold lodes, but there are in addition areas of workable placers where no workable lodes have been discovered. The department of Antioquia and the intendencia of Chocó have been and are the great placer-gold producing regions of the country. Practically all the tributaries of the Magdalena and Cauca heading in the Cordillera Central carry placer gold, but by far the most productive have been the Nechi and Porce and to these largely does Antioquia owe its preëminence in Colombian gold mining. The most important of the gold-bearing tributaries of the two major rivers are shown on the map, Fig. 40. In

Tolima the Guali and Saldaña rivers appear to have been the most productive. The upper courses of the Magdalena and Cauca rivers in the departments of Valle, Cauca, and Huila were important producers in Colonial times and the deposits were among the earliest discovered, but present operations are restricted to native washings on a very small scale. Second only to the rivers of Antioquia is the river system of the Chocó, the San Juan and Atrato and their tributaries from the slopes of the Cordillera Occidental. South of the San Juan River are a number of large rivers emptying into the Pacific from the western slopes of the Andes most of which have attracted attention as producers of gold. The best known of these have been the Patia and its tributary the Telembi, the Mira, and the Iscuandé in Nariño and the Timbiqui in Cauca (Fig. 42). East of the Magdalena River, the only region that has been of importance is that of the Suratá and Girón rivers near Bucaramanga in Santander.

The types of gold placers represented in the various parts of Colombia are many and the methods of working them that have been and are now employed are still more numerous. Mention has already been made of the eluvial type representing the zone of oxidation of auriferous stockworks that has been worked in several of the lode districts. There are the gravels of the high plateaus about Santa Rosa, Rio Negro, Anorí, and Amalfi that cover large areas and were very extensively worked in the past, but what is left of them is for the most part too lean to work under existing conditions or they are located above available water supply. Other ancient gravels are represented by the river terraces found along some of the streams, particularly the Cauca River which has seven or eight terraces extending to a height of 300 feet above the present river level. These gravels seem for the most part to have been too lean to work. The great productive areas, however, have been the stream beds themselves and the adjacent flood plains, or *playas*, of the rivers. The principal gold-bearing rivers are the mecca of the natives, men, women, and children, at each period of low water in the dry seasons. Many of the smaller streams have been worked over so thoroughly as to no longer be profitable. The larger streams with shifting bars can often be worked over and over again as each rainy season brings down new material and causes a new concentration of the whole. Though much of the gold-bearing ground has been worked and in many places reworked many times, there are still great areas of untouched ground on the larger rivers that can be reached only by means of dredges and hydraulic elevators, methods of operation now successfully established in the country.

All kinds of statements have been published in regard to the tenor of Colombian placers, many of them so extravagant as to be clearly based on the results of a single pan or at most a small rich pocket and not representing the average run of a deposit. Perry (68, p. 586) describes operations on some of the high plateau gravels in the Vivorita mine that lie in depressions back of a ridge bordering the Porce River which are being worked by sluicing the gravels through a tunnel driven from the Porce Valley. Some of these gravel deposits were 160 feet deep and are said to run 30 to 50¢. per cu. yd. A great deal of panning of the *playas* and gravel bars is done along the Cauca from Caceres to the Nechi River, about $35,000 of such gold being brought to Caceres annually. The gold particles are small and average about twelve colors to the milligram. Ward (83) states that one such bar, worked at each period of low water, yields at first $3 and is abandoned when the returns drop to 30¢. per day. The washing is done with the *batea*, and it is estimated that a native will wash as high as fifty *bateas* a day, equivalent to about one-third cubic yard of gravel. Others estimate the returns from washing the shifting bars at 20¢. to $2. The fact that these are representative of selected rich spots must not be lost sight of. Garrison (34, p. 218) states that drilling along the Cauca below Valdivia showed over 40 feet of gravel in the river bed and benches of 60 to 75 feet above bedrock suitable for hydraulicking. Rich streaks in this ground carried $1 and peculiarly favored spots as eddies close to the water's edge $4 to $5.

Of more representative value are the results of recent explorations of dredging ground and of actual dredging operations. The first successful dredge was the Pochet dredge installed in 1910 on the Nechi River below Zaragoza. The first seven months of operations, working gravels to a depth of 27 feet, yielded 49¢. per cu. yd. at a cost of 17¢. The low water that followed made it possible to reach bedrock and increased the yield to $1.24 (44). The most extensive dredging operations are those of the Oroville Dredging Company on the Nechi River at Zaragoza, where they have developed two properties on opposite sides of the river called the Pato and the Nechi. The prospected area of the Pato property is 529 acres, the average depth of the gravels 26.3 feet, and the average tenor 31.6¢., making a total of 22,500,000 cu. yd. containing $7,000,000 gold. Dredging was commenced in October, 1913, and the cost during the first year was 17.71¢., but at the close had been reduced to 11¢. With a second dredge on this property and one on the Nechi, it was estimated that the cost would be reduced to 7½¢. On the Nechi property in 1914, 89 acres had been developed with an average depth of gravel of 47.6 feet and average value of 71.86¢ per cu. yd., a total of 7,000,000 cu. yd. containing $5,000,000 gold. The estimated operating costs were ½ to 1¢ higher than on the Pato property (72). The gold recovered by the dredges is in small particles, averaging about thirteen colors to the milligram, and only rarely as heavy as ½ mg.

Many of the methods used by the natives to win the gold-bearing gravels are extremely interesting on account of the ingenuity displayed in overcoming the difficulties of reaching the pay streak with their crude equipment. To attempt to adequately describe them would demand too much space, but reference to such descriptions can readily be obtained from the annotated bibliography at the end of the chapter. Most of the gold washing is done by women. One of the most remarkable native methods is that in which the miner weighs himself down with a heavy stone and walks into the stream to depths of 10 and 15 feet to gain access to the richer gravels, and after emerging possibly several times to regain his breath finally comes forth with his *batea* full of gravel which is then washed by a comrade while he rests preparatory to the next plunge. Hydraulic monitors were first introduced at the Malpaso mine near Mariquita in 1871 but were not used in Antioquia until 1884 (63). In 1882 attempts to install dredges on the Nechi and the Atrato failed, as well as a number of subsequent attempts, and it was not until 1910 that a successful dredge was established on the Nechi, and 1912 on the Certegui, a branch of the Atrato. In 1915, the Anglo-Colombian Development Co. controlled by the Consolidated Gold Fields of South Africa, launched its dredge on the Condoto River, a branch of the San Juan. After a number of failures extending over a long period of years, it has finally been definitely established that dredging can be carried on successfully in Colombia and the growth of such operations should result in an appreciable increase in the gold production.

THE PLATINUM PLACERS

The fame of the Chocó as a gold producer has been referred to. Restrepo says it was the first gold region discovered by the Spaniards and its placers were mentioned in 1513. The warlike tribes that inhabited the country hindered its development until the last half of the seventeenth century. From that period to 1886, Restrepo gives the production at $114,000,000, and the present annual production is in the neighborhood of one-half million dollars. The presence of platinum in the placers of the Chocó has been known for many years, but previous to 1778 no attention was paid to it. In that year platinum returns were required at the Royal Treasury but the metal was not paid for until 1788. Granger and Treville (37, p. 40) estimate the production to 1898 at 18,000 kg. With the increasing value of platinum in recent years has come a rapid increase of the Colombian production.

Annual Production of Platinum in Colombia

1910	10,000 oz.
1911	12,000
1912	12,000
1913	15,000
1914	17,500

Colombian crude platinum contains 80 to 85 per cent platinum, the remaining 15 to 20 per cent consisting chiefly of iridium and osmium. Nuggets are not common and those as heavy as 1 oz. are considered large. The largest found weighed a little over one pound (49).

The principal gold- and platinum-bearing rivers of the Chocó are shown on the map, Fig. 40. In the tributaries of the Atrato the platinum forms from 5 to 15 per cent of the metallic content of the placers, but in some of those of the San Juan it is more abundant and in the Condoto exceeds the gold in amount.

But little is known as to the source of the platinum of this region. The sands are described as brown in color and carrying besides platinum and gold the heavy minerals chromite, magnetite, and ilmenite. Castillo (16, p. 827) says the mother rock of the platinum is a typical gabbro in which pyroxene predominates over feldspar and that he found native platinum in dikes of jet black rock consisting of dense pyroxene containing crystals of pyrite and small quantities of nagyagite. Kimball (49) reports having seen a specimen of basic igneous rock probably a peridotite carrying native platinum in small flaky particles. According to Ospina (63) the platinum is found only as far up the tributaries of the San Juan and Atrato as the basal Tertiary conglomerates which are made up of fragments of basic rocks as diabase, melaphyre, and gabbro, derived from innumerable sills and bosses. In this connection mention might be made of a bed of conglomerate 6 to 12 feet thick described by White (86, p. 189) which was laid bare by the Spaniards over an area 2 miles long by ½ mile wide through ground sluicing of the overlying auriferous sands and gravels. Tests showed it to have an average content of ½ oz. gold and ½ oz. platinum. It is located in the heart of the platinum area, at Novita Vieja, between the rivers Tamaná and Cajon.

Until recently platinum mining was carried on solely by the natives who worked the platinum-bearing sands and gravels by the same methods in vogue among them for gold washing. Kimball (49) says the platinum, as well as the gold, is purchased by Armenian traders who travel through the country paying good prices for the metals but charging exorbitantly for the goods and supplies they furnish the natives. Several attempts of regular platinum buyers to secure supplies of the metal direct have failed, because the Armenians at once outbid them even to the extent of paying more than the metal is worth and still make their profits by increasing the prices of the goods they supply in return. With the advent of dredging operations on the Condoto in 1915, a new era in platinum mining was inaugurated which will undoubtedly result in changed industrial conditions and a considerably augmented production. The first dredge was that of the Anglo-Colombian Development Co. which has developed 27 million cubic yards of dredging ground and 8½ million of hydraulicking near Novita.[1] This company has consolidated with the Adolph Lewisohn interests under the name South American Gold and Platinum Co., Ltd.

[1] The Mineral Industry, 1914, p. 337, New York.

THE MUZO EMERALD DEPOSITS

The location and a brief historical sketch of the Muzo emerald deposits have been given in a previous section. The region about the deposits is covered with tropical jungle and characterized by excessive heat and humidity. The elevation is about 800 m. above sea level. Exploration is difficult and expensive and abandoned workings are rapidly obscured by luxuriant vegetation. The following data are taken largely from the very excellent description recently published by Joseph E. Pogue (70).

Geology.—The Muzo emerald deposits occur in the Villeta series which is probably of lower Cretaceous age and consists of

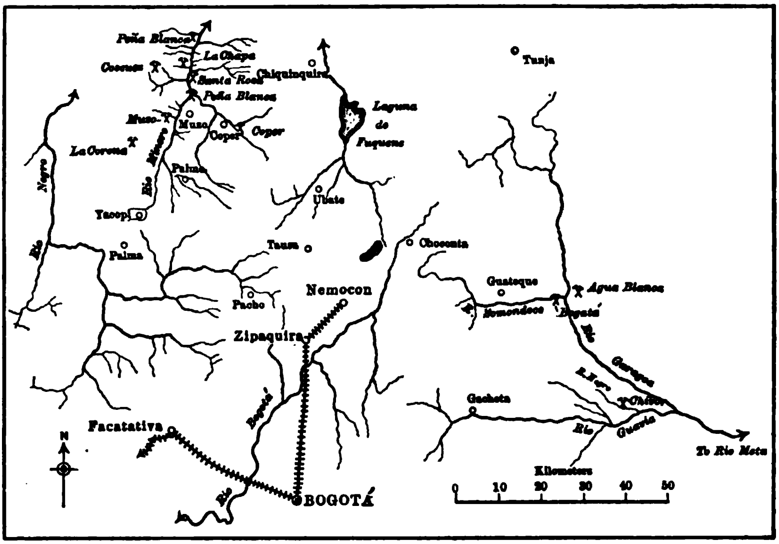

Fig. 43.—Sketch map showing locations of important emerald mines and prospects in Colombia. (*After Pogue.*)

black, carbonaceous shales and shaly limestones. The two major rock units involved are the *capas esmeraldiferas* and the *cambiado*. The *cambiado* consists of beds of black crystalline limestone, averaging in thickness about 25 cm., alternating with thin-bedded shale. The beds dip steeply, and generally about 60° to the south. They are traversed by calcite veins, some following fault planes, that are barren of emeralds but carry seams, nodules, and scattered crystals of pyrite but in less quantity than the emerald formation. Under the microscope the *cambiado* is seen to carry a few to many fragmental crystals of albite, in places it grades upward into the so-called albite rock and also contains some thin albite veins.

Discordantly overlying the *cambiado* are the *capas esmeraldiferas*. They consist of thin beds, averaging 2 cm. in thickness, of alternating shale and limestone, with the former predominating. The shale is a dense, black rock, soiling the hands with carbonaceous matter and usually contains more or less calcium carbonate. These beds are gently to intensely folded and even contorted. The folds are small, irregular, and non-persistent, indicating local rather than regional pressure. Fractures are prominent and healed for the most part by white calcite veins. The emerald is usually found in this calcite, and seldom in the shale or limestone. In many places the beds carry nodules or seams of pyrite in well crystallized condition, and in other places they are shot through with well-formed pyrite crystals.

The contact of these two formations is a sharp, clean-cut, overthrust plane marked by the presence of three other rock types—albite rock, *cenicero*, and *cama*. The gradation of the upper edges of the *cambiado* strata into albite rock has been mentioned. The microscope shows this rock to consist of clear laths 1 to 3 mm. in length and irregular crystals of albite in a groundmass of calcite dusted and stained with carbonaceous material. The albite is distinctly later than and replaces the calcite, in some places almost completely. The *cenicero* occurs as irregular lenses or beds up to a meter in thickness, connected below with the albite rock into which it grades locally. At a few places it forms vein-like bodies in the emerald formation. It is a crumbly, light-gray aggregate of crystals of calcite, dolomite, quartz, and pyrite in a fine-grained calcareous groundmass stained with carbonaceous matter. Toward the top the *cenicero* frequently carries abundant small shale fragments forming masses of breccia rarely over 2 m. in thickness. There are three phases of the *cenicero*, dolomitic, pyritic, and baritic, the normal sequence being upward in that order. The *cama* is composed of rhombs and rhombic twins of calcite, from 5 to 10 cm. in diameter, in a calcareous and quartzose cement.. It rests directly upon the *cambiado* but is not continuous and in places shows plainly a connection with calcite veins both in the emerald formation and in the *cambiado*. In addition to the rocks already described, a few pegmatites have been discovered recently.

The geologic relations just described are graphically illustrated in Fig. 44.

Mineralogy.—The emeralds are usually found in pockets or embedded in calcite veins traversing the emerald formation, and only rarely in that formation or in the *cenicero*. They occur as six-sided prisms with base, and also in rarer forms and few crystals are larger than the thumb. When first taken from the matrix, most crystals are clear, but later they develop cracks and some fall to pieces upon removal. Choice specimens show a rich green color, others display zones of color, and a few are dark to black owing to inclusions of carbonaceous matter. The most

Fig. 44.—Sketch showing the relations of the albite rock to the *Cambiado* and the *Cenicero* (normal and baritic). Exposure near foot of Banco Central. (*After Pogue.*)

common associated minerals are calcite, dolomite, parisite, pyrite, and quartz, more rarely barite, fluorite, and apatite. Parisite is a rare mineral of the composition $(CaF)(CeF)Ce(CO_3)_3$, first discovered here which occurs in the form of crystalline masses of double hexagonal pyramids usually less than 1 cm. in length, with or without the base, in immediate association with the emerald.

Genesis.—Pogue has summarized the evidence bearing on the origin of the emerald under four heads:

1. The association of such minerals as emerald, parisite, fluorite, apatite, and barite in a sedimentary formation implies the introduction of material from an external source.

2. The presence of pegmatites is significant, because the conditions of their formation are fairly well understood and their mineral content doubtless correlates their formation with the general period of mineralization.

3. The presence and position of the albite rock are taken to indicate the passage of strongly effective mineralizing solutions and the rock itself to be a product of pneumatolytic contact metamorphic action at a distance from the parent magma.

4. Mineralization followed the overthrust of the emerald formation upon the *cambiado*, and the emerald veins are the result of the same period of mineralization that produced the *cenicero*, the *cama*, the albite rock, and the barren calcite veins in the *cambiado*.

Based upon these premises, Pogue infers that the emerald was deposited under pneumatolytic conditions although the general temperature of mineralization was probably below 575°C. He further suggests that the solutions, entering along the shattered fault plane, effected a separation there, their liquid portion penetrating the rocks on either side, their gaseous portions rising and causing the formation of emeralds in the upper rocks only. The albitization along the contact doubtless freed sufficient calcium carbonate to account for the calcite filling of the veins.

Mining Methods.—The emerald mines consist of open cuts on the steep hill slopes in the form of a series of benches about ¾ m. high and ¾ m. wide. Workmen stand on one bench and attack the bench below with long iron crowbars, whereby the comparatively soft limestone and shale are readily broken away without resorting to blasting which would have a disastrous effect on the fragile emeralds. The emerald-bearing calcite veins are removed by hand and taken to a sorting shed. The accumulated débris is washed away from time to time with water stored in reservoirs for that purpose.

In the sorting shed, the calcite veins are broken by hand and the emerald crystals picked out. The finer material together with gem-bearing débris gathered from bedrock and the water channels below the banks is washed on sloping tables and the emerald fragments are picked out by boys. Loss by theft has to be carefully guarded against. A body of military police is assigned to the mines when in operation and watchmen are constantly overseeing the workmen who are Indians from the neighborhood.

The inferior stones are destroyed and those of gem value sorted into a number of grades according to color, transparency, size, freedom from fractures and inclusions, and various other considerations. The Muzo emerald is remarkable for its color and water. Other emeralds have a yellow nuance and glassy lustre, whereas the Muzo stone has blue nuance and lustre known as *gota de aceite*, or "drop of oil" (32, p. 345).

CONDITIONS GOVERNING AND AFFECTING THE MINING INDUSTRY

Transportation problems, problems that confront the mining industry in practically every South American country, have greatly influenced the development of the industry in Colombia. The Magdalena with its navigable tributaries, the Cauca, Nechi, and Porce, has afforded easy access to the edges of a large portion of the mineralized area of the country. The region bordering the Pacific coast has been made accessible in like manner by such rivers as the Atrato, San Juan, and the numerous large rivers to the south, of which the Patia is the most important. The upper navigable part of the Cauca is reached by the railroad from Buenaventura. These highways supplied by nature have been but little supplemented by modern means of transportation. The map, Fig. 40, shows the sum total of railroads in Colombia that serve to open up its mineralized areas; there are only 715 miles of railroads in the entire country. Consequently to penetrate beyond the navigable waters, it becomes necessary to resort to pack trains and to travel over trails which as a result of lack of attention and heavy rains are almost without exception, save in the more populous sections of Antioquia, characterized by those who have had to use them by adjectives ranging from execrable to impassable. Many of the most important mining centers can be reached only in this way. Transportation costs are, therefore, almost prohibitive and the transportation of large and heavy pieces of machinery practically impossible. Take, as an example, the cost of supplies in the Mallama district in Nariño. In addition to the ocean freight to Tumaco, the freight by boat to Barbacoas is 40¢ per *bulto* (100–130 lbs.) and thence by mule-back to Mallama $1.92 per *bulto*. Heavier pieces, in so far as they can be transported at all, pay a higher rate. The effect has been to cause the simplest mining methods and metallurgical processes, the needs of which can be supplied to a large extent locally, to be adopted and adhered to as long as possible and hence to hinder the development of the mining industry along modern lines and on a large scale. Colombia is still a country of many, but mostly small mining enterprises.

The country is sparsely settled and for that reason labor is not abundant, but the labor situation is not as acute as in some of the South American countries. The mining industry being so widely distributed over the country and there being no very large enterprises, the demand for labor has been equally widely distributed and the native population has for the most part been adequate to meet local needs. Wages range from about 35¢ to 75¢ or more, according to the character of work required and the locality. At the mines, board is usually included as part of the compensation and costs in the neighborhood of 25¢ to 30¢. In the low altitudes along the rivers, the laborers are negroes; in the mountains, consequently at most of the lode mines, they are Indians, except in Antioquia where there is a considerable proportion of white, mestizo, and mulatto laborers. Two events that were of considerable moment to the mining industry in their time were the decree of the King of Spain in 1729 relieving the Indians from compulsory work in the mines which had a disastrous effect on the operations of such districts as Mariquita and Pamplona, and the manumission of the negro slaves in 1851 which affected particularly the Chocó and the region about Barbacoas, districts that have never since reached the height of their former production.

The fuel situation which is such a serious problem in some of the countries further south has offered no particular obstacle to the mining industry in Colombia. The development has taken place along such lines that there has been no great demand for fuel. There are abundant streams for power purposes and coal exists at many localities where it has been needed and may be needed in the future.

The climate has been a great drawback to the development of placer mining, as that of the principal river valleys is typically tropical and generally very unhealthy. Tropical sanitation is so well understood now, however, that this is no longer an insurmountable obstacle, and foreign capital in increasing amounts will be attracted by the rich alluvial grounds so located as to have been inaccessible to the native miner with his primitive methods. In the lode mining districts the climate is with few exceptions favorable.

In 1825 the first stamp mills were introduced for the treatment of the lode ores. They were of the Cornish type with wooden stamps and have served as the pattern of the native stamp mill ever since. The number of stamps rarely exceeds 10, for, if the mine prospers and greater capacity is needed, the number rather than the size of the mills is increased. They are run by overshot water wheels and the stamps drop 10 to 15 times per minute, and will crush 1 to 3 tons of ore per day. The screens are coarse meshed and frequently nothing more than a plate in which holes have been punched. The gold is collected on the riffles of grooved boards and on blankets. Amalgamation is rarely used. If much pyrite is collected with the gold, it is further concentrated in the *batea*, and the pyrite may be ground still finer in an arrastre and then again washed in the *batea*. A native mill of this sort can be put up at a cost of about $300. If the ores are from the oxidized zone, the recovery is fairly good, but as soon as sulphides come in the recovery falls and many mills make a recovery of considerably less than 50 per cent. These conditions have undoubtedly frequently resulted in the abandonment of good mines. The first California mill with iron stamps was erected in 1867 and the first cyanide plant about 10 years ago. But even at the present time there are only 12 mines equipped with iron-stamp mills and only 3 of these employ copper amalgamation plates (63). The number of cyanide plants is constantly being added to. These improvments mean increased recoveries and consequently greater success in mining. The small native companies are for the most part unable to install modern plants through lack of capital and there would appear to be an excellent opportunity for foreign capital along these lines. Some of the ores carry the base metal sulphides in such quantity as to require smelting, for example, at Titiribí where the Zancudo ores have been successfully smelted for over half a century. The conditions there are unusually favorable, however, and it is doubtful whether successful smelting operations could be conducted elsewhere.

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CHAPTER VII

ECUADOR

RÉSUMÉ OF MINERAL PRODUCTION

The total mineral production of Ecuador has been less than that of any other South American country with the exception of Paraguay and possibly Uruguay. Gold is the only metal now being produced, and the annual output is between $500,000 and $600,000 about equally divided between lode gold and placer gold. Silver was mined at several localities in the past, but there has been no production for over two decades. Copper, lead, and zinc ores have never been produced. A small amount of platinum occurs in association with the placer gold in the northwestern part of the country but not in commercial quantities. Mercury was produced in past centuries, but nothing is known in regard to the production. Other rarer metals do not occur and no commercial deposits of iron and manganese ores are mentioned.

Though coal occurs at many localities, there are no coal mines in operation. Petroleum has been produced in small quantity for many years on the peninsula of Santa Elena, west of Guayaquil; and in 1913 the output was 10,000 to 20,000 barrels (17, p. 162).*

Small quantities of sulphur for local needs are produced at Santa Elena and Jipijapa. Salt is a government monopoly and is produced in quantity sufficient for domestic use with a small amouut for exportation to Colombia.

TOPOGRAPHIC AND GEOLOGIC FEATURES

There are three sharply-defined major topographic divisions—the Pacific coastal country, the Andean region, and the region to the east of the Andes in the upper Amazon basin. The coastal region is a relatively flat country of typical tropical aspect,

* Numbers in parentheses refer to articles in bibliography at close of chapter.

interrupted here and there by groups of hills and ranges of no great elevation representing in many instances spurs and outliers of the Andes. Such development as this portion has undergone

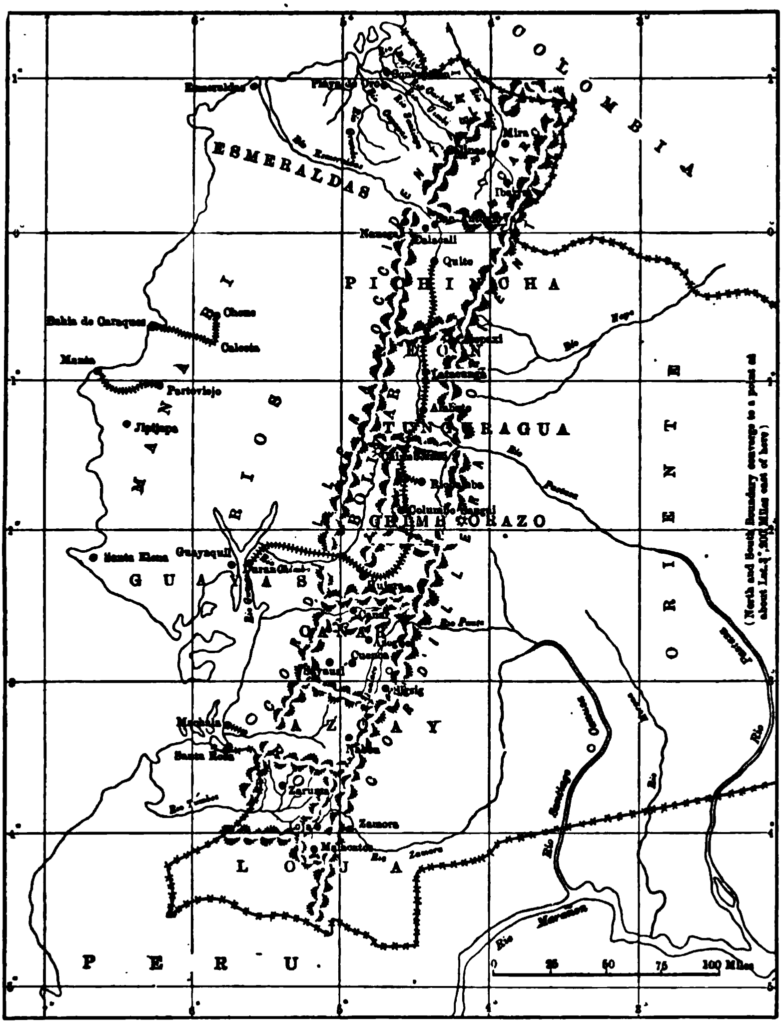

Fig. 45.—Map of Ecuador (western part) showing locations of mining districts.

is limited largely to a belt adjacent to the coast and along the principal rivers. The region east of the Andes gradually slopes off to the eastward from the flanks of the mountains to the low flat Amazon country and consequently grades from a region of more or less temperate climate to tropical. It is a vast region, little known and unexplored, and inhabited by a sparse and in part savage Indian population.

The Andean region comprises a belt about 50 miles in width extending across the country in a direction N 20° E, and consists of two ranges known as the Cordillera Oriental and the Cordillera Occidental, of which the former is the more pronounced and regular in its extent. The most highly developed portion of Ecuador and its principal towns, with the exception of the coast ports, lie within the area between these two ranges. This inter-Andean region is not a continuous valley, but a series of high plateaus and basins, called *hoyas*, drained by rivers that cut through one or other of the ranges, separated by transverse ridges called *nudos*, which form connecting links between the two main ranges. Some of the more important peaks reach elevations of 20,000 feet as for instance, the well known mountains of Chimborazo and Cotopaxi, the divides across the *nudos* may exceed 10,000 feet in elevation, and the principal inter-Andean towns lie at elevations of 7,000 to 10,000 feet. The region is consequently one of temperate to even cold climate. Rainfall is slightly greater than in the ranges to the south, which combined with equatorial location, gives the Andean portion of Ecuador a more genial aspect than the corresponding country to the south in Peru and Bolivia.

The broader geologic features of the western part of the country have been fairly well determined, principally through the excellent work of Teodoro Wolf (21). Nothing is known in regard to the mineral resources of the region of the Oriente and so little of its geologic features, that no attempt will be made to describe the easternmost part.

The Cordillera Oriental is made up of gneisses and crystalline schists with which are associated more or less granite and syenite, particularly in the extreme south in the province of Loja. In the southern part of the country these pre-Cambrian rocks are also found in the deep inter-Andean valleys and occasionally in the western range, but further north they are practically confined to the eastern range. The rivers flowing over these rocks carry more or less gold but no workable precious metal veins have been discovered in them, so it seems that they must contain the gold in disseminated form.

As in Colombia, the Paleozoic, Triassic, and Jurassic formations appear to be missing and the oldest known rocks above the crystalline complex are of Cretaceous age. The Cretaceous rocks make up the greater part of the Cordillera Occidental, some of the inter-Andean country, especially in the southern half, and parts of the coastal region, and in each of these areas it has a different development. The Cretaceous beds of the littoral region consist of marls, shales, sandstones, and greensands; those of the western range are prevailingly thick conglomerates with abundant igneous fragments, though sandstones and shales also occur; and the sediments of the inter-Andean region which reach their greatest development about Cuenca consist of sandstones and shales containing much bituminous matter. Associated with the Cretaceous sediments and extending the entire length of the Andean region are extensive areas of igneous rocks consisting chiefly of diorites and porphyrites, and it is in these that nearly all of the mineralization thus far known occurs.

Rocks of Tertiary age are represented by the marine coastal sediments and by the inter-Andean fresh water and lacustrine deposits. The marine beds are chiefly sandstone and shale. Though occasionally bituminous, they contain no workable lignite. The lacustrine deposits have their chief development in Loja where they consist of sandstones, conglomerates, shales, and limestones, and carry considerable lignite.

Quaternary and Recent marine sediments occur along the western edge of the littoral belt and contain some petroleum and sulphur. The alluvial deposits are locally of value on account of the placer gold they contain. Of very extensive development in the inter-Andean region and parts of the western and eastern ranges are fragmental volcanic materials and lavas. They range in age from post-Tertiary to the present. As far south as Chimborazo, the volcanic rocks form a continuous mantle over the inter-Andean region and extend over the crest of the western range, and as far south as Sangai they extend to the summit and even beyond in the eastern range. South of these points they are confined to the inter-Andean region and become more and more local in their distribution, until they finally disappear in the southern part of the province of Azuay.

DISTRIBUTION AND OCCURRENCE OF MINERAL DEPOSITS

GOLD

Lode Deposits.—The gold-lode deposits that have been worked lie in the southern part of the country, either in the crystalline complex or in the Cretaceous igneous rocks. The Spanish conquerors found the natives working gold mines and established several mining towns, of which the most important were Zaruma founded in 1549, in the southern part of El Oro; Zamora in Loja; and Sevilla del Oro and Logroña del Oro in Cañar. In 1599 an Indian uprising, resulting from the harsh treatment accorded the natives by their conquerors, put an end to the operations, and the Zaruma district appears to have been the only producer since. The entire lode gold production of Ecuador, amounting to about $300,000 annually, comes from this district which will be more fully described in a subsequent section. There are no data as to the nature of the occurrences in the other three districts mentioned. Gold quartz veins have been reported from time to time in many parts of Ecuador, some of them situated far down on the eastern slopes of the Andes, but they are either so low grade or so remotely situated as to be of no economic value.

Placer Deposits.—The most productive area of placer gold has been the Santiago river system in the extreme northwestern corner of the republic. These placers were discovered in the middle of the sixteenth century and have been worked more or less continuously since. In 1906 (20, p. 386), they were yielding from native washings $200,000 to $300,000 annually. The auriferous gravels are found along the streams and covering the interstream areas of the rivers Bogotá, Cachabi, Uimbi, Santiago, and Cayapas. The deposits are said to be suitable for both hydraulicking and dredging. Banks suitable for hydraulicking are described with a height of from 15 to 80 feet (15, p. 246). In 1892, an American company, the Playa de Oro Mining Co., began hydraulicking gravels yielding 10¢ to 12¢ per cubic yard, and in 1900 produced $35,000 in gold (13, p. 99). Other properties were examined in the early nineties and most glowing reports published as to quantity and tenor of the gravels. Large tracts were acquired by American and English capital, but results thus far achieved have not substantiated most of these claims. In 1905, a small dredge was erected at the head of navigation on the Santiago River to be moved into the Uimbi River for operation but there is no further information in regard to its history. These attempts at large scale operations seem to have ended in failure and the production now comes only from the native washings which are carried on under the same conditions as in the adjoining Colombian gold fields. More or less platinum occurs in association with the gold of this region, but not in quantity sufficient to make it of economic importance. The statement that there are large areas of gold-bearing gravel averaging 22 feet in thickness and yielding 50¢ per cubic yard (3, p. 411) would indicate, if trustworthy, that failure in the past has been due largely to the great difficulties inherent to dredging operations in low tropical countries. It should be remembered in this connection that dredging operations have only recently achieved success in Colombia.

The headwaters of most of the rivers having their source in the crystalline complex of the eastern range contain auriferous gravels, but operations have been confined largely to native washings. The most productive region has been in the province of Azuay where work has been carried on since prehistoric times. The best known deposits are those in the vicinity of Sigsig. An intimate spatial relation between the auriferous portions of the rivers and the area of outcrop of the crystalline rocks has been generally recognized. The further one gets from the crystallines, the finer the size of the gold particles and the less the quantity of gold, pointing unquestionably to those rocks and the quartz veins that occur abundantly in them as the source of the gold.

Almost all the streams traversing the area of Cretaceous diorites and porphyries carry a little gold, which seems to have been derived from auriferous veins in these rocks as the amount is directly proportional to the prominence of such veins. The river system of the Túmbez which drains the Zaruma region has always furnished a small amount of gold.

The numerous gold implements and ornaments found in many of the *huacas*, or ancient sepulchres, and the abundance of gold in possession of the Indians on the arrival of the Spaniards as compared with the present paucity of production has led to the belief that the rich auriferous gravels of Ecuador have been exhausted. T. Wolf (21, p. 639) is of the opinion, however, that the placers are as rich as ever and that the apparent greater productiveness of ancient times is due solely to the accumulation of the gold and to the abundant unremunerated labor supply utilized in those days.

SILVER

Silver ores have been mined at a number of places in southern Ecuador in the provinces of Cañar, Azuay, and Loja, but little is known either in regard to the operations or the nature of the occurrences. In many instances the remains of old plants and dumps are the sole evidences of the operations. The only attempt at silver mining in recent times was made in 1891 to 1894 in the Pillzhum district near Azogues in Cañar, at which time 77 tons of ore were exported to Freiberg in Saxony consisting of argentiferous tetrahedrite and pyrite that yielded 320 oz. silver and some gold.

The Cerro de Pillzhum situated a short distance to the northeast of Azogues is composed of porphyries with those of dioritic composition predominating. It is cut in both a north and south and an east and west direction by a series of veins 1 to 3 meters wide made up of silicified porphyry, quartz, and barite, that weather in relief against the decomposed outcrops of the igneous rock. In general the main mass of the vein consists of quartz accompanied by threads and stringers of barite, but in places the barite predominates. Accompanying these minerals are pyrite, tetrahedrite, and other compounds of silver and copper with arsenic and antimony. After having been idle for many years, the district was examined in 1891 by C. van Isschot who found 23 veins and 18 abandoned mines on the mountain. The most important vein was that of the Esperanza mine which has a north-south strike and can be plainly followed for more than 1,000 feet. The vein filling corresponds to the description already given except that it contains small patches of kaolin. Assays of the ore gave $5 to $6 gold, 16 to 240 oz. silver, and up to 7 per cent copper (21, pp. 627–629).

To the west of Cañar, abandoned mines and treatment residues containing considerable silver give evidence of early operations. The most important mine seems to have been the Zhuya on the Cerro de Zhuya, 15 miles west of Cañar. There are a number of caved openings on the same vein, and nearby are the ruins of a mill and smelter. The vein strikes N 80° W and has a width of

.8 to 1 meter. The ore consists of quartz with pyrite, galena, sphalerite, and tetrahedrite and probably carried 150 to 180 oz. silver (21, p. 629). In the vicinity are evidences of two similar mines, the Ger and the Malal. At Sayausí, west of Cuenca, is a hill of diorite cut by quartz veins carrying pyrite but no visible silver minerals, the ores of which assay about 40 oz. silver. They were worked during the first part of the eighteenth century. Argentiferous galena was worked in the vicinity of Malacatos in Loja, the principal mine being located on the northeast slope of a neighboring hill known as the Cerro de Santa Cruz. The material on the dump indicates a quartz-galena vein with a little pyrite, sphalerite, and fluorspar, and also a small amount of phosgenite. No silver minerals are recognized and the silver content is low, but doubtless the ore that was utilized ran high in silver (21, pp. 626–627). Isschot (13, p. 100) gives the silver content at 80 oz.

OTHER METALS

No real copper veins have been discovered. Some of the Pillzhum silver veins carry a high copper content; and near the road from Guayaquil to Cuenca, about 55 km. from the former, there is a wide vein of argentiferous and auriferous chalcopyrite mingled with galena (13, p. 100). The only known lead veins are those of argentiferous galena near Malacatos, and no zinc deposits of any kind are mentioned in the literature. Traces of mercury have been found at a number of places. Globules of metallic mercury have been noted in the alluvial deposits near Guayaquil and Pascuales, in the auriferous sands of Esmeraldas, and in parts of the eastern range in the valley of Cuenca and Azogues and in the Collay region. Cinnabar has been discovered near Riobamba (13, pp. 100–101). These occurrences are so insignificant, however, as to be scarcely of mineralogic interest. Of greater interest are extensive old galleries in the Cretaceous sandstones of the Cerro de Huaizhun, near San Marcos, in the vicinity of Azogues, which are supposed to represent old mercury workings, but there is not a trace of the ore left so that it is not known if it occurred as native mercury or cinnabar. Drops of mercury are occasionally found in the soil in the vicinity (21, p. 251).

FUELS

Coal.—Though there are no coal mines in operation in Ecuador, coal is known to occur at a great many localities. The seams are for the most part of Tertiary age and most of the coal is a low-grade lignite, high in ash and volatile matter. At a few localities the coals are said to be of good quality and even of anthracite character. Anthracite is reported from San Antonio de Pomasqui and near Riobamba. On the Columbo River near the Guayaquil and Quito railroad are coal deposits which it was expected would furnish coal for that railroad. The seams vary from 18 inches to 5 feet in thickness, but lie in a vertical position between clay and solid rock and are constantly being ground to pieces by heavy landslides so that they have proven unworkable. Coal beds 60 miles distant are not subject to these disturbances and a branch line may be built to reach them, the estimated cost of which is $3,000,000 (18, p. 404). Extensive coal deposits occur in Cañar between the towns of Cañar and Cuenca that will soon be tapped by a branch line being built from Huigra to Cuenca. Thick seams of lignite have also been discovered in Azuay and Loja, but they have not been adequately tested to determine their value and their inaccessible location will prove a drawback to their development for many years to come.

Oil.—Though oil has been reported from the eastern slopes of the Andes and oil springs in the coastal plain north of Guayaquil, particularly at Atacamas, and in spite of efforts to encourage further explorations in the province of El Oro by a law exempting petroleum and its derivatives from production and export taxes for twenty years, the only region of promise thus far discovered and developed is that of the peninsula of Santa Elena, about 64 miles west of Guayaquil. The principal surface indications, consisting of "gum" deposits and oil seepages, occur at San Raimondo, where shallow dug wells have been put down near the coast, and at Santa Paula and Achagian, 2 or 3 miles inland. About 40 dug wells at Santa Paula yield a small quantity of heavy oil and dug wells were formerly operated at Achagian. Mercer (17, p. 162) places the 1913 production at 10,000 to 20,000 barrels which is used chiefly as fuel in Guayaquil. The oil ranges from 12° to 22° Baumé, is low in asphaltum, gasoline, and kerosene, and high in fuel and lubricating stock. Arnold (6, p. 309) says the field is probably a northward continuation of the Peruvian area and that the oil comes from Eocene sandstones and shales. Though the field has not been thoroughly tested, he considers the surface indications too meagre to promise a large production. The oil thus far discovered is of shallow depth, and a 2,000-foot bore put down in 1912 gave negative results.

Asphalt.—Asphalt is said to occur, but no deposits promising enough for commercial exploitation are known.

NON-METALLIC MINERALS

Deposits of sulphur, salt, and gypsum are encountered in the Santa Elena oil fields. T. Wolf (21, p. 290) describes the occurrence there in the marine Quaternary of a 1- to 2-meter bed of crystallized sulphur, carrying as high as 64 to 70 per cent sulphur mingled with fine sand which is overlain by ½ to 1 meter of saliferous beds. The sulphur he thinks has been formed through the reduction of sulphates by decomposing organic material. The Mineral Industry for 1908 states that at Santa Elena and Jipijapa sulphur is obtained from hot springs. In the Andean region volcanic sulphur also occurs.

The greater part of the Ecuadorean salt output comes from the Santa Elena region where it is produced by solar evaporation. Saline springs yield salt in the province of Carchi at Mira and Salinas. At Mira the evaporation of saline ground water resulting from saline springs issuing from the underlying trachyte impregnates the sandy soil with salt to a depth of several inches. This sand is collected and the salt washed from it. At Salinas the saline spring waters are evaporated directly for the salt. That obtained from these two localities contains iodine.

Wolf (21, p. 634) mentions the occurrence of potassium nitrate in the plains about Latacunga but gives no details in regard to it.

THE ZARUMA DISTRICT

The early history of the Zaruma district and a description of many of the older mines has been incorporated by Wolf in the appendix of his "Geografía y Geología del Ecuador."[1] The Spaniards found the Indians washing gold from the outcrops of the large quartz veins here in 1549 and forthwith commenced operations of their own. The old workings extend over an area

[1] (21, pp. 600–626). This is chiefly a reprint from LaNacion, Guayaquil, January, 1891, of an article by F. G. Saenz de Tejada on "El distrito aurífero de Zaruma," in which he gives a detailed account of the history of the district and a full description of the mines.

at least 15 miles long in a north-south direction and 5 miles wide. The mines were actively worked until the outbreak of the War of Independence, after which a long period of idleness ensued. In 1878 mining men from Peru and Chile entered the district, and in 1880 the Great Zaruma Gold Mining Company was organized in London. This company exhausted its resources in an attempt to build a road from the coast to the mines and finally had to abandon its expensive machinery at tidewater. Between 1883 and 1887 additional capital was raised to start operations and some shipments were made, but in 1887 the company liquidated and the Zaruma Gold Mining Company was organized. The latter finally abandoned the district entirely in 1895. In the meantime, in 1889, French capital had made an unsuccessful effort to enter the district. In 1897 an American company, the South American Development Company, took over the properties of the English company and has worked them continuously since.

The district lies in the headwaters of the Túmbez River, at an elevation of 2,000 to 5,000 feet, in the inter-Andean valley east of the Cordillera of Dumari in the province of El Oro. It is distant 150 km. from Guayaquil and is reached by steamer to Santa Rosa and thence 70 km. by muleback. Geologically it is located within the area of Cretaceous diorites and porphyrites which have been thrust through and spread out over the underlying older schist and granites, exposures of which are found a a short distance to the south. The volcanic rocks consist of rhyolite, dacite, andesite porphyry, and diorite. The rock in the immediate vicinity of the veins is described by Finlay as a fine-grained, holocrystalline diorite, whereas Baragwanath and Mercer call it andesite. The rock weathers very rapidly and where it has not been eroded is decomposed to great depth into yellow to deep-red clay. Near the veins the feldspars have been partially replaced by pyrite and sometimes quartz and in places the whole rock has been silicified.

The region is cut by several large faults with north-south strike and numerous cross-faults. The most prominent of these can be traced for several miles and is marked by a series of ancient mine workings. Its strike is about north-south and its dip 70° E. Ore bodies carrying quartz and calcite gangue are encountered at intervals along it, and coming into it but not crossing it are large quartz and calcite veins with a northeast strike and dip of 70° or steeper to the east. Large ore bodies are found at the junctions. The cross-faults cause offsets of slight displacement in the veins. The vein filling is principally quartz with more or less mineralized country rock included in it, but in places, particularly in the vicinity of the main fault, much calcite occurs, and occasionally also rhodonite. The ore minerals consist of pyrite, chalcopyrite, sphalerite, and galena, often present in great abundance, together with bornite, tetrahedrite, malachite, and azurite. The valuable constituent of the ore is gold which occurs disseminated through the quartz and calcite and also locked up, probably mechanically, in the sulphides. It is so finely divided that $10 ore will often not yield a color and much higher grade ore only a few small particles. No silver minerals are recognized but the bullion contains about 30 per cent silver. The width of the veins ranges from a few

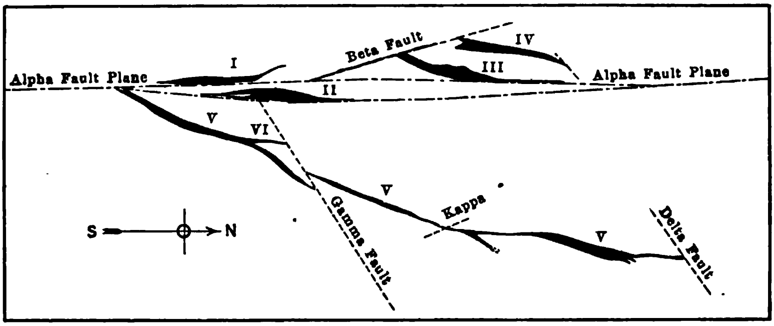

FIG. 46.—Sketch plan of veins in part of tunnel level, Zaruma mines, Ecuador.

inches to a number of feet and often exceeds 20 feet. The richest values occur in distinct shoots with a northerly pitch, the limits of which must be determined by assay. The average grade of the unsorted ore is $15 to $30 per ton.

The South American Development Company is working two connected mines, the Portovelo and the Mina Grande. Finlay and Baragwanath have each described the vein system of these mines, but the descriptions do not seem to be in complete accord. Both say that the ore bodies occur in the major fault and in veins on each side of it, and each gives a sketch illustrating his interpretation of their relations. Baragwanath's sketch is reproduced in Fig. 46 for the reason that it is the more recent one.

The mines are worked by adit and shaft and have been opened to more than 700 feet below the outcrop. The ore is treated in a 40-stamp mill run by water power, and after amalgamation it is reground in tube mills and cyanided. The company employs about 400 native workmen of mixed Spanish and Indian blood, supplies free food, and pays 50¢ per day for laborers and $1.00 or more for miners.

CONDITIONS AFFECTING AND GOVERNING THE MINING INDUSTRY

In the light of our present knowledge of the ore deposits of Ecuador, the unimportance of its mining industry must be ascribed primarily to the paucity of discovered mineralization. This is due in part to the fact that it does not seem to have been as highly favored in this respect as its neighbors on the south and on the north, and in part to the great mantle of fragmental volcanic material that covers so much of the northern portion of the Andean region and some of the southern half. But even in the southern half where this obstacle is not serious, mineralization seems to have been relatively weak, and this appears to be the real cause of the present status of the Ecuadorean mining industry.

As regards some of the other factors that influence the development of the mining industry, the situation is more favorable with respect to some and less favorable with respect to others in comparison with other South American countries. The political unrest that has been so prominent in the history of this country has seriously hampered its economic development and thus contributed directly to the undeveloped state of most of its natural resources. Natural obstacles to transportation are on the whole not so great as in other West Coast countries. Railroad construction has lagged, however, and there is only the one important line from Guayaquil to Quito, nearly 300 miles in length. The southern portion of the Andean region which has the more favorable showing of mineralization is entirely without modern transportation facilities. Fuel appears to be abundant enough that with more highly developed transportation facilities, the fuel problem should offer no serious difficulties. Though the population of the country is not great, it is ample to meet all reasonable demands for labor. In short, conditions in Ecuador are such as to make possible the development of a mining industry if the necessary ore deposits are discovered.

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CHAPTER VIII

GUIANA

The three Guianas—British, Dutch, and French, frequently designated as Demerara, Surinam, and Cayenne—are the only European possessions on the South American Continent. The whole region between the Orinoco and Amazon rivers was once called Guiana and those portions now belonging to Venezuela and Brazil are still known as Venezuelan Guiana (Guayana) and Brazilian Guiana (Guayana).

In general characteristics, the three countries are similar although their history and development are decidedly unlike. All of them are very thinly settled, with almost the entire population confined to the narrow low-lying coastal belt that is seldom more than 40 miles in width. Back of that are great unexplored portions occupied by scattered tribes of Indians and seldom visited by white men, except along the large streams where the gold seeker has recently pushed his way in search of hidden wealth.

TOPOGRAPHY AND GEOLOGY

The countries are divided into three belts known as the Coastal Plain, the Sand and Clay Belt, and the Mountain Region.

Coastal Plain.—The low-lying land bordering the ocean constitutes the Coastal Plain. In places it is low and swampy and portions of it must be protected by dikes to prevent inundation. It is the great agricultural section and particularly adapted to the growth of sugar cane. Some sand dunes are present in this area.

The strata consist of sands and clays with some layers of vegetable débris. These have been bored to a depth of 200 feet and are perhaps considerably thicker. The lower portions may be late Tertiary in age, although most of the beds were undoubtedly deposited during the Pleistocene or Recent periods.

No mineral deposits of any consequence are known to occur in the Coastal Plain. At times a little inflammable gas has been obtained from borings, and asphalt washed ashore has given rise to the belief in the existence of asphalt deposits beneath the ocean waters a short distance from the shore.

Sand and Clay Belt.—Back of the Coastal Plain is a region known as the "sand and clay belt," as sands, gravels, and clays are almost all the traveler sees in going through the region, except in the stream beds during periods of low water. Where there are rapids or waterfalls, one discovers that the original rocks of the region consist of various kinds of igneous and metamorphic rocks of which the sands and clays are decomposition products. Decomposition and disintegration has gone so far as to leave practically no fresh rocks exposed except where rapid streams have caused active erosion. The region has a thick cover of forest in almost all portions which tends to hold the products of decomposition.

The section is one of undulating hills cut by many streams that are navigable throughout the greater portions of their courses although interrupted here and there by rapids or even large waterfalls. There are sand-dune ridges in places and some low mountain ranges composed of more resistant rocks. In British Guiana the belt runs across the country from northwest to southeast with a maximum width of about 100 miles.

The original rocks of this belt are exceedingly varied, and their structures are so intricate that they have not been determined except in small areas. Harrison[1] (18) has made a careful study of these rocks as exposed along the major streams in British Guiana and describes the following types: gneisses (aplite, granitite, hornblende-granitite, epidote-granite, diorite, etc.), schists (muscovite, epidiorite, amphibolite, hornblende, actinolite, talc, sericite, chlorite, quartz, etc.), granites (muscovite, aplite, hornblende, augite, etc.), felsites, tuffs, quartz-porphyry, pegmatite, syenite, diorite, diabase, gabbro, norite, etc.

Much laterite and concretionary iron ore occurs at the surface in many sections, and kaolin of excellent quality occurs where pegmatites have undergone decomposition. Some of this has been utilized.

The Sand and Clay belt contains practically all the gold and diamond districts of the country.

Mountain Region.—Overlying the basement complex of crystalline rocks and largely concealing them from view, in the

[1] Numbers in brackets refer to articles in bibliography at close of chapter.

southern portions of the three countries is a great thickness of nearly horizontal sandstones, conglomerates, and shales, mainly pink to red in color. In Venezuela these have been called the Roraima Series and in British Guiana the Kaieteurian Series. The maximum thickness is believed to be about 2,000 feet.

These strata constitute the highest mountains of the countries. Mt. Roraima, about 8,600 feet in height, forms the boundary between Brazil, Venezuela, and British Guiana. The mountains are in the main flat-topped with precipitous cliffs formed of the harder sandstone layers. The streams of the mountainous region have cut to grade in many places and are sluggish and bordered by swamps.

The absence of fossils renders the determination of the age of these beds somewhat problematical. Some writers have considered them of pre-Cambrian age, but this is undoubtedly incorrect. They are surely Mesozoic, but whether Triassic, as they are thought to be by some Brazilian geologists, or Cretaceous, as given by Harrison (18), cannot be determined. These sandstone and conglomerate strata are intruded by dikes, sills, and laccoliths of diabase usually of coarse grain. Some gold has been found in these beds, although they are not thought to be the source of much of the gold of the country.

BRITISH GUIANA

Of the three Guianas, British Guiana is of the greatest importance in almost all particulars. It has an area calculated at 90,277 square miles, larger than the combined area of French and Dutch Guiana, and a population also far in excess of the combined population of the other two countries. Although large portions are still undeveloped, there are few unexplored regions such as exist in French and Dutch Guiana. Gold, diamonds, and bauxite are the only mineral products of importance known to occur in British Guiana.

GOLD

The gold deposits of the country have been described in detail by J. B. Harrison in "The Geology of the Goldfields of British Guiana" published in 1908, from which the following descriptions are largely taken.

During the 18th century several expeditions were sent into the country to search for gold but none was successful in locat-

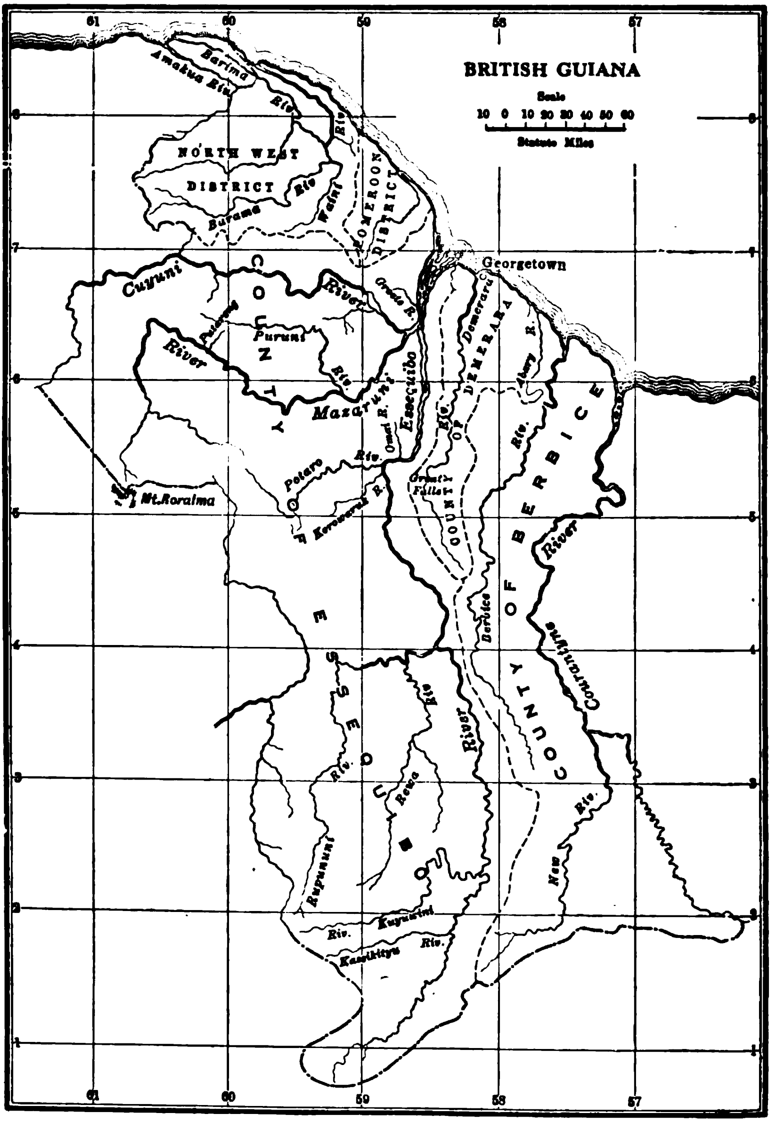

Fig. 47.

ing the precious metal in paying quantities. Gold was being worked in Venezuela, Dutch Guiana, and French Guiana long before any systematic work was begun in British Guiana. In 1863 the first operations of consequence were started at Wariri on the Cuyuni River, but no records of output are available until 1884, during which year 250 ounces were exported. Ever since, there has been a considerable production, the maximum being reached in 1893–94, during which year 138,528 ounces of gold were produced.

The gold deposits of the country are distributed over a wide area in the northern half of the County of Essequibo, and a few small areas in the counties of Demerara and Berbice. In most of the districts both placers and lodes have been found, although up to the present the great part of the production has come from the rich gravels and only a few lode properties are developed.

DISTRIBUTION AND CHARACTERISTICS OF THE GOLD LODES

Northwest District.—Many gold-bearing quartz veins have been found in the Northwest District, particularly in the vicinity of Arakaka where the Barima mine is located. The rocks containing the quartz veins are mainly acidic schists or granite gneisses. Epidiorite and hornblende schists contain some disseminated gold. The rocks are decomposed to a considerable depth. Harrison states that the workable portions of the quartz veins are confined to the decomposed portions of the rocks, thus indicating secondary enrichment. Secondary quartz, which is frequently observed, is also richer than the primary quartz veins.

Cuyuni River District.—Quartz veins are not numerous in the Cuyuni River district but most of them carry gold in small quantities. A quartz mine has been worked on the Arimu River, a tributary of the Cuyuni. Large masses of pegmatitic quartz in gneiss, observed between Paiyuki Cataracts and Popekai Rapids, contain practically no gold.

Mazaruni-Puruni District.—Many auriferous quartz veins have been reported from various places along the Mazaruni and Puruni rivers but few have been developed. At Peter's Mine on the Puruni River some extensive quartz veins have been worked. The country rock is a chloritized hornblende schist.

Essequibo, Potaro, and Demarara Districts.—Auriferous quartz veins are not common along the Essequibo, Potaro, and

Demarara rivers although large masses of barren pegmatitic quartz are common. At Kanaimapu, Appaparu, and Darina, near the Great Falls of the Demarara River some fairly rich quartz veins have been worked. They contain most gold in those portions included in the laterite derived from basic rocks. Dikes of diabase are common in these areas.

Along the Omai River, a tributary of the Essequibo, large masses of auriferous aplite have been found, and in the Potaro gold district mineralized masses of basic rocks occur. The gold is believed to have been derived from neighboring dikes of diabase. They are of little economic importance.

DISTRIBUTION AND CHARACTERISTICS OF THE PLACER DEPOSITS

Northwest District.—Numerous areas of auriferous gravels have been worked in the Northwest District, although the low gradient of most of the streams somewhat interferes with their working. They are found along the Barima and Barama rivers and their tributaries. In most places the gold-bearing gravels are overlain by 2½ to 8 feet of blue to yellow clay, and the gravels vary in thickness from 1 to 7 feet. The gravels consist of quartz, concretionary ironstone, and small to large pieces of basic metamorphic rocks. In the upper portion of the Barima River district, coarse gold is common, one nugget having been found weighing 333 ounces.

Groete Creek and Cuyuni River Placers.—The Groete Creek placers are about 2 feet in thickness and overlain by several feet of red to yellow clay. The gold is very fine and the gold content rather low.

The Cuyuni River placers are located on the Oko, Arawak-Matope, Arimu, Mariwa, Quartz Stone, Waimu, St. John's, and Kopang creeks. The characteristics of these different deposits are similar, in that they commonly have from 1 to 3 feet of auriferous gravels overlain by 2 to 10 feet of clay.

Mazaruni and Puruni Placers.—The Puruni placers are important because of their location, directly bordering or only a few miles from the main stream. The principal placers of the Mazaruni are those on Isenaro Creek where an average yield of $3.10 per cubic yard has been obtained. The laterite of the adjoining hills also contains gold.

Essequibo, Potaro, and Konawaruk Placers.—The most important placers of these streams are those of the Omai and Konawaruk rivers, particularly the former which is a tributary of the Essequibo River. The laterite and concretionary ironstone gravels of the hillsides also contain considerable gold. The Konawaruk River gravels, covered with only about 2 feet of yellow clay, consist of angular quartz pebbles containing about $1.56 of coarse gold per cubic yard.

ORIGIN OF THE PLACER GOLD OF BRITISH GUIANA

The evidence thus far collected seems to indicate that most of the gold of the British Guiana placers, and this also applies to similar deposits in Dutch Guiana and French Guiana, has not been transported far from its source. Harrison states that there is a general consensus of opinion that "the gold has been derived either (1) from mineralized masses of acidic rocks, (2) from that disseminated through the mass of metamorphosed basic rocks, now amphibolites, epidiorites, and hornblende schists, and in part contained in thin veins or threads of quartz, which in places are more or less abundant in them, or (3) from the minute amounts of the metal which are disseminated through unaltered gabbro and diabase." He believes that the larger portion of the placer gold has come from the mineralized masses of the country rock rather than from the quartz veins. If this is the case, gold quartz mining may never develop into an important industry.

Most geologists who have examined the gold regions of the Guianas have come to the conclusion that the gold has been derived from intrusions of basic rocks—diorite, gabbro, and diabase. Careful analyses of these rocks and their metamorphosed products have almost invariably shown appreciable amounts of gold.

The laterite which is so extensively developed in the Guianas and which represents the product of decomposition of the basic rocks is also auriferous in many places. Where the iron oxide from the iron-bearing minerals has formed pisolite or ironstone conglomerate, the gold content of these masses is much greater than in the original rocks, indicating a concentration of the gold as well as the iron. It is also probable that the gold-bearing laterites have been enriched by solution and subsequent precipitation of the gold.

That gold does enter into solution under the conditions prevailing in British Guiana was proved by Harrison who found gold in the ash obtained from the trunk of an "ironwood" tree which had grown on the laterite covering a mass of auriferous aplite at Omai.

FUTURE OF THE GOLD INDUSTRY OF BRITISH GUIANA

The gold industry of British Guiana has had its periods of expansion and of depression. The statistics for 1916 show a production of only 37,129 ounces, of which 24,057 ounces were derived from placer washings, 11,967 ounces from dredges, and 1,105 ounces from quartz lodes. This is but little more than one-fourth the yield during the most productive year. Although some of the richest placers have been exhausted, it seems probable that, in the large areas—aggregating more than 1,000 square miles—where auriferous gravels are known to occur, other equally rich deposits may be found.

Lode mining does not seem to offer especially attractive opportunities and will probably continue to occupy a subordinate position.

DIAMONDS

Diamonds were first reported to have been found in the Puruni River district of British Guiana in 1888. Search was made for them in the succeeding years with some success, but not until 1900 was systematic work undertaken. Until recently most of them have been found in the gold placer deposits and incidental to the quest of gold, but an independent diamond mining industry is now being developed. During 1916 the output amounted to 93,782 stones weighing 16,408 carats, an amount greatly in excess of that of any preceding year, and indications point to even greater production in the future.

The circulation of the discovery of diamonds along the Puruni River caused the gold placer miners in other areas to look for them with the result that they were shortly reported from many other sections. In addition to the Puruni River district, diamonds have been found in the Upper Mazaruni River district at Putareng Creek, in the Jimbo Creek region of the Barima River, in the Ianna district of the Barama River, along the Cuyuni River, at Omai on the Essequibo River, at several places along the Potaro and Konawaruk rivers, near the Kuribrong River, and along the Akaiwanna path between the Essequibo and Demerara rivers. It is probable that they will be found in many other places.

The Putareng Creek district has been studied particularly by Harrison who states that the diamonds are found in a belt about 3 miles in width that extends for a distance of about 20 miles parallel to the Mazaruni River and about 5 miles distant. The diamond-bearing gravels lie on the tops and slopes of low hills about 70 feet above the river and in a few places in the valley. The surface layers, about 18 inches in depth, consist of white quartz sand or sand stained by iron oxide. Beneath these are from 8 to 15 feet of yellow sandy clay containing small irregular fragments of quartz and iron conglomerate. The material is coarser toward the base where most of the diamonds are found. The gravels rest upon laterite. Associated with the diamonds are some nodules of concretionary limonite, ilmenite, tourmaline, corundum, spinel, topaz, and zircon. Both as to occurrence and immediate source, the diamonds of British Guiana resemble those of Brazil. The source of the diamonds is believed to have been the Mesozoic sandstones and conglomerates which originally covered the area where the diamonds are now found, but which at present have been largely removed by erosion. In all probability the diamonds were secondary in these sandstones but no evidence of their primary origin is available. At Omai the diamonds are found in a bluish-gray clay probably formed from the decomposition of gabbro or diabase *in situ*, possibly the original country rock of the gems.

The diamonds of British Guiana are mainly small, averaging from 10 to 15 to the carat, but several weighing more than 12 carats have been found. The stones are of good quality. At Dukwarri above Devil's Hole on the Cuyuni River considerable bort and some pieces of carbonado have been found.

The diamonds are obtained by throwing the dirt into a sloping trough of running water where it is stirred and the mud separated from the gravels. These are then sorted by a series of screens. The fine gravel which passes through a screen with one-eighteenth of an inch mesh is thrown on an iron plate where it is carefully examined for the gems which are readily distinguished.

BAUXITE

Promising deposits of bauxite are reported from the Demarara River district but as yet are only partially developed. The principal deposits seem to be those in the vicinity of Wismar, Christinburg, and Three Friends, near the head of navigation on the Demarara River, from 65 to 80 miles above Georgetown. Many claims have been located and the prospects for an important bauxite industry are favorable.

IRON ORE

Although no attempt has been made to develop the iron ores of British Guiana, extensive deposits of surficial pisolitic limonite are present in many places where basic igneous rocks have undergone decomposition. The concretions are either loose or cemented together to form ironstone layers. The ore is similar to that of the north coast of the eastern part of Cuba which is now being extensively worked.

DUTCH GUIANA

Dutch Guiana (Surinam) has an area of about 45,700 square miles. It is 300 miles long in a north-south direction by 260 miles broad. The geology has been imperfectly worked out, but in general it is much the same as that of British Guiana.

GOLD

Although gold had been found much earlier, it was not until 1876 that it was discovered in paying quantities.

Percival (36) states that there are three gold zones known.

The first zone, lying only about 50 miles from the coast, is located in the northwestern portion of the country. It embraces the heads of the streams that flow into the Saramacca River and the Atlantic Ocean, or the regions lying on both sides of the Nassau Mountains.

The second belt lies inland about 100 miles and extends across the entire country from northwest to southeast. The Mindrenette and Sara Creek districts are the most important of these. The Government has constructed a railroad 175 km. in length, from Paramaribo into this district.

The third zone is about 160 to 180 miles from the coast and is less well known.

The important gold workings are almost entirely placers, most of which have been worked in a small way although a few dredges have recently been installed. The gravels vary in thickness up to 20 feet, and some of them are very rich, particularly those of the Lawa River, which were extensively worked

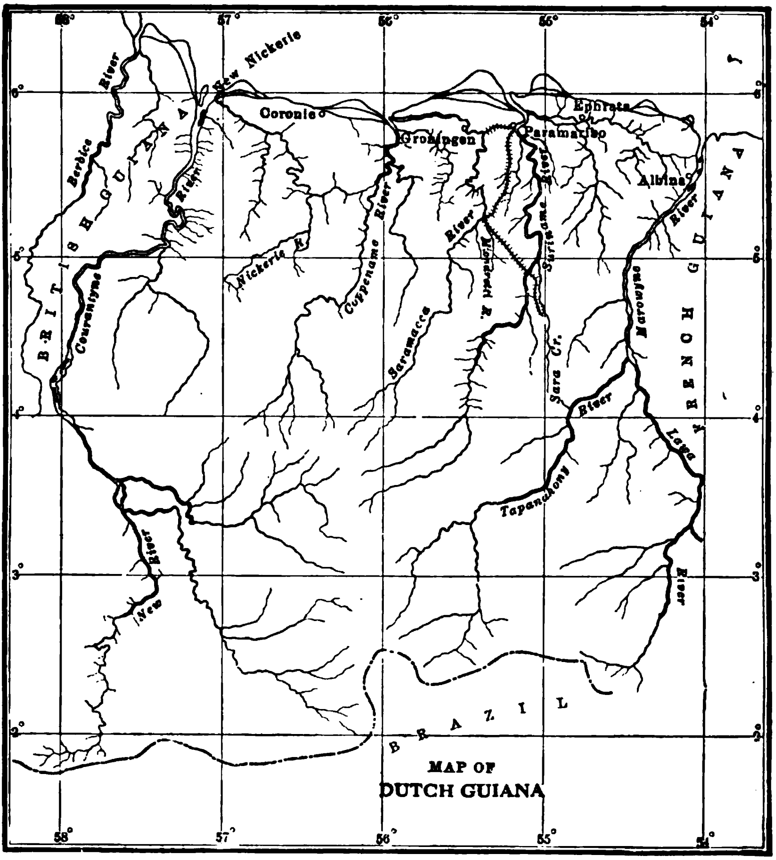

Fig. 48.

about 30 years ago. Average values are not obtainable and would not be of any assistance to prospective miners on account of the wide variations. The gold is usually coarse. One nugget found in 1899 in Mindrenette Creek weighed 509 ounces and contained 274 ounces of gold and 4 ounces of silver. Many of the gold particles are covered with a coating of iron oxide.

Although the gold placers have been worked for many years, the average annual production until within the last few years has not been great. From 1879 to 1900 the total gold production was only 536,220 ounces. In 1912 the country produced 16,273 ounces, in 1913, 27,546 ounces, and in 1914, 40,046 ounces, almost all of which was obtained from placer workings. Many deposits have been exhausted, but thousands of acres of equally promising ground still remain undeveloped. Practically all stream-gravel deposits in the great belt of decomposed igneous and metamorphic rocks are worthy of investigation.

From time to time quartz lodes have been worked but in most cases with indifferent success. The great depth to which rock decomposition has proceeded and the dense tropical vegetation covering the greater portion of the country have rendered the location of the veins difficult. Comparatively little prospecting for gold lodes has been done. As in British Guiana, the gold is found in quartz veins closely associated with igneous dikes that cut the ancient metamorphic rocks.

One of the most recent lodes discovered (38) is located on the Saramacca River and easily accessible from Paramaribo. Samples containing as high as 34 ounces of gold to the ton have been obtained. The work already done by the Janapau Gold Mining Syndicate has shown 20,000 tons of milling ore. There is an abundance of water and wood in the region for use in the development of the mine.

BAUXITE

Extensive deposits of high-grade bauxite have been investigated recently. Some of the best known are at Oncribo, Para Creek, Surinam River; at Rena Ren Creek, Surinam River; on the Cotteca River; and on the Marechals Branch of the Surinam River.

MERCURY

Cinnabar has been found in the Maroni District, but as yet the lode, which has been traced 15 km., has only been worked in a small way. A test pit 30 feet in depth is said to have exposed a thickness of 20 feet of rich ore (25).

PETROLEUM AND NATURAL GAS

Traces of petroleum and natural gas have been observed in borings near the coast but the probability is that neither exist in economic quantities.

FRENCH GUIANA

French Guiana (Cayenne) is the smallest of the Guianas, having an area of about 30,000 square miles. Owing to the fact that it has been used by the mother country as a penal settle-

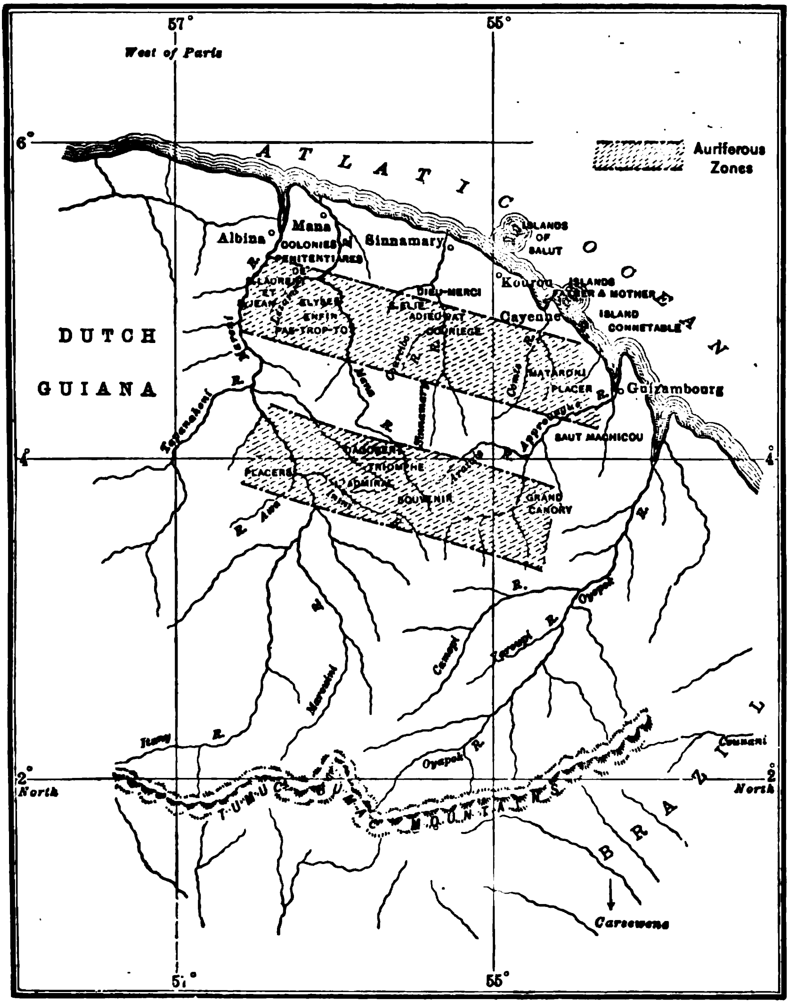

FIG. 49.—Map of French Guiana, showing principal auriferous zones. (*Bordeaux.*)

ment at several different times, its development has been retarded and its mineral wealth only partially developed. Gold is practically the only mineral of value thus far worked. Some silver occurs with the gold, and between 1652 and 1658 a silver deposit near the mouth of the Oyapok River was prospected by the Dutch. Copper, lead, tin, iron, and manganese have been reported from various places; a deposit of coal is said to occur near the Maroni River; and a deposit of phosphate of alumina has been worked by an American company on Connetable Island.

GOLD

Gold was first discovered in the Arataye River gravels in 1852 and soon after along the Orapu and Cirubé rivers. In 1873 the placers of the Sinnamary River system were discovered. Up to 1910 these had produced gold to the value of $10,000,000. The Mana River placers were discovered in 1878 and have produced upward of $5,000,000. Ten years later the Awa placers along the Maroni (Marowyn) River between French and Dutch Guiana were located. These latter have produced more than $12,000,000.

Bordeaux (42) states that there are two auriferous zones running parallel to the coast, each from 40 to 50 km. in width. The first is from 50 to 100 kilometers inland, and the second includes the upper courses of the Mana and Maroni rivers. Within these belts gold-bearing gravels have been found along scores of both large and small streams. As almost all travel through the gold country is accomplished by means of boats, naturally the main placers thus far located have been along the large streams.

The first gold workers employed sluices entirely, and this method is still in use in many places. Dredges are being used more and more, however, so that soon they may be producing the bulk of the output. By the sluicing system the gravel must have a minimum gold content of $2.00 per cubic yard, but some dredges are operating with profit in gravels containing only 50 cents a cubic yard.

The following placer districts are the principal ones thus far worked: Maroni, Sinnamary, Kourou, Comté, Approuague, Oyapok, and Carsavéne.

Gold-bearing quartz ledges have been found in many places adjoining the placer deposits but have received comparatively little attention. Quartz veins cut the ancient metamorphic rocks in many places, but most are barren, except those associated with more recent igneous intrusions of diabase or diorite. Pyrite and arsenopyrite are associated with the gold. In places the diorite and diabase contain appreciable quantities of pyrite and gold.

Probably the most valuable quartz mine ever worked in French Guiana was located at Adieu-Vat on the Sinnamary River. It was worked several times between 1878 and 1905 and paid dividends of approximately $1,000,000. It was worked by La Société Anonyme de St. Elie. The veins which occur in decomposed diorite, ranged from 2½ to 4 feet in width and contained values up to 3 ounces of gold per ton.

BAUXITE

Extensive deposits of high-grade bauxite have recently been reported, but definite information by the investigating companies has not been given out.

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CHAPTER IX

PARAGUAY

RÉSUMÉ OF MINERAL PRODUCTION

Paraguay seems to be the poorest of all South American countries in mineral resources, and possesses practically no mining industry. Iron ore mined for domestic use in the region about 75 miles southeast of Asuncion appears to be the only metallic ore that the country has produced. Except for very local uses of which there are no records in the literature, the non-metallic minerals have not been worked at all, though the recent formation of a company to work extensive kaolin deposits at Tobati near Aparipy is reported.

TOPOGRAPHIC AND GEOLOGICAL FEATURES

The country is divided into two distinct parts by the Paraguay River that traverses it from north to south. The portion west of the river, known as the Paraguayan Chaco, is an extensive, comparatively flat country. The portion lying to the east of the Paraguay River consists of a rolling country made up of a number of chains of hills with numerous spurs, the summits of few of which reach 1,500 feet in elevation, intersected by countless streams. The reported mineral occurrences are all located east of the river. The rocks of this region consist of igneous rocks ranging in composition from granite to basalt; gneisses, schists, and quartzites; and shales, sandstones, and limestones.

DISTRIBUTION OF MINERAL DEPOSITS

There are no authentic occurrences of gold and silver. Copper in the form of malachite and azurite is found in a basalt dike near Encarnación. Lead ores are not mentioned. Zinc is reported from the Cordillerita and mercury from San Miguel.

Rich and abundant manganese deposits are said to exist in the Cordillerita in the form of beds between sandstones. On account of difficulty of access, the deposits are not now workable.

The ore is chiefly pyrolusite. The most important metallic ore has been that of iron which is widespread and abundant in its distribution. Limonite occurs throughout the country, chiefly in sandstones in contact with the igneous rocks. The prin-

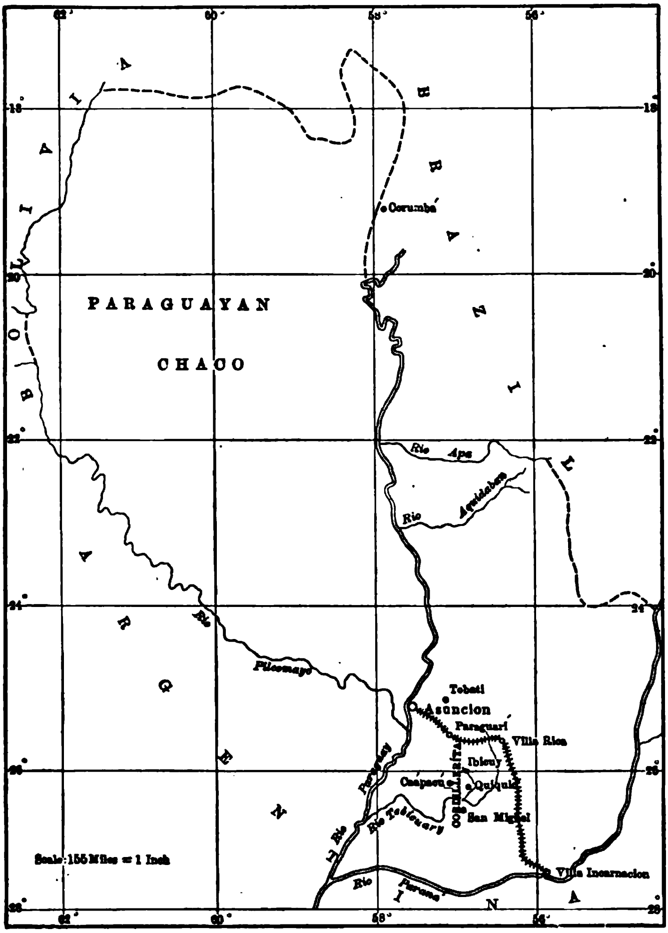

FIG. 50.—Map of Paraguay.

cipal occurrences are between the rivers Apa and Aquidaban. Magnetite and hematite deposits occur in a belt extending from Paraguarí to San Miguel, several of which have been worked to supply ore for the Ibicuy iron works. The principal producers have been Quiquió, Caápucú, and San Miguel. The Caápucú deposits consist of veins of high-grade hematite in porphyry and are found on both sides of the Yaguary River, a navigable branch of the Tebicuary. The ore carries 40 to 50 per cent iron. The Quiquió ores are likewise hematite and average 36 per cent iron. At San Miguel the ore occurs as thick layers of low-grade material averaging 32 per cent iron and 50 per cent silica in syenite. The Ibicuy iron-works were established by the government in 1854 in a picturesque valley at the foot of the Cordillerita. They consisted of a charcoal furnace producing about 1 ton of pig iron a day, forges, and shops for the manufacture of cannon and projectiles for government use. The plant was run by water power, the surrounding forests yielded an ample charcoal supply, and the flux was obtained from Paraguarí.

Kaolin is widespread in its occurrence as a decomposition product of feldspathic rocks, and the deposits at Tobati are estimated by Dr. Beder to contain 6,000,000 cubic meters of kaolin. Numerous deposits and veins of talc are found in the quartzose rocks near San Miguel de la Misiones. Graphite occurs as irregular pockets among the crystalline and plutonic rocks. Other non-metallic products mentioned as occurring in the country are ochres, marls for use as fertilizer, gypsum, nitrate, various kinds of clay, white glass sand, and material suitable for whetstones.

A great variety of rocks suitable for building and ornamental stones is available, but the stage of development of the country is such that no appreciable demand has arisen for these materials. They include serpentine, dark and red porphyries, granites, etc., among the igneous rocks; marbles, limestones, sandstones, and quartzites among the sedimentary.

CONDITIONS AFFECTING MINING INDUSTRY

The inland position of Paraguay, the lack of transportation facilities except along the large navigable rivers, its attractiveness from an agricultural standpoint, and its sparse population are all factors that have not been conducive to the encouragement of a mining industry. Whether the country is actually as poor in mineral resources as our present knowledge in regard to them would indicate it is impossible to say. The fact, however, that no deposits of importance have as yet been discovered is evidence that it constitutes a portion of the South American continent that has not been favored by important mineralization.

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CHAPTER X

PERU

RÉSUMÉ OF MINERAL PRODUCTION

The mineral production of Peru has been increasing rapidly in recent years owing to large-scale operations instituted in a few districts by foreign capital, chiefly American and English. Its value increased from $16,000,000 in 1910 to $28,500,000 in 1915. The output of the various mineral products in the order of their value in 1915 was: copper, 34,727 metric tons; petroleum, 363,162 tons; silver, 294,425 kg.; vanadium ore, 3,145 tons; gold, 1,690 kg.; coal, 290,743 tons; tungsten ore, 375 tons; lead, 2,696 tons; salt, 25,729 tons; bismuth, 25 tons; antimony ore, 522 tons; borates, 510 tons; molybdenum, 2,740 kg.; mercury, 920 kg.; zinc ore, 47 tons. The fact that the three principal mineral products, copper, petroleum, and silver, totaling over 80 per cent of the mineral output, are produced chiefly by outside capital emphasizes the dependence of the country upon foreign capital for the development of its mineral wealth.

The precious metal output is derived chiefly from copper ores and lead ores. In the past, these ores were mined solely for their precious metal content, but in recent years the copper values have far exceeded those of gold and silver. During the present decade, the gold output has been slowly increasing. In 1915, placers yielded 4.7 per cent of the production, precious metal ores 43 per cent, copper ores 51 per cent, and lead ores 1.3 per cent. Silver production has remained about stationary and in 1915 silver ores yielded 15 per cent of the output, copper ores 80 per cent, and lead ores 5 per cent.

Copper production has been showing a progressive increase, due mostly to developments in the Cerro de Pasco and Morococha districts in the department of Junín. The average production during the period 1911 to 1915 was nearly 29,000 tons and in 1917 had increased to 45,000 tons. Lead production has shown but little change, and only occasionally is there an output of a few tons of zinc ores.

The production of vanadium ores fluctuates greatly from year to year, but from 1911 to 1916 averaged nearly 2,000 tons. Tungsten production increased under war conditions to 530 tons in 1916, but is normally under 200 tons. Bismuth is limited to 25 tons annually by the syndicate controlling the bismuth market. Greater activity at Huancavelica increased the mercury production above the average of 500 kg. before the war. Molybdenum and antimony production has been initiated through war conditions.

Peru is the leading fuel producing country in South America. Petroleum production is still on the increase, and there is an annual coal production of about 300,000 tons. The pre-war average production of borates of 1,500 to 2,000 tons was cut to a third in 1915. The salt industry is a government monopoly that maintains a nearly uniform production in the neighborhood of 25,000 tons.

TOPOGRAPHIC AND GEOLOGIC FEATURES

Three physiographic belts extend longitudinally across Peru from the Bolivian boundary on the south to the Ecuadorean on the north. They are the coastal, the Andean, and the *montaña*, respectively, from west to east. The coastal belt is a narrow strip bordering the Pacific Ocean and extending inland to the foot-hills of the western range of the Andes. It is a relatively flat country, for the most part desert, except where crossed by major streams emerging from the mountains. Immediately adjacent to the coast is commonly a series of low hills. The *montaña*, which areally comprises the greater part of Peru, includes the eastern slopes of the eastern Andean range, and the basin of the Amazon and its tributaries beyond.

Between the coastal belt and the *montaña*, is a region of pronounced relief and high elevation which includes the various ranges comprising the Andes. The southern end of Peru is topographically a continuation of northern Bolivia. The Andes enter from the south as two distinct chains corresponding to the Cordillera Oriental and the Cordillera Occidental of Bolivia, enclosing the northward continuation of the *altiplanicie* beyond Lake Titicaca. Upon entering Peru, the Cordillera Occidental deviates from its northward trend to the northwest. The Cordillera Oriental which has already taken a northwesterly direction in northern Bolivia, swings further to the west, in a direction about N 75° W, so that it converges toward the western range and cuts off the *altiplanicie* finally by merging with the latter range in the southern part of the department of Cuzco in the great mountain mass known as the *nudo de Vilcanota.*

From the massif of Vilcanota emerge three ranges, known as the Cordillera Occidental, the Cordillera Central, and the Cordillera Oriental, separated by deep longitudinal valleys. The western range runs parallel to the coast, conforming more or less to its changes in direction and sinuosities. The central range lies between the valleys of the Apurímac and Mantaro on the west and the Vilcanota or Urubamba on the east. After diverging considerably, the three chains converge again to form the *nudo de Cerro de Pasco,* in the northwestern part of the department of Junín.

The *nudo de Cerro de Pasco* also breaks up to the northward into three chains which are known by the same names as those to the south. The central range is separated from the range on the west by the valley of the Marañon and from that on the east by the valley of the Huallaga. In southern Cajamarca, the western and central ranges begin to diverge through the latter taking a more northerly course. In Amazonas, the central range is cut through by the Marañon River. Before reaching this far north, the eastern range, with its altitude diminishing, has been cut through by the Huallaga River, has taken a northwesterly trend, and is merging with the central range. The western and central ranges pass out of Peruvian territory as distinct chains, but reunite in southern Ecuador in the *nudo de Loja.*

Throughout the extent of the Andean region in Peru, the western range constitutes the divide between the waters of the Pacific on the one side and those of the Lake Titicaca and Atlantic drainage on the other. In its southern and central parts, the passes are from 14,500 to 16,500 feet in elevation; in its northern portion, they are lower, and in Piura some are 8,000 feet and less. The peaks in the more elevated parts of the chain are 20,000 feet and over in elevation, and the loftier chains are covered with perpetual snow and ice. In the department of Ancachs, the western range bifurcates to form the Cordillera Blanca and Cordillera Negra, two chains separated by the valley of the Huaraz River, known as the Callejón de Huailas. The Cordillera Blanca, so called from its snowy peaks, represents the main western range; the Cordillera Negra is a lower range paralleling it on the west.

Though much has been written concerning the geologic features of Peru, the available information is for the most part not specific and frequently rather conflicting, so that it is difficult to give more than a generalized outline. Geologically the eastern range, and particularly its southern part, is identical with the northern part of the eastern range of Bolivia. It is made up of folded Paleozoic strata, to a large extent of Silurian age, consisting of mica schists, gneisses, sandstones, and very prominently black shales. These rocks have been penetrated by granitic intrusions. Here and there are sandstones, shales, conglomerates, and limestones of Carboniferous age. The Paleozoics are also encountered at a number of points in the littoral belt, as for example, the peninsula of Paracas, where coal-bearing Carboniferous strata are found, and in some of the deeper valleys of the western and central ranges.

The central or Andean zone is characterized by the extensive development of Mesozoic strata. Lower Jurassic limestones, which include horizons of bituminous shale and deposits of salt, are found in the three ranges. The lower Cretaceous is represented by shales, sandstones, and quartzites, with which are associated seams of coal, and has a very wide distribution in the western and central ranges. Equally prominent is a series of limestones of upper Cretaceous age in which are interstratified marls, shales, red and green sandstones, gypsum, etc. The Mesozoic strata frequently include large quantities of subaqueous lavas and stratified tuffs which have given rise to what is known as the "porphyritic facies." This is particularly well-developed in the department of Lima on the western flank and summit of the western range.

Tertiary strata of marine origin are represented in the littoral belt, and lacustrine deposits are met with here and there in the intra-Andean region. Beds of this age also occur in the Amazon region.

The western flank of the western range and the littoral belt have a zone of quartz diorite intrusions that extends the entire length of the country and in places attains a width of 100 km. These rocks are similar in composition but differ in texture from the porphyritic rocks, largely of andesitic composition, that have been intruded at innumerable points in the shape of dikes, sills, and stocks throughout the Andean region. Both the diorites and the porphyrites are of Tertiary age.

DISTRIBUTION OF THE MINERAL DEPOSITS

With the exception of the northern oil fields and a few non-metallic deposits, the mineral deposits of Peru are confined to the Andean belt, which extends across the country from north to south with a width of about 150 miles. North of the *nudo de Vilcanota,* the important deposits are not even coextensive with this belt, but are restricted to its western half, and are found for the most part on both slopes of the western range and the western slopes of the central range. Few deposits are known east of the crest of the central range. The most highly mineralized portion of Peru is consequently a zone rarely over 75 miles wide extending from Ecuador through northern and central Peru. In southern Peru the mineralized belt is wider and includes the eastern range, but the deposits are more widely scattered and the mineralization appears to have been less intensive.

In the main mineralized zone, which includes the southern part of the department of Cajamarca, Libertad, Ancachs, western Huánuco, eastern Lima, western Junín, and Huancavelica, the rocks in which the ore deposits are found are chiefly the Mesozoic sediments and the porphyries of Tertiary age which have intruded them, and the mineralization is genetically related to the latter. Further south the Paleozoics attain increasing importance as the counry rock of the mineral deposits, particularly of the gold deposits of the eastern range in the northern part of the department of Puno. The petroleum deposits of the north coast are enclosed in Tertiary beds, and many of the salt deposits of the coast are Quaternary in age.

The metallic deposits of Peru show the same intimate relationship between ore deposition and igneous intrusion that is so strikingly manifested by the deposits of Bolivia. Geologic data are not yet at hand to determine as definitely in what part and over how long a portion of Tertiary time the period of igneous intrusion extended as can be done in the case of Bolivia. The probability is, however, that the Peruvian argentiferous lead and copper deposits represent a well-defined metallogenic epoch and an almost equally well-defined metallogenic province. Much of the gold mineralization may belong to an older epoch of ore deposition.

The distribution of the Peruvian mineral deposits is shown on the map, Fig. 51.

GOLD

Gold deposits are found throughout Peru, both in lodes and in placers. In the coastal region, they are encountered in quartz veins in the holocrystalline rocks which predominate in the low hills. The metal is associated with quartz and varying quantities of iron oxide. Native gold is also occasionally associated with ores of copper. The deposits have never been very productive, and the mines are now idle. In the Andean region gold veins are enclosed both in igneous rocks and in shales and quartzites. The ore consists of quartz carrying native gold and auriferous pyrite and other sulphides. The disintegration of the lodes has given rise to numerous detrital deposits both in recent and older periods. Lodes and placers are found throughout the Andean region, but more abundantly in the southern part. Bedded lodes in talcose and argillaceous shales are very abundant and widespread in the southern part of the eastern Andean slopes. Large detrital deposits have also been derived from them. Gold mineralization is of relatively greater prominence, therefore, in southern Peru than in other parts of the country. Considering only the output from strictly gold ores, the rank of the departments is Apurímac, Puno, Junín, Libertad, Arequipa, and Ayacucho. The rank of those yielding placer gold is Puno, Ancachs, Cuzco, and Apurímac.

Lode Deposits.—The only important producing mines in recent years have been those of the Cotabambas Auraria in the Ccochasayhuas district in Apurímac; the Inca Mining Company at Santo Domingo in Puno; the New Chuquitambo Gold Mines near Cerro de Pasco in Junín; the Compañía Minera El Gigante at Parcoy, Libertad; and the Sociedad Aurífera Posco Andaray at Andaray in Arequipa.

Ccochasayhuas District.—The Ccochasayhuas vein (119, 109)* cuts for a distance of 1,600 m. dacites and porphyrites, and limestones, sandstones, and shales into which they were intruded, in a north-south direction with a dip of 55° to 60° W. Its width is 2.5 to 3 m. The filling consists of nearly barren milky quartz, rhodonite, and rhodochrosite containing aurif-

* Numbers in parentheses refer to articles in bibliography at close of chapter.

erous and argentiferous pyrite, chalcopyrite, galena, some sphalerite, nagyagite, and free gold. The valuable portion of the vein seems to have been deposited subsequent to a reopening of the barren quartz vein. The ore in new workings is reported to average 2 oz. gold and old pillars and waste two-thirds ounce gold.

Santo Domingo District.—At Santo Domingo (74) the country rock of black Silurian shales encloses bedded quartz lodes characterized by ore shoots carrying high values. The values are distributed in the quartz and sulphides constituting the vein filling and also in the shale wallrock. The veins range from 60 cm. to 3 to 4 m. in width, and the ore shoots are said to average 4 oz. gold. The only igneous rock observed is a diorite dike that cuts the Santo Domingo vein.

Chuquitambo District.—The Cerro de Chuquitambo (203, pp. 96–97) consists of upper Cretaceous strata with an easterly dip. At the base of the series are limestones and fossiliferous marls; these are overlain by sandstones and conglomerates; the uppermost beds are sandy dolomites. Dikes of andesite cut the sediments, and at their contact with the dolomite are two replacement deposits of auriferous quartz lying more or less concordant to the stratification. The width of the ore bodies exceeds 20 m. and they are worked in open cuts. In the quartz are traces of copper carbonate, silicate and oxide of iron, and particles of pyrite and chalcopyrite. The tenor of the ore is ⅕ to 1¼ oz. gold.

Parcoy District.—The Parcoy deposits (120, pp. 25–31) are veins 80 cm. to 2 m. wide in quartz porphyry with a filling of nearly barren quartz containing auriferous arsenopyrite in considerable abundance and small quantities of galena, sphalerite, and pyrite. The tenor of the ore is 1¼ oz gold.

Andaray District.—The Andaray district (48, 6) lies between the Rio Grande and the Rio Chorunga, east of their confluence to form the Rio Ocoña. The veins are in the Cerro San Antonia and Cerro San Juan, which are made up of quartz diorite. Their strike is northwesterly and width from a few centimeters to over a meter. The vein filling consists of quartz with as much as 10 to 20 per cent pyrite and clay resulting from the decomposition of the wallrock. The tenor of the ore is ½ to 3 oz. gold. Posco lies in the same mineralized area, about 20 km. west of Andaray.

Placer Deposits.—Only two placer areas are of present importance as producers, the provinces of Sandia and Carabaya in Puno, and the Rio Tablachaca on the boundary of Ancachs and Libertad. Sandia and Carabaya (142, 167, 127) are regarded as the most promising gold region of Peru, but they are handicapped by their inaccessible location, stretching as they do from the summit of the eastern range well down into the *montaña*. The country consists of Silurian shales and sandstones, resting on a granite massif. The shales enclose and are cut by innumerable auriferous quartz veins. Though some of them as the Santo Domingo are workable, for the most part they are too small and have their values too irregularly distributed to be workable. Extensive denudation through glacial and stream action has concentrated their gold content into widely distributed placers. These deposits lie near the crest of the Cordillera de Azangaro, which is a range of snow-covered peaks, with an east-west trend and on its northern slopes to the Hauri Hauri or Ynambari River at their base. They consist of three types—glacial débris of great thickness and extent, of which the best known example is Poto; extensive and thick beds of ancient stream gravels, exemplified by Aporoma; and deposits in present stream beds which are of smaller size than the preceding. The detrital material consists of fragments of quartz, sandstone, and shale which in the older deposits are more or less consolidated by siliceous or argillaceous cement. In the glacial débris, the gold is distributed throughout the mass and not concentrated near bed rock as in water-sorted material. The Poto district comprises a belt of glacial material 50 km. long and 12 km. wide lying at an elevation of 15,500 feet. The gold is chiefly in a fine state of subdivision but nuggets as large as one-half ounce are encountered. Auriferous veins in talcose shales in the vicinity of Pallasca in Ancachs are probably the source of the placer gold of that section.

Other Districts.—Both lode and placer deposits are widely distributed through the department of Cuzco, especially in the province of Paucartambo. In the valley of the Huallaga River, in southern Huánuco, lodes are found in country rock consisting of foliated sediments and granular rocks in the districts of Ambo, Huánuco, Higue as, and Valle. Ancient and modern auriferous gravels are found in the same region and in the adjacent part of the Marañon River on the west. The east side of the Marañon

Valley in the province of Pataz, Libertad, in which the Parcoy district is situated, contains other lode and placer deposits, as in the Pataz and Rio Cajas districts respectively.

SILVER

It is difficult to distinguish between silver deposits and argentiferous lead deposits on the one hand, and silver deposits and argentiferous copper deposits on the other hand. Nor is there a sharp line of demarcation between argentiferous lead and argentiferous copper deposits. In the Peruvian Andes, these three types of deposits grade into one another in their mineralogic composition and are identical in areal distribution and geologic occurrence. The deposits coming under these heads are the most numerous and widely distributed metallic deposits of the Andes. They attain their greatest development in the departments of Cajamarca, Libertad, Ancachs, Junín, eastern Lima, and northeastern Huancavelica. With few exceptions, these deposits have attracted attention and have been worked primarily for their silver content.

The silver deposits are found characteristically in Mesozoic sediments and Tertiary intrusive rocks and occur in the form of veins or replacements. The gangue is commonly silica with which are associated varying quantities of calcite, siderite, and barite. The common sulphides, galena, sphalerite, chalcopyrite, and pyrite are nearly always present. Tetrahedrite is rarely absent, and in the cupriferous types of ores enargite is common. The more highly argentiferous ores contain larger quantities of tetrahedrite or are notable for the occurrence of the polysulphides of silver and copper or silver and lead, argentite, and native silver. Through the complete subordination of the base metal sulphides such ores grade over into strictly silver ores. The silver content of the ores ranges from the richest silver ores containing several hundred ounces of silver through the more usual grade of 10 to 30 oz. silver to each per cent of copper and 5 to 10 oz. silver to each per cent of lead, to the lowest grade ores containing about 1 oz. silver and less to 1 per cent of the base metals.

As a separation of these deposits into three distinct groups—silver deposits, copper deposits, and lead deposits—would necessitate purely arbitrary lines of division, and convey an impression of distinctness that does not as a rule exist, they will be described as a single group under the category of silver deposits, in geographic sequence by departments from north to south. The number of such deposits that have been worked is indefinite. Most of them were gutted of their richest silver ores at comparatively shallow depths in the days of higher silver prices and have now lain idle for many years. A description of all of these would be a constant repetition of similar features, if indeed data were available to give an intelligent description of most of them. In the following paragraphs, the more important occurrences in each department are briefly described.

Cajamarca.—The province of Hualgáyoc contains the important district of Hualgáyoc, the elevation of which is 12,000 feet. The country rock is an extensive limestone formation with subordinate shale and sandstone facies, which has been intruded by igneous masses ranging in texture from andesite to diorite. The veins are found in both the igneous and sedimentary rocks but grouped about several centers of eruption. According to their filling, they may be classed as copper veins and as silver veins; the copper veins are more closely associated with the diorites and the silver veins with the andesites. In the Cerro Jesús, the center of the silver mineralization, are four systems of veins having the directions of N 67° E, N 45° E, N 80° E, and N 20° W, of which the first is the most important. In addition to the common sulphides of copper, lead, zinc, and iron, the ore contains native silver, argentite, pyrargyrite, stromeyerite, bournonite, tetrahedrite, and enargite. The gangue minerals are quartz, calcite, and barite. More or less gold is present, and some veins show threads of native gold in tetrahedrite and galena. The ores are not uniformly distributed but occur in pronounced shoots. The silver content is high, and the oxidized ores, now exhausted, carried very high values.

El Punre and Agua Santa are in the province of Celendín, in eastern spurs of the western range. At El Punre are east-west striking sandstones with a northerly dip which have been contact metamorphosed by amphibole dacite dikes running parallel to their strike. Of three systems of veins, a northwesterly, a north-south, and an east-west, the first mentioned is the most important. The width of the veins is usually over 1 m., but ore constitutes only a part of the filling. Tetrahedrite, chalcopyrite, sphalerite, pyrite, and quartz are the most abundant minerals.

One of the veins at the contact of a dacite dike and sandstone, contains chiefly argentiferous galena. A *manto*[1] of dark quartzite with a footwall of white quartzite and roof of shale contains irregular pockets of ore and at intersections with veins rich ore shoots. At Agua Santa the country rock is limestone, and tetrahedrite is not mentioned among the ore minerals.

On the west slope of the western range, in the province of Cajamarca, are the Chilete, Surupampa, and Chaidamonte districts. The Cerro Chilete, 4,400 feet in elevation, consists of diorites and amphibole porphyries, green, violet, and red in color. Two principal veins 40 m. apart and united by a branch between them are from 1 to 5 m. in width. The filling consists of antimonial argentiferous galena, sphalerite, and quartz. In the oxidized zone, lead sulphate and antimoniate, zinc carbonate, silver chloride, and native silver occur. The base of the mountains at Surupampa consist of the same igneous rocks, but the summits are capped by quartzites into which the veins extend. The ores are copper ores consisting of tetrahedrite, chalcopyrite, pyrite, and quartz and carry as high as 300 oz. silver. At Chaidamonte, are sandstones, shales, and limestones cut by andesite dikes. Veins of one system strike north-south, dip 35° W and are 7 to 80 cm. wide; those of a second system strike N 15° to 25° W and are 20 to 40 cm. wide. They contain argentiferous lead ores with small quantities of iron and copper sulphides in quartz.

On the same slope of the western range are the districts of Morochillo, Cascabamba, and San Felipe in the province of Contumazá. In the Morochillo district, sandstones metamorphosed by granulite dikes on the Cerro Cushtón are cut by a northwest system of fractures with a dip of 40° to 60° northeast and width of 20 to 30 cm. The ore consisting of tetrahedrite, marcasite, pyrite, arsenopyrite, and quartz occurs in lenticular shoots 2 to 3 m. long. On the Cerro Morochillo are veins in limestone with a filling of pyrrhotite in which are streaks of magnetite, pyrite, and quartz. The geology and ores of San Felipe district are analogous except that sphalerite is abundant. The Cascabamba district differs in the presence of rhyolite instead of microgranulite.

Cajabamba province is underlain by Cretaceous limestone,

[1] A *manto* is a flat or comparatively flat tabular ore body following stratification or a contact.

shale, and sandstone traversed by a great dike of trachyte which extends from Huamachuco in Libertad to Algamarca. The dike was intruded subsequent to mineralization as branches from it parallel to the bedding cut across the veins. The deposits of Cochas are interstratified in sandstone and contain tetrahedrite, pyrite, and quartz. At Sayapullo, the veins are in limestone overlain successively by sandstone and shale. The position of the strata is east-west with northerly dip, and of the veins northwest with dip of 30° to 35° southwest. Their width is 125 cm., and the filling argentite, tetrahedrite, enargite, chalcopyrite, pyrite, sphalerite, and quartz. The Algamarca veins are in shales and quartzite. They have a northeast strike, 60° to 70° W dip, and width of 80 to 120 cm. The filling is the same as the preceding except that enargite and sphalerite are mentioned. The Capán ores are argentiferous lead ores with 15 to 20 oz. silver and 50 per cent. lead. The veins strike northwest, dip 60° to 80° east, and are 1 m. in width with ore streaks 3 to 5 cm. wide and are enclosed in metamorphosed sandstone near the trachyte dike.

Libertad.—The principal districts in Otuzco province are Carangas, Malín, and Salpo, which lie on the western side of the western range. The veins of the Carangas district are enclosed in shales and sandstones which have been metamorphosed by an amphibole granite a short distance to the north. The mineralization is richer and more uniform in the shales than in the sandstones. The Santa Catalina vein is 1 m. wide and contains tetrahedrite, chalcopyrite, pyrite, and quartz with banded structure. The silver content is from 50 oz. upward, and there is about 1 per cent copper to 30 oz. silver. The Malín district, 2,000 feet in elevation, consists of sandstone and shale cut by a 10 m. rhyolite dike parallel to the sediments in strike but at right angles in dip. The veins are parallel to the dike. The ores contain fine-grained galena, pyrite, patches of tetrahedrite, and quartz and average 50 oz. silver. Ores with abundant tetrahedrite have much higher silver values. A vein with the dike for one of its walls contains chalcopyrite. The Cerro Salpo is composed of contact metamorphosed sandstone resting on rhyolite. The Salpo vein has been followed in a northwesterly direction for 8 km. and has a width of 8 m. Ore does not extend across the entire vein, but occurs as bands 1 to 2 m. wide on the walls, the intermediate part being filled with quartz and decomposed rock. In the sandstone, the ore consists of oxidized minerals, tetrahedrite, and chalcopyrite, with a high gold content near the outcrop followed by an increase in silver in the copper sulphides; on entering the igneous rock at greater depth, the copper minerals give way to galena, a change accompanied by a decrease in the silver content. At Milluachaqui, south of Salpo, are similar ores in narrower but more uniformly mineralized veins.

The most important district of Santiago de Chuco province is Quiruvilca. The country rock is hornblende and augite andesites which have been cut by veins running in all directions and characterized by considerable length, 9 to 10 km. in some instances, much variation in width, a smooth and well-defined footwall, an irregular and decomposed hanging wall, and the occurrence of ore shoots at intersections and junctions. The zone of oxidation extends 15 to 20 m. in depth. The sulphide ores carry enargite, tennantite, tetrahedrite, bornite, and pyrite, and smaller amounts of galena and sphalerite. The gangue minerals are quartz, barite, and calcite. Rich silver values appear to be associated with sphalerite and barite, rather than with the copper minerals. The width of the veins is 1 to 3 m., but the ore occurs in bands parallel to the walls rarely 40 cm. wide. In most of the veins the silver tenor is about 1 oz. to 1 per cent copper. The Aguiñuay deposits are analogous but contain more galena. At Santa Rosa, the veins are in hornblende andesite, have a strike and dip N 65° to 80° E, 70° to 85° S, and width from almost nothing to over 1 m. The oxidized zone rarely extends below 30 m., and is succeeded by ore consisting of jamesonite, pyrite, patches of tetrahedrite, gypsum, and quartz. Nuevo Mundo is one of several districts on the opposite, or eastern side, of the western range with a country rock of shales overlying white quartzite. The veins lie both parallel to and transverse to the bedding of the strata. Their width is 60 cm. to 2 m. In the shales, bournonite, galena, and sphalerite predominate, and the ores average 70 to 80 oz. silver, 33 per cent lead, and 18 per cent copper; in the quartzites, tetrahedrite and chalcopyrite predominate and the grade of the ore is the same in silver, but 17 per cent each in lead and copper. Realgar and orpiment also occur, and the gangue is quartz.

Among the districts in Huamachuco province are Sanagorán, El Toro, Cerro Negro, and Serpaquino. The Sanagorán deposits are argentiferous lead ores in veins 110 cm. wide enclosed in sandstone metamorphosed by a great andesite intrusion which passes through Cerro Negro. The El Toro veins are found in both sandstone and andesite. Those in sandstone have a deep zone of oxidation that has been extensively worked on account of its gold values. In the andesite, the zone of oxidation is shallow and the veins are marked by shoots at intersections and junctions containing enargite, tennantite, and pyrite. At Cerro Negro are east-west veins with southerly dip in hornblende andesite. The width of the veins is 1 m., but the ore streaks are not over 20 cm. The ore consists of stibnite, galena, arsenopyrite, pyrite, and quartz, and carries 30 to 40 oz. silver, 35 per cent lead, and 12 to 15 per cent antimony. In the Serpaquino district, the veins occur in both shales and quartzites and in andesites. Those in the sediments contain tetrahedrite, chalcopyrite, pyrite, galena, and sphalerite with 16 oz. silver and 1½ per cent copper. The veins in the andesite carry no silver values, and may or may not contain copper. The minerals are quartz, pyrite, specularite, and magnetite, with or without copper minerals. The width of both types of veins is ¾ to 1½ m.

Ancachs.—The deposits of this department are found in both the Cordillera Negra and the Cordillera Blanca. In the province of Huaylas are the Macate, Huaylas, Colquipocro, Pueblo Libre, and Yungay districts. The Macate district, including the mineralized mountain Patara, has both veins, and *mantos* in country rock of shales and sandstones intruded by mica diorite. Though the veins are well defined, the ore occurs in pockets. The minerals are a little native silver, argentite, pyrargyrite, tetrahedrite, galena, pyrite, and quartz, and their oxidation products. The ores of the other districts are also essentially argentiferous galena ores including, in addition to the minerals mentioned, chalcopyrite, sphalerite, bournonite, and siderite, characterized by a high silver tenor and classed chiefly as silver ores.

The deposits of Huaraz province are located on the eastern slopes of the Cordillera Negra and include the Carhuaz, Huayta Pallanca, Huinac, Aija, and Recuay districts. In the Carhuaz district, the ore deposits are veins and *mantos* of argentiferous tetrahedrite in greatly dislocated, compact, dirty-white sandstone overlying shales. The Huayta Pallanca veins traverse a mountain of amphibole porphyry in an east-west direction with a steep northerly dip. The ore is highly argentiferous antimonial galena but in depth contains less silver and increasing quantities of sphalerite. The Huinac mines are at the summit of the range at an elevation of 14,300 feet. The Cerro Huinac is a volcanic cone to the north of which are ferruginous outcrops with carbonate and silicate gangue. The principal vein strikes N 67° E, dips 60° to 70°, and has variable width up to 180 cm. The filling is quartz, pyrite, chalcopyrite, bornite, tennantite, and tetrahedrite, averaging 30 to 60 oz. silver and 8 to 12 per cent copper. Some of the veins also contain galena and arsenopyrite. The Aija ores are argentiferous lead ores with some sphalerite. The Recuay is the most important district of the province. The principal vein is the Collaracra which is enclosed in a greenish-colored porphyry dike much decomposed along the vein. The width varies between ½ m. and 4.5 m., but the ore streak is rarely over one-half meter wide. The dip is variable and the flatter parts of the vein are the more highly mineralized. The ore in the southwest part of the vein contains pyrite, stibnite, and tetrahedrite, with occasional patches of chalcopyrite, bornite, arsenopyrite, and sphalerite, and with or without quartz. Boulangerite and bournonite also occur. Silver averages about 75 oz. and copper from 3 to 7 per cent. The northeast part of the vein contains instead of the copper minerals antimonial galena and sphalerite and averages over 45 per cent lead.

The ores of Pallasca province are characterized by high silver values as compared with their lead and copper content. The Pallasca district yields argentiferous antimonial ores with such minerals as jamesonite, berthierite, and stibnite; the Cabana district argentiferous tetrahedrite and argentiferous limonite; and the La Pampa district argentiferous anglesite with 100 oz. silver and 61 per cent lead. The Magistral or Conchucos district, at one time an important silver producer, now yields copper ores from mineralized zones reaching 30 m. in width in limestone intruded by andesite. The ore is pyrite and chalcopyrite with a little tetrahedrite and bornite in quartz and calcite gangue, averaging 12 per cent copper.

In the province of Huari are the districts San Luis, Chacas, Huari, Tulla, and Chavin. San Luis and Chacas are located in a region of quartz diorite upon which rests in succession contact metamorphosed black shale, sandstone, and coal-bearing strata. The ores are silver-lead ores carrying more or less copper and zinc. Three systems of veins have northwest, northeast, and north-south strikes respectively. The gangue is siderite and quartz. The ores in order of abundance are cubical or fine-grained galena, yellow and black sphalerite, stibnite, pyrite, chalcopyrite, tetrahedrite, and some stephanite, polybasite, bournonite, and arsenopyrite. Sphalerite runs 22 to 45 oz. silver and the leanest galena over 90 oz. The oxidized zone is rich in cerussite and anglesite. The Huari ores are argentiferous galena and tetrahedrite and occur as *mantos*, with a maximum thickness of 6 feet, in metamorphosed sandstone. At Tulla is a system of three parallel veins with north-south strike and 53° west dip cut by a fourth at right angles with 45° south dip. The country rock is gneiss and slate cut by igneous rocks. The width varies from zero to 120 cm. and the tenor averages 40 to 60 oz. silver. The ore contains in a gangue of quartz, calcite, siderite, and fragments of wallrock, galena, sphalerite, auriferous pyrite, and small amounts of tetrahedrite, ruby silver, and native silver. The Chavin ores have more copper than the preceding. They occur in veins and *mantos* in sandstone alternating with small beds of shale and consist of argentiferous pyrite and tetrahedrite in quartz and siderite, with smaller amounts of bournonite, galena, and chalcopyrite. In the vicinity of Antamina in this district are limestones intruded by porphyritic rocks in which the ore bodies are still more cupriferous.

At Tuco in Bolognesi province, are fissures in sedimentary rocks filled with cupriferous pyrite, chalcopyrite, tetrahedrite, and sphalerite. Their width is 1½ m. but the ore does not constitute more than one-third of the width. They assay 60 oz. silver and 15 to 35 per cent copper.

A few of the districts in the province of Cajatambo are Auquimarca, Raura, Quichas, and Chanca. The Auquïmarca veins are in dioritic rocks, and have a width of 2 m. Quartz, barite, and calcite constitute the gangue. The ore minerals are native silver in threads and dendritic forms in quartz, tetrahedrite, galena, chalcopyrite, and pyrite, and the ore ranges from 135 to 550 oz. silver. In the Raura district, the veins have an east-west strike and width of about 1 m. The ore is banded with a central zone of quartz, then tetrahedrite, sphalerite, and galena, followed successively by calcite, dolomite, and pyrite. It occurs in shoots with a stope length of about 30 m. The average tenor is about 70 oz. silver and 9 to 15 per cent copper. The country rock of the Quichas district is limestone and sandstone. The principal vein has the position N 15° E 75° E, and is from 80 to 120 cm. wide. The ore is tetrahedrite with pyrargyrite, realgar, and pyrolusite, in a gangue of calcite and grossularite, and has an average tenor of 70 oz. silver. Pure tetrahedrite has 900 oz. silver. The Chanca district includes a group of porphyry hills of which the Cerro Chanca is the central one. The veins have a strike of N 20° E to N 80° E and a width of from a few centimeters to 1 m. Ore shoots are at vein intersections. The ore in the Socorro mine is banded; the successive layers from the center to the walls are quartz and calcite sprinkled with pyrargyrite and tetrahedrite, fine and coarse pyrite, thin bands of quartz and calcite, and thick bands of pyrite. Galena, sphalerite, and chalcopyrite also occur.

Huánuco.—The silver-copper-lead belt traverses the province Dos de Mayo in the western edge of this department. The ores of the Huallanca district consist primarily of argentiferous pyrite and tetrahedrite in quartz gangue. First-class sorted ore carries 500 to 600 oz. silver and 14 to 17 per cent copper, and milling ores 50 to 70 oz. silver and 1½ to 2 per cent copper. Accessory constituents of the ore are chalcopyrite, galena, and sphalerite. The country rock of the veins is chiefly sandstone and graywacke, and less prominently shale and limestone. In the sandstone are caves and vugs, many 25 to 30 feet in length, coated with 2 or 3 inches of tetrahedrite crystals. The two principal veins parallel each other for 5 km. in the direction N 45° W with a dip of 65° NE, separated by 100 m. of barren rock. In the Chonta district are three *mantos* interstratified in sandstone and quartzite consisting of pyrite, sphalerite, galena, cinnabar, and tetrahedrite. The ore occurs in patches and pockets connected by small veins of pyrite, and is reported to carry 300 oz. silver and 10 per cent mercury, and was formerly worked especially for its mercury content. The veins of the Queropalca district are in two quartzite hills overlooking the town. Their width is 20 cm. to 150 cm., and the filling is quartz, clay, pyrite, chalcopyrite, sphalerite, and tetrahedrite with variable silver values and some copper and gold.

Junín.—The silver-lead-copper deposits of the department of Junín occur in a belt less than 50 km. wide in its western part. The northern half of this belt includes the important districts of Cerro de Pasco, Morococha, and Colquijirca. The first two districts are large producers of argentiferous copper ores and the third yields silver ores; they are described in some detail on pages 475 to 487. Yauli has also been an important producer in the past. Other districts in this northern half are Vinchos and Huancavelica. In the Vinchos district limestones have been intruded by igneous rocks and are cut by veins which contain ore shoots at intersections. In a gangue of quartz, calcite, and barite are galena, pyrite, arsenopyrite, chalcopyrite, tetrahedrite, bournonite, pyrargyrite, and native silver. The silver tenor varies from 70 to 300 oz., and the lead from 25 to 30 per cent. The width of the veins is 20 cm. to 50 cm. The Huancavelica district is in a region of Jurassic and Cretaceous sandstones and marls intruded by a major mass of dacite from which extend dikes and sills. The veins occur in both rocks. A range of rhyolite to the east shows no mineralization. The veins constitute a network of fractures with a prevailingly east-west strike. In the eruptive rock the gangue is siliceous and the ore chiefly enargite and tennantite; in the sediments the gangue is more calcareous and the ore carries less of the copper minerals and more galena and sphalerite. Pyrite and chalcopyrite are also present. The grade of the ores ranges from 10 to 100 oz. silver and 2 to 16 per cent copper.

The Yauli district proper is comparatively restricted in area, but noted for the richness and size of the deposits. According to Remy (160), there is a progressive change in the mineralogic composition of the ore from the surface to a depth of 90 m. In the uppermost part of the veins are encountered native silver and argentite mingled with small quantities of sphalerite, pyrite, and galena. In depth argentite gives way to pyrargyrite and this in turn to sternbergite with native silver becoming very rare. Galena, sphalerite, and especially pyrite show progressive increase in amount with depth. Copper ores are completely absent at those horizons. Still lower are geodes with small amounts of native silver, pyrite becomes cupriferous, and argentite again appears, followed by the appearance of tetrahedrite and the almost complete disappearance of the rich silver minerals. The richest silver ores, those characterized by native silver and the silver sulphides, are found on the south side of the Yauli valley; on the north side, adjoining the Morococha district, tetrahedrite is a more prominent constituent of the ores. Of the two minerals, tetrahedrite and tennantite, the higher silver values are in the former, and, as in other Peruvian districts, fine-grained galena carries higher silver values than coarsely crystallized. The most notable of the Yauli veins was the Carahuacra, which runs in a northeast direction for 4 km. with a width of 30 m. to 40 m. on the outcrop along a contact of dacite with limestones, marls, and sandstones. It is of course not a true vein but a mineralized zone. Some veins are in propylitized rock, and others in limestone. At the Esperanza mine are three *mantos* of galena ore in limestone 15 m. apart.

On the western slopes of the central range in the provinces of Jauja and Huancayo, immediately east and northeast of Jauja and Huancayo, are a great number of deposits, none of which are of any particular importance with respect to present developments, in some of which copper ores predominate and in others lead ores but with low silver values in all. The region is made up of Cretaceous sediments consisting chiefly of limestones, shales, and sandstones, into which have been intruded basic igneous rocks. The copper deposits fall into two groups. Those in the shales and quartzites contain pyrite and chalcopyrite, but rarely tetrahedrite, in a gangue of siderite, manganosiderite, and quartz. The silver content is less than 1 oz. to 1 per cent copper. Those in the limestone and igneous rock have tetrahedrite, bornite, and calcite as the principal minerals with nests of chalcopyrite, pyrite, rarely galena, and a little quartz. These ores carry somewhat higher silver values. The argentiferous lead ores occur mainly northeast of Jauja and consist of galena and sphalerite.

Lima.—On both sides of the Oroya railroad on the upper western slope of the western range are numerous occurrences of silver-copper-lead ores, the most important of which are those of the Casapalca district in which the principal values are in silver. This district is described in some detail on pages 483 to 485.

Huancavelica.—Deposits of the character under consideration are widely distributed through the department of Huancavelica, but the Castrovirreina district is the only producer of any importance. In Tayacaja province, the Despensa and Hauri districts are in the southward extension of the mineralized area of Jauja and Huancayo of Junín. The deposits are of the cupriferous type. The Pichcas district has a system of veins striking northeast and dipping 40° to 70° northwest in limestone, carrying galena and calcite and a little tetrahedrite and pyrite, and having a tenor of 3 to 22 oz. silver. The veins of Cerro Atocc are in black shales and silicified slates. They strike north-south, dip 70°, and are 20 cm. wide. The filling is quartz and siderite with pyrite, chalcopyrite, tetrahedrite, and galena, and carries high silver values. The Coris district, also in a country rock of shale, has both argentiferous galena ores with calcite gangue and argentiferous tetrahedrite ores. Carhuancho has argentiferous galena ores. Cerro Vizcayna is cut by a system of north-south veins with easterly dip. The wide ore shoots consist of almost pure galena with 100 oz. to 125 oz. silver. Less abundant are pyrite, chalcopyrite, tetrahedrite, quartz, and siderite. Calcite is the principal gangue mineral. The Transwal vein differs from the others by containing considerable auriferous quartz.

In the province of Huancavelica, in the porphyritic facies of the Mesozoic are numerous copper deposits, some in the form of stockworks, others impregnating sandstone, consisting of bornite and other rich copper sulphides in calcite gangue which carry 1 oz. silver or less to 1 per cent copper. In the Sapralla and the neighboring Ñañantuyo district are westerly and southwesterly dipping veins in limestone with sandstone intercalations, in which the filling is galena, sphalerite, some tetrahedrite, pyrite, in places cupriferous, and a little quartz. The silver values in the galena range from 45 to 90 oz. The Huachocolpa district and the Carhuapata adjoining it on the east, lie in an area of the porphyritic facies. The veins have various strikes and dips and range in width from a fraction up to 1 m. The minerals in their order of abundance are galena, tetrahedrite, chalcopyrite, pyrite, sphalerite, pyrargyrite, oxidation products of zinc and copper, quartz, and barite. The tenor averages from 20 to 40 oz. silver.

The Julcani district in Angaraes province is made up of intrusions of amphibole mica rhyolites in the west, dark-colored and green porphyries in the east, and flows of amphibole rhyolites. There is an east-west system and a northwest system of veins. The first contains auriferous pyrite, quartz, and tungsten ores, the second argentiferous copper and lead ores, consisting of chalcopyrite, galena, tetrahedrite, siderite, barite, and some quartz. They have a width of from 40 cm. to 60 cm. First-class ore contained 200 to 300 oz. silver and 15 to 18 per cent copper. In the Vizcachas and Pampamali districts, similar porphyries constitute the country rock and the ores contain both copper and lead, either in the same veins or in separate veins.

The Castrovirreina district in the province of the same name is notable for its rich silver ores. First-class ore contains 400 oz. silver, second class 70 oz. The country rock is porphyries and porphyrites. One of the important groups of mines, the Quespesisa, at an altitude of 16,500 feet, yields ores irregularly distributed in pockets containing argentite, pyrargyrite, stephanite, proustite, galena, sphalerite, stibnite, barite, and quartz. Another important vein, the Caudalosa, contains galena, sphalerite, tetrahedrite, stibnite, and quartz. Other veins carry considerable chalcopyrite and tetrahedrite and in some galena is the principal constituent.

Other Departments.—In the Cerro de Ccorihuilca northeast of Huanta, Ayacucho, in metamorphic rocks, are silver veins carrying 35 oz. in the oxidized zone and higher values in galena beneath. The silver-nickel ores of Rapi are described on page 466. Hardly more than the fact of their existence is known concerning this type of deposit in Apurímac. Many silver-lead-copper deposits are known in the southern half of Cuzco, but few have received much attention. The Vilcabamba district in a region of limestones contains four types of veins—one group of argentiferous tetrahedrite and native silver in calcite gangue; another of chalcopyrite and bornite, rarely tetrahedrite, assaying 16 oz. silver and 25 per cent copper; a third group of argentiferous galena and a little tetrahedrite with about the same silver values. The fourth group is analogous to the nickel and cobalt ore of Rapi in Ayacucho. The principal filling is calcite and niccolite, less abundant are gersdorfite, smaltite, cobaltite, pyrite, tetrahedrite, and galena. The Chimboya district was famous in the past for its silver production from ores containing pyrite, galena, sphalerite, and stibnite. Huine has yielded a few tons of copper ores containing tetrahedrite, bornite, chalcopyrite, galena, sphalerite, quartz, chalcedony, and calcite.

In the department of Puno, west of Lake Titicaca, are a number of districts that were at one time active, but which are now idle except in the vicinity of the Maravillas smelter, where argentiferous copper ores are being produced. Others, as Pomasi and San Antonio, yielded argentiferous galena ores with varying quantities of polysulphides. The districts of Ubinas, Ichuña, Tablabaya, and Huairurí in Moquegua also contain argentiferous ores of lead and copper, with lead more abundant than copper, and considerable sphalerite in some of the veins.

In Arequipa is the important silver district of Caylloma, in which the mines lie as high as 16,500 feet. The country rock is andesite in which the veins occupy well-defined fractures. The ores contain galena, sphalerite, pyrite, chalcopyrite, tetrahedrite, argentite, polybasite, pyrargyrite, native silver, and their oxidation products. The gangue minerals are rhodonite, quartz, and some barite and calcite. All the veins contain some gold. Sorted ores run as high as 300 oz. silver, and milling ores over 20 oz. The mines are operated by the Sociedad Explotadora de Caylloma.

COPPER

With few exceptions the copper deposits of Peru contain sufficient silver to make the latter an appreciable contributor to the values in the ores. These deposits have been described in geographic order in the preceding section. From the standpoint of production, the Cerro de Pasco and Morococha districts are preëminent, contributing about nine-tenths of the copper output, and are described in more detail on pages 475 to 483.

A few localities contain copper ores either without or with inconsiderable silver tenor. Of these a belt in the department of Ica extending from Ica to Nazca was at one time a considerable producer (76, 85). Bounding the desert pampas on the east, along the eastern edge of the department, is a range or series of hills made up of older rocks. Between Ica and Nazca, however, the range consists entirely of labradorite diorites with large basic and acidic segregations injected by more recent diorites, one of which is quartz diorite grading into granite. Dikes of andesite and flows of basalt are also encountered. The veins follow roughly parallel to the line of basalt eruption, and the basalt contains segregations of copper minerals, so that the mineralization may be genetically related to the basalt though the diorites form the wallrock of the veins. The individual veins are not of great length, have a nearly vertical dip, and are wide only in ore shoots. The ores occur in shoots and pockets separated by barren or lean zones. There is a north-south system of veins which are narrow and barren and occur in faults, and an east-west system of wider mineralized veins. The workings were confined almost entirely to the oxidized zone. Nearest the surface, the ore minerals are malachite, chrysocolla, atacamite, and cuprite; lower down are cuprite, native copper, malachite, azurite, and atacamite; still lower are small masses of covellite, chalcopyrite, chalcocite, bornite, pyrite, marcasite, pyrrhotite, and arsenopyrite. The gangue minerals are kaolin, clay, epidote, chlorite, tourmaline, quartz, calcite, gypsum, chalcedony, and the minerals of the wallrock. The chief centers of production were San José de Los Molinos, Canza, Tingue, and Nazca. At San José the ores averaged 6 to 12 per cent copper and the veins were from less than 1 m. to 2 to 4 m. in width, with ore shoots from 15 m. to 60 m. in stope length. The Canza ores averaged 9 to 12 per cent copper and less than 1 m. in width. The Tingue veins were still narrower. Most of the work at Nazca was on veins with a gold content containing chrysocolla.

At Huitor (30), near Yauyos in Lima, are two systems of veins with northwest and northeast strikes respectively, and nearly vertical dip, along the contact of metamorphosed shales and diorites. The ore consists of red hematite impregnated with oxidized copper minerals, mainly malachite and chrysocolla, with quartz and calcite gangue. The copper content is from 12 to 15 per cent. In Moquegua, in the Toquepala Valley, are abandoned copper mines in granite country rock. The Vesuvius vein, with north-south strike, 70° dip, and 8 m. wide, consisted of chrysocolla, malachite, azurite, cuprite, melaconite, and ferruginous quartz. Other veins also carried some calcite and were 2 m. to 5 m. in width. The copper content averaged 11 per cent. To the north and northeast of Ilo are similar ores containing also copper sulphides. The ore from the San Juan mine contained 20 per cent copper. At Cachi Cachi in Junín (77), melaphyre or andesite intrudes Jurassic or Cretaceous limestone, sandstone, and shale. The mineralization which is genetically related to the igneous rocks consists of cuprite, malachite, native copper, pyrite, hematite, limonite, quartz, and calcite. The copper ores of Checca in Cuzco are described as ill-defined deposits of bornite and calcite, a small shipment from which yielded 30 per cent copper.

LEAD AND ZINC

Lead deposits in Peru are mined only for their silver tenor and lead-bearing ores have been described in the section on silver. Junín contributes 84 per cent and Ancachs 11 per cent of the lead output. Occasional small shipments of zinc ores have been made from the Yauli district in Junín which is reported to contain large deposits. Otherwise sphalerite is described only as an accessory constituent of argentiferous copper and lead ores. This status of lead and zinc mining is due almost entirely to lack of cheap transportation facilities and not to a dearth of deposits of these ores.

IRON

Iron deposits of various sorts are mentioned at a number of Peruvian localities, but not much information is available concerning most of them. Tambo Grande (205), in the department of Piura, shows a group of outcrops in and about the town, of which the largest is a hill at the northern edge 100 m. long and 40 m. wide. The ore is red hematite, compact, earthy, or cavernous in texture, with kidneys and veins of quartz, angular fragments of quartzose rock resembling sandstone, and rounded fragments with conchoidal fracture like jasper. The pure material contains over 50 per cent iron and 18 per cent silica. The geologic relations of the occurrence are not clear as the ore outcrops project above a surrounding plain covered by a mantle of soil. Venturo suggests it may be a sedimentary deposit formed in a lacustrine or marine basin. If the isolated outcrops are continuous beneath the soil covering, the minimum horizontal dimensions of the ore body are 1,050 m. by 700 m.

On the west slope of the Cordillera Negra in Ancachs, are the deposits of Calleycancha and Aija. At Calleycancha, in sandstones and quartzites, with the nearest igneous rock a quartz diorite 5 km. to the south, are veins of loose micaceous hematite and quartz, 1.5 to 5 m. wide, containing 50 to 70 per cent iron, which are reported to be 6 km. long. They lie at an elevation of 11,000 feet, in two hills, China and Orco dominating the town, composed of sandstone and shale cut by andesite dikes. It is not clear whether the deposits are veins or contact deposits. The magnetite outcrops are 2 m. wide and 1½ m. high, contain 67 to 70 per cent iron and minute quantities of pyrite.

Huacravilca in Junín is located near the Jatunhuasi coal field (63). Two almost homogeneous masses of magnetite, frequently passing into dark-red hematite, outcrop at the contact of an acidic massif and Jurassic limestone and sandstone.

The ore analyzes 68 per cent iron, small sulphur content, and only traces of phosphorus. Dueñas estimates the tonnage at 64,000,000. Other localities in Junín are magmatic segregations of magnetite in granite at Torsioc and beds of micaceous hematite in slates and quartzite at Gallupacrestan.

On the Cerro Chunchulanca at Huine, Cuzco, are large hematite outcrops in quartz diorite and at the contact of biotite dacite porphyry and limestone.

ANTIMONY

A few tons of antimony ore were produced in 1915 in the departments of Cajamarca, Huánuco, and Junín, but the bulk of the production came from the department of Puno. These deposits were worked with some enthusiasm in 1906 and 1907, and then lay idle until 1915. The deposits occur in the vicinity of Santa Rosa, Tirapata, Juliaca, and San Antonio. The ores average about 59 per cent antimony. At La Raya, 8 km. north of Juliaca, sandstone, limestone, and conglomerate are cut by east-west veins, one of which is 5 m. wide.

BISMUTH

The bismuth production comes from the San Gregorio mine (187, pp. 585–586), Junín, about a mile east of Hauraucaca, where the ore is treated. The mine is near the base of a small hill that rises about 150 feet above the pampa, consisting of sandstone that varies in texture from quartzitic to saccharoidal. The ore deposit is in a brecciated mass of this rock. The ore consists entirely of oxidized bismuth compounds, said to be principally the arsenate. It occurs together with a yellow to brown clay as a filling of the brecciated sandstone. In places it fills the interstices between the sandstone fragments in the form of the light yellow bismuth compounds, but more generally it impregnates the yellow and brown clays. The crude ore averages about 3 per cent bismuth. The deposit has been worked in an open-cut with a length of 1,000 feet and a width of 80 feet. At a depth of 20 to 30 feet below the surface, the bismuth content is said to become very low, and as yet no sulphobismuthides or corresponding bismuth minerals of which the deposit might represent the gossan have been encountered. It is not clear whether the ores were deposited in their present condition or whether they represent oxidized remnants of primary minerals of a different character. Consequently the source of the bismuth cannot be explained. All that can be said is that the ore has been localized in the shattered portion of the sandstone.

The mine has been in operation since about 1905. During the first ten years the ore was concentrated to yield a 20 per cent market product, and 10,000 tons of middlings averaging 5 per cent accumulated. The present production is obtained by lixiviation and smelting of the middlings, so that mining has been temporarily suspended. The tonnage in sight is sufficient to supply the world's demand for bismuth for many years.

MERCURY

Mercury has been mined at Huancavelica in the department of Huancavelica and at Chonta in Huánuco. The Chonta occurrence is described on page 454. Huancavelica is one of the world-famous mercury deposits.

The Huancavelica deposits (200) were discovered about 1566 and the Santa Barbara mine at once became an important producer. The total output has been 50,000 tons of mercury, nearly all of which came from the Santa Barbara mine prior to 1790. The mine was abandoned after the independence of Peru until 1839, since which date numerous attempts to resume operations have been made without success, so that only a small production has been maintained. The mineralized belt extends discontinuously from Chunamachay in a southeasterly direction through Huancavelica to beyond San Antonio, a distance of about 60 km., and has a width of 1 to 3 km. The productive area, however, is restricted to the vicinity of the town of Huancavelica, in the Santa Barbara mine (Fig. 52). The town lies on the Huancavelica River at an altitude of 12,500 feet and the mine is on the mountain at 14,000 to 14,500 feet. The workings of this mine are caved to such an extent that the depth to which they penetrated is unknown. The average tenor of the ore is given as 2 per cent.

The prevailing rock of the district is Cretaceous limestone in which are intercalated zones of sandstone and shale. Conglomerates with large angular fragments and calcareous cement are widespread superficial deposits. The sediments are intruded by large masses of basalt and porphyrite, and along the mineralized zone are small andesite intrusions. The mineralized zone follows a belt of sandstones in the limestone, the ore usually impregnating the sandstones, but where they are more

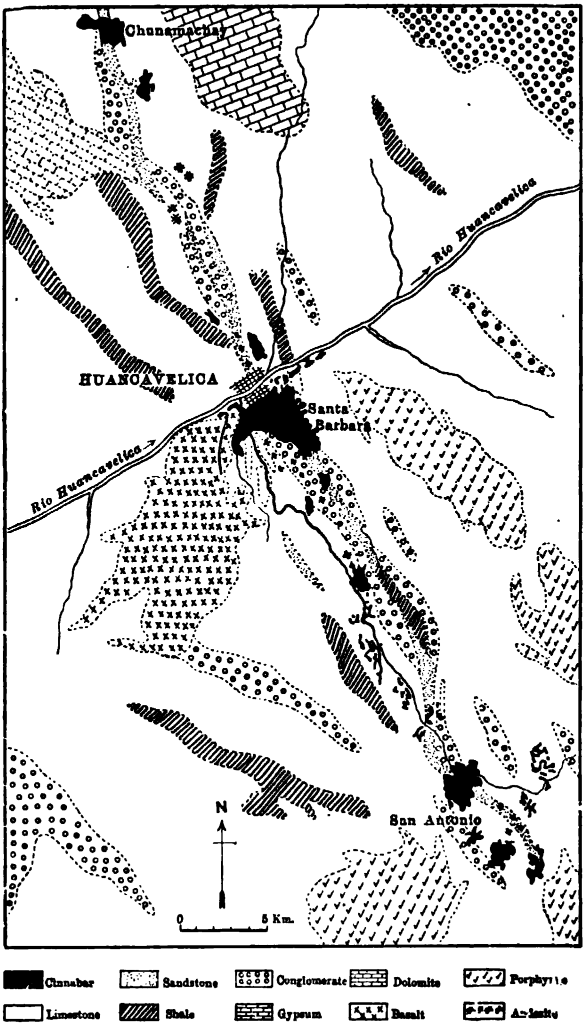

FIG. 52.—Geologic map of Huancavelica district. (*After Umlauff.*)

compact and their texture unfavorable and the limestone more fractured, the ore enters the latter. The masses of compact andesite are frequently surrounded by cinnabar, but have been very little impregnated by it. In other instances they are separated from cinnabar by a compact layer of barren sandstone. Umlauff summarizes the modes of occurrence of the ore as follows:

I. In sandstone occurs:
   1. In threads perpendicular to the stratification.
   2. In grains impregnating it.
   3. In slender masses.

II. In limestone occurs:
   1. In gash veins in joints in which cinnabar has crystalline structure.
   2. In small stockworks.
   3. In lenticular masses.
   4. As cavity filling in pulverulent form.

III. In conglomerates occurs:
   1. Disseminated throughout mass.
   2. A vein of detrital origin in basalt.

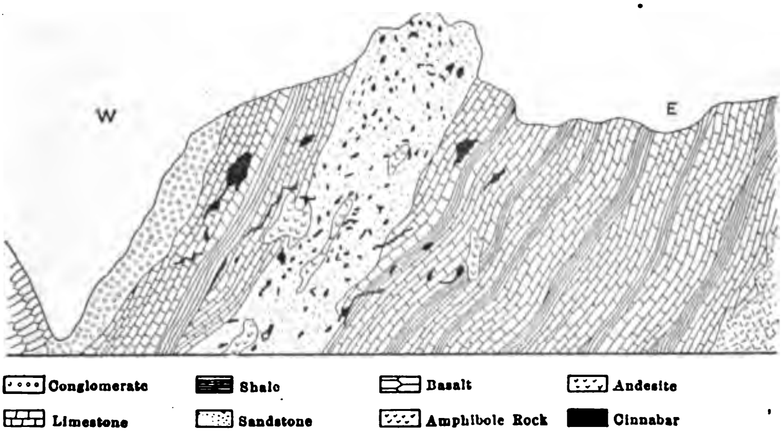

FIG. 53.—Vertical section of Santa Barbara ore body. (*After Umlauff.*)

Figure 53 shows the geologic position of the Santa Barbara ore bodies. The sandstone is a light-colored rock with occasional layers of bluish-gray limestone. The metalliferous zone spreads out in places to a width of 40 to 50 yards. The general appearance is of common sandstone with small particles of bright red cinnabar scattered through the mass. Associated minerals are native mercury of secondary origin, arsenopyrite, pyrite, marcasite, stibnite, realgar, galena, sphalerite, and bituminous substances.

MOLYBDENUM

The molybdenum production comes from Jauja province, Junín (58, pp. 93–95). These deposits are estimated to contain a considerable tonnage of ore averaging 5 per cent molybdenite, and the marketed product contains 80 per cent. The veins are in the upper portions of granitic intrusions and about their periphery on the east side of the central range, in what is known as the Ricrán region. At Turma the veins are quartzite near a granitoid rock and vary in width from a few centimeters to 40 cm. The ore consists of quartz and flakes of molybdenite with small quantities of chalcopyrite, pyrite, black and yellow sphalerite, and scales of white mica. The ore at Torrioc is similar. The veins measure up to 15 m. in width and occur in a hill of granitic to rhyolitic rock.

NICKEL

Nickel ores occur at Rapi, province De La Mar, Ayacucho (93, 162) and at Vilcabamba in Cuzco. The latter are described on page 459. The Cerro Cascamarca at Rapi is composed of limestones, sandstones, and quartzites resting on a diorite massif. It is cut by dikes of rhyolite and masses of serpentine are encounter in association with the ores. There are a number of nearly parallel veins with a strike north of west and width of 60 to 120 cm. The filling consists of silver, nickel, and cobalt minerals, and the veins have been worked for silver ores. The silver minerals are native silver, argentite, tetrahedrite, and occasionally pyrargyrite; the nickel minerals are niccolite, gersdorfite, ullmannite, and annabergite; and the cobalt minerals are cobaltite and smaltite. The niccolite is described as occurring in the form of kidneys. The average of several samples was 49 oz. silver, 26 per cent nickel, and 18 per cent cobalt. Gangue minerals are quartz, manganocalcite, and calcite. Pyrite and chalcopyrite also occur.

TUNGSTEN

The tungsten production comes almost entirely from a district lying on both sides of the Pelagatos River which forms part of the boundary between Pallasca province in Ancachs and Santiago de Chuco province in Libertad. The tungsten occurs chiefly as hübnerite in a quartz gangue, often mingled with tetrahedrite and occasionally galena. The Huaura deposits in Pallasca are described by Tarnawiecki (193). Sandstones and shales have been upheaved and contact metamorphosed by a granite intrusion which along the contact has greisen structure. The river has cut through the granite mass and exposed tungsten deposits on each side, but the greater mineralization is on the Huaura side. On this side the granite encloses enormous masses of sediments which have been folded and faulted into a great syncline along the contacts of which appear two immense quartz veins with parallel outcrops that are difficult to distinguish from the metamorphosed sandstone. Along this contact crystals of hübnerite and feldspar of unusual size were deposited. Subsequent movement reopened the contact and there was deposited comb quartz and small shoots of pyrite, tetrahedrite, and galena. In the earlier tungsten mineralization some apatite and massive quartz were deposited. Large well-defined quartz veins cutting granite contain no tungsten, indicating ore deposition took place only along the contact. The mineralized zone, including branching bodies of quartz, reaches as much as 100 m. in width. Two main streaks of tungsten-bearing quartz are 5 to 25 m. wide. Hübnerite occurs in irregularly distributed nests near the hanging wall and footwall of the veins and also in conspicuous crystals and crystal groups throughout the veins.

An occurrence that has been longer known, but not productive, is on the Cerro Julcani, 3 leagues northwest of Lircay, Angaraes province, Huancavelica (93). The country rock consists of green and dark porphyrites or diorite, more or less altered and impregnated with pyrite near the veins. They have a west to northwest strike, vertical dip, and width of a few centimeters which expands to 1.5 m. in pockets. The filling is quartz, pyrite, and wolframite, with small specks of gold. The veins have been worked for many years on account of their gold content, but not for tungsten.

VANADIUM

Vanadium is widespread in its occurrence in western Junín, south of the Oroya railroad, in association with asphaltite deposits. Those that have received greatest attention on account of their vanadium content are the deposits of the Yauli district (99, pp. 276–280). Extending southeastward from Yauli is a contact between eruptive rocks on the northeast and Jurassic and Cretaceous rocks on the southwest. The Jurassic rocks are coarse conglomerates and sandstones, the Cretaceous are prevailingly limestones with thin-bedded gray and green shales. Veins of asphaltite occur in the sediments parallel to the contact for 15 miles in the form of lenticular bodies from a fraction of an inch to 22 feet wide and with a maximum length of 500 feet, which approximately follow the bedding planes. The asphaltite, however, breaks through from one stratum to another and layers 5 feet thick may be separated by several inches of shale. Pencillate structure in the asphaltite and numerous small throws indicate movement subsequent to its introduction. The asphaltite is black, lustrous, softer than ordinary bituminous coal and has an average vanadic oxide content of 1 per cent.

The most important vanadium deposit in Peru, and doubtless in the world, is that at Minasragra, north of the railroad, where the vanadium content is much higher and the vanadium minerals are recognizable in the ore. This deposit is described on pages 487 to 491.

COAL

Coal deposits are distributed throughout almost the entire length of the Peruvian Andes and small productions, largely for local use, are reported from the departments of Cajamarca, Libertad, Ancachs, Huánuco, Junín, and Arequipa. In Junín, the mines of the Cerro de Pasco Mining Company at Goyllarisquisga and Quishuarcancha account for almost the entire Peruvian production. The output from these mines is used in the operations of the company. That the coal mining industry has not developed at other points is due principally to difficulties of transportation. Further, most of the deposits seem to be of limited extent, the seams irregular in thickness, and the coals high in ash. Local variations in the degree of metamorphism the deposits have undergone, gives a range in composition of the coals from lignitic to anthracitic. For the most part the coals are of Cretaceous age but on the peninsula of Paracas, Ica, are Carboniferous coals.

In Tumbez, coal occurs along the coast and outcropping in the hills and ravines. In the region of Tambo Grande, Piura, are a number of localities. Between Ferrenafe and Motupe, Lambayeque, is a zone of coal deposits. A promising locality in Libertad is Huayday, where there are two beds of anthracite, 1.5 m. and 2.3 m. thick respectively, the first of which is of good quality. Large deposits extend inland from the coast to Cupisnique and Trinidad in Cajamarca. In Ancachs are the important deposits at Oyón, located in the midst of a coal-bearing area extending from the department of Lima to Huallanca, with a length of over 200 km. and width of 55 km. The seams at Oyòn are notable for their number, thickness, and quality. They have been metamorphosed by igneous intrusions, so that the coal varies from lignitic to graphitic in character. The range in thickness is 40 cm. to 9 or 10 m., and the dip from flat to vertical, and is usually to the west. Some seams maintain a thickness of over 1 m. for considerable distances. The adjoining province of Chancay, Lima, contains the southward extension of the Oyón fields.

The Goyllarisquisga and Quishuarcancha mines (129, pp. 715–717) are located about 25 miles north of Cerro de Pasco, with which they are connected by railroad lines. The country rock of the region is primarily sandstone, but there are numerous layers of limestone and shale in addition to the coal seams. At Goyllarisquisga are four workable beds known from top to bottom as First Cap, Second Cap, Parallel, and Principal. The First and Second Caps thinned out and disappeared in depth. They had a maximum thickness of 3 and 4 feet respectively. The Parallel bed is the most persistent, has an average thickness of 6 feet, and maximum of 12 feet. The Principal has an average thickness of 10 feet and a maximum of 60 feet. The interval between the beds is variable. In some places the Parallel and Principal are separated by only a narrow band of fire-clay, elsewhere they are as much as 10 feet apart. At Quishuarcancha there is but one bed, usually 5 to 8 feet thick, but in one place 50 feet. The beds are disturbed by gentle folds and faults which in most instances have small throws.

The Goyllarisquisga coal contains numerous nodules of pyrite, especially in the lower portions. At Quishuarcancha are great concretions as much as 20 feet in diameter, rich in pyrite, which in places practically cut the coal out completely. Within the seams are frequent lenses and pockets of brown clay which give the coal a high ash content. In places they are so abundant as to render the coal worthless. The washed coal produces a satisfactory coke for the Cerro de Pasco Mining Company's smelter. The following analyses indicate the character of the coal:

	B.t.u.	Volatile Matter	Fixed Carbon	Ash
Goyllarisquisga coal..............	9,930	36.8	30.7	32.5
Goyllarisquisga steam coal washed.	12,425	44.9	37.1	18.0
Goyllarisquisga coking coal........	12,300	40.6	40.8	18.6
Quishuarcancha raw coal..........	9,980	36.7	35.7	27.6

Another coal region of considerable extent and promise in Junín is on the eastern slopes of the western range in the provinces of Huancayo and Jauja. The outcrops extend from Cochas to Vilca. The coals at Jatunhuasi were formerly coked for use in the Yauli smelter. They range in composition from 24 to 41 per cent volatile matter and 5 to 26 per cent ash. The thickness is commonly 50 to 80 cm. with a maximum range of 25 to 140 cm. The seams outcrop at elevations of 12,500 to 15,000 feet.

Drilling on the peninsula of Paracas, Ica (55), indicated two seams of coal, an upper one 60 cm. thick and 100 feet lower down one of 120 cm. thickness. The strata are Carboniferous shales and sandstones with north-south strike cut by rhyolite porphyries forming series of north-south trending hills across the peninsula. Analyses of both seams are similar; the lower one showed 3.05 per cent moisture, 35.16 per cent volatile matter, 52.8 per cent fixed carbon, 8.99 per cent ash, 0.34 per cent sulphur, and 7,634 calories.

Peat deposits occur at a number of localities in Peru. Peat has been quite extensively used as fuel for the mining and metallurgical operations at Caylloma, Arequipa. The Caylloma deposits are 400 m. to 1,500 m. in diameter, and contain as high as 7 m. of good peat, analyzing 4.5 per cent moisture, 47.6 per cent volatile matter, 40.90 per cent fixed carbon, 7 per cent ash, and 5,000 calories. Near Cuzco are peat occurrences 3 m. thick with the composition 49.7 per cent volatile matter and water, 21.26 per cent fixed carbon, and 29 per cent ash. Porous and black peat near Cerro de Pasco contains 3 per cent ash and 15 per cent fixed carbon. At Apaicancha, Junín, is an occurrence covering three-fourths square mile, 2 to 3 m. thick, with the composition 14.5 per cent moisture, 36.7 per cent volatile matter, 27.5 per cent fixed carbon, and 21.3 per cent ash. In Loreto, on the banks of the river Cahuapanas, are deposits of varying thickness.

PETROLEUM (53, 16)

The northern oil field of Peru is the most productive in South America. The first serious operations in this region commenced in 1870 at Zorritos. The convenient and accessible location along the sea coast has led to continuous developments and increase in the area of proved territory. The field extends from latitude 3° 30′ S to 6° 30′ S, and from the Pacific to the foot of the western range or outliers of it, covering an area of 10,000 square miles. The stratigraphic sequence from top to bottom is: massive, well-cemented conglomerates; thick, horizontal beds of clays of different colors alternating with sandstones; alternating sandstones and clays of various colors with loose sands and conglomerates lying in an inclined position; discordantly beneath the latter a series of more compact, dark, fine-grained sandstones alternating with shaly beds, which contains the petroliferous horizons; and a series of metamorphic shales which lie in contact with crystalline rocks. The oil-bearing beds are of Eocene age.

The structure of the field is broken, but essentially monoclinal, with the beds dipping east. Though there are some anticlines, the production is principally from monoclines with local saturation due to strike and dip faults. The petroleum impregnates the sandstones, but the impregnations are isolated, irregular, and limited in area. As a rule the deeper the horizon, the more important the occurrence. Initial production has been as high as 800 barrels, but regular flow soon settles down to 4 to 7 barrels. The oil averages 32° to 34° Baumé, 15 per cent gasoline, 35 per cent kerosene, and 50 per cent residuum with an asphaltic base. Production is over 2,500,000 barrels annually. The principal productive areas are Zorritos, Lobitos, Negritos, and Lagunitas.

In the Zorritos area, oil is encountered at 252 feet, but the best horizons are at 400 feet and between 1,500 and 1,750 feet. The deepest holes, maximum 2,902 feet, are not in oil sands. There are 27 producing wells, yielding as high as 3,600 gallons daily, averaging 38.4° Baumé. The operations are conducted by a Peruvian company and most of the oil refined at Zorritos.

The Lobitos area, discovered in 1901, has 115 producing wells.

Two important horizons lie at 1,500 to 2,000 feet and 2,800 to 3,200 feet respectively. A third horizon, presumably at 4,500 feet, is being drilled. The operator is an English company and the oil is exported unrefined.

Talara is the port for the Negritos area, which is developed by a subsidiary of the Standard Oil Company. There are 480 producing wells, of which the deepest and most productive are at a depth of 3,900 feet. The oil is partly refined at Talara. The Lagunitas field, productive since 1911, adjoins the Negritos on the northeast and has 192 producing wells.

In central Peru are petroleum indications, but they have been scarcely explored. In Ica, south of Pisco, in the Paracas region, are Tertiary beds of the same age as those in the northern field which are supposed to be petroliferous on account of the presence of solid hydrocarbons; and southwest of Nazca are dark limestones that manifest the odor of petroleum in fresh fractures. Solid hydrocarbons are found in limestone in the Huallanca district, Huánuco. Oil probably occurs in the asphalt regions of the provinces of Tarma and Jauja, Junín, in the lower Cretaceous bituminous limestones, as seepages are found at Yauli, Oroya, and other points along the Mantaro River. The existence of petroleum is assumed at Condorocana in Angaraes, Ayacucho, and near Chumpi in Parinacochas. At the latter place, almost pure asphalt impregnates porphyritic rocks.

Better known and at one time productive, is the field in southern Peru in the provinces of Canas, Lampa, Azángaro, and Huancané of the departments of Cuzco and Puno. The best known occurrences are at Pallpata in Canas and Pusi in Huancané. At both localities are exudations of dark brown oil, poor in volatile constituents and rich in residuals with a paraffin base. The oil-bearing zone follows an anticline with much dislocated flanks, having a northwest strike, in a series of shales, sandstones, and limestones of various colors and character.

At Pallpata the oil flows from a greenish-colored sandstone overlying a limestone that seems to be petroliferous. The area has not been explored.

The Pusi field was drilled in the vicinity of Pirín in 1905. Oil was encountered at 120 to 250 feet and the holes sunk to 700 feet. One of the wells was a gusher and later yielded 50 barrels by pumping. In 1910, the output was 50,000 barrels, but production has since ceased.

ASPHALT

In the valley of the Mantaro, southern Junín, in the provinces of Tarma and Jauja, are veins of asphaltite, 1 to 3.5 m. wide, in lower Cretaceous or Jurassic limestones with intercalations of sandstones and marls (58, pp. 62–72; 191). The strata strike northwest and generally dip southwest. The asphalt occurs practically pure in fractures in the rocks. Among the localities at which such deposits are known are Yauli, described on page 467, Oroya, Huari, Chacapalpa, Llocllapampa, and Cochas. In the vicinity of Huari they have been worked for use as fuel and more recently for street paving in Lima. Noteworthy is the vanadium content. The Chuichos mine, near Huari, at one time furnished 900 tons monthly used as fuel at Morococha. The occurrence is an almost vertical vein in limestone consisting of shoots with a maximum length of 650 feet and varying in width from mere stringers to 50 feet. The ash contained 8 per cent V_2O_5. La Lucha mine in the same vicinity is furnishing asphalt for paving purposes from a vein 1 to 3.5 m. wide.

BORATES

The Peruvian borate production comes from the Laguna de Salinas on the boundary between the departments of Arequipa and Moquegua, 12 leagues from Arequipa (108). The lake is 6½ leagues in circumference, lies at an elevation of 14,200 feet, and is surrounded by a group of volcanoes including El Misti, which rise to elevations of 18,000 to 20,000 feet. The lake is dry nearly the entire year, and the borates form a discontinuous layer of varying thickness. The uppermost saline crust consists of chloride and sulphate of soda and is followed successively by 10 to 14 cm. fine sand, 6 cm. coarse sand, 20 to 50 cm. sand with layers of borate, occasionally thin layers of sand, and a 40 cm. to 1 m. layer of borates. The mineral is ulexite, or boronatrocalcite, containing 30 per cent boric acid in the crude state and 52 per cent after calcining. The operations are conducted by the Borax Consolidated, Limited.

SALT

The salt industry is under the control of the Compañía Salinera Nacional, supervised by the government. The production comes from *salares* along the coast, beds of rock salt, and the evaporation of saline spring water. South of Sechura, in Piura, is a depression into which the Piura River overflows in the rainy season. It has leached the saline ground over which it flows, and salt is deposited upon the evaporation of the water in the depression. The Salinas de Morrope in Lambayeque contain a layer of salt from a few to 50 or 60 cm. in thickness, covered by at least 20 cm. of sand, over an area 10 km. long and 6 km. wide. At Guadalupito, Libertad, is a saline marsh of ground-water moving toward the sea. Salt accumulates in ditches cut in the marsh through evaporation by sun and wind. Other important producers of similar character to the preceding are the Salinas de Casma, Ancachs, and the Pampas de las Salinas near Playa Chica, Lima. The latter represent dessicated cut-off arms of the sea in which the quantity of salt has been augmented through the aid of ground-water resulting from the condensation of fogs. The deposit is 2 miles long, 1 mile wide, and in places several yards thick. It is taken out as rock salt of various degrees of purity according to depth, the purest at the bottom.

At San Blas, Junín, 8 to 10 m. of rock salt are being removed from a bed of unknown thickness. Rock salt is also mined at Cachi in Huancavelica. At Maras, Cuzco, a stream of salt water, emitted from a mountain, flows down a gulch emptying into the Urubamba River. The water is evaporated in the dry season.

SULPHUR

Marsters (126, pp. 121–122) describes a sulphur deposit at Reventazón, Piura, where operations were established in 1904. The workings are open cuts on a knoll in which a somewhat coarse firm sandstone is underlain by loose sand. Sulphur occurs at the contact and impregnating the sandstone to a depth of 8 feet. The average grade is 10 to 20 per cent but the richest material, that at the contact, contains 30 to 40 per cent sulphur. The origin of the deposit is not clear, but Marsters thinks it was liberated from petroleum. At Chuquiquillán, Pallasca province, Ancachs, at an elevation of 9,000 feet is a deposit of sulphur and alum that has not been developed or explored. Resting on quartzite is a succession of beds of shale, gypsum, and sulphur, iron and aluminum sulphate, and gypsum and marls with iron and aluminum sulphate. Most of the sulphur is found in association with gypsum and clay in layers from 2 to 40 cm. thick.

GUANO

A few words regarding the guano deposits may not be amiss. The guano deposits extend along the coast from the southern extremity to about latitude 6° S. They have been worked since 1842, and yielded millions of tons of guano. The production is now rigidly regulated by the Peruvian government in order to conserve and provide for the augmentation of the deposits. The guano-bearing areas are divided into zones workable at intervals of three and four years. In 1890 the Peruvian Corporation leased the privilege of extracting 2,000,000 tons, of which three-fifths have been removed. The other large producer is the Compañía Administradora del Guano, Limitada. The annual production amounts to about 100,000 tons. The main habitats of the guano-depositing birds are the Chincha Islands, next in importance are the Lobos Islands. In some places the guano is 8 to 10 feet deep.

DESCRIPTION OF IMPORTANT DEPOSITS

The Cerro de Pasco District

History.—The Cerro de Pasco mining district was discovered in 1630 and until 1898 was a silver-mining camp. During this period only the oxidized, or *pacos*, ores were worked and it has been estimated that a total of 9,000,000 tons of ore yielding an aggregate of $565,000,000 was taken out. After the district had long been on the decline, it suffered a great setback in 1893 when the price of silver dropped, and another in 1897 when the Peruvian government refused to coin any more silver.

The copper-sulphide ores had been worked only sufficiently to supply the copper sulphate required in the *patio* process, but in 1897 the smelting of these ores to matte was commenced. Ores ranging above 30 per cent copper were exported to Europe or sold to the Yauli and Casapalca smelters, and those lower in copper were reduced to matte for exportation. The first blast furnace in the region was that of E. E. Fernandini at Hauraucaca. In 1898 an American syndicate became interested in many of the mines, and in 1902 the Cerro de Pasco Mining Company was organized. This company's smelter at La Fundicion was put in operation in 1906 and again placed Cerro de Pasco among the foremost metal-producing districts of the world, but this time as a producer of copper.

The principal operator is the Cerro de Pasco Mining Company, but E. E. Fernandini, a Peruvian, is an important producer though on a much smaller scale, and in addition there are several small producers. The Cerro de Pasco Mining Company obtains its coal supply from its own mines to the north of Cerro de Pasco; has at La Fundicion, 14 km. south of the mines, a smelting plant that is producing over 6,000,000 lbs. of copper per month; has built near Oroya a 12,000 hp. hydro-electric plant with a 70 mile transmission line; and the company completed and operates the Cerro de Pasco Railroad, running from Cerro de Pasco to connect with the Ferrocarril Central del Perú at Oroya, a distance of 132 km., with branch lines to the coal mines, 58 km. long.

The output of the Cerro de Pasco mines is over 30,000 tons per month. The ores carry copper as the most valuable constituent, with appreciable quantities of silver and gold. The average grade of the ore shipped from the district is about 11 oz. silver and 7 per cent copper. The ratio of precious metals to copper is such that the blister copper carries 1 oz. gold and 140 oz. silver per ton.

Geology.—The Cerro de Pasco district (186) is situated in the midst of a group of low hills on the *pampa* between the western and central ranges of the Andes at an elevation of a little more than 14,000 feet. The greater part of the country in the vicinity consists of limestones and limestone conglomerates associated with which are some shales and sandstones. These sedimentary rocks are of Mesozoic and probably chiefly Cretaceous age. They have been cut by numerous igneous intrusions, and immediately to the west and northwest of the town of Cerro de Pasco is an area of igneous rock surrounded by limestone, which has a diameter of about 1¾ miles and has the composition of rhyolite. Roughly, the western part of this area of igneous rock consists of rhyolite and the eastern part of rhyolite agglomerates and tuffs. The ore deposits are found mainly in the rhyolite agglomerates and tuffs, and the greatest mining activity has centered in the southeastern part of this area in the immediate vicinity of the city of Cerro de Pasco (Fig. 54).

Oxidized Ores.—The area between the Esperanza and Diamante shafts was the scene of the greatest activity in the days when this was a silver-producing camp. Down to a depth of as much as 100 feet this area was underlain by a great mass of oxidized argentiferous material known as the *pacos* ores, the richer portion of which was worked first by means of open cuts and later also by shallow underground mining. The huge caves left unsupported have since collapsed and increased the size of the open cuts, leaving the series of immense pits, or *tajos abiertos*,

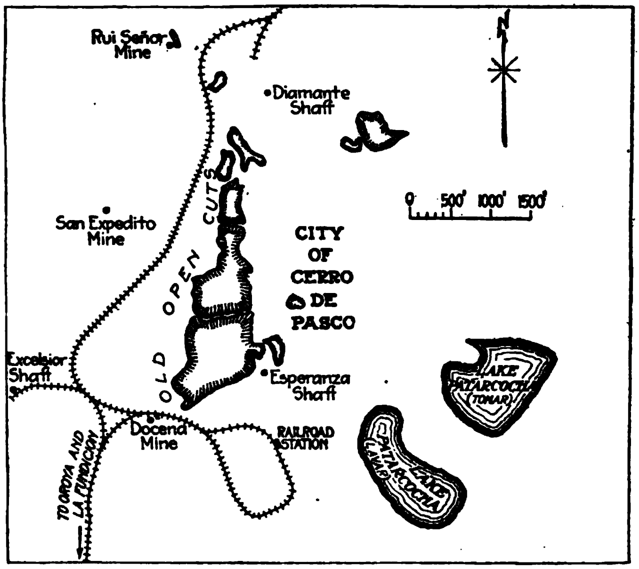

Fig. 54.—Sketch map of part of Cerro de Pasco district.

as evidence of the great amount of material removed in those days. The silver content of the *pacos* material left behind varies greatly, but the copper content is almost uniformly negligible. It is an excellent example of enrichment in silver and leaching of copper in the zone of oxidation. Even to this day local patches of *pacos* ores are found that carry enough silver to make them profitable and are worked by raising on them and allowing them to cave into the lower suphide stopes. The oxidized ores, which were the source of the Cerro de Pasco's riches for several centuries, are of practically no importance in the present mining activity of the district.

Sulphide Ores.—Below the oxidized zone an enormous mass of low-grade pyritic ore is encountered that for the most part is too low-grade to be workable at present. At the north end, in the vicinity of the Diamante shaft, there is a layer of rich copper ore between the zone of oxidation and the deeper-lying pyrite. On the other hand, the latter in depth grades over into an ore carrying appreciable quantities of galena and sphalerite. A little farther south toward the Esperanza shaft, the principal ore shoot of the mine, the Piña Blanca, is encountered. This ore is a mixture of pyrite with enargite and famatinite, and in places consists almost entirely of the copper minerals. Here and there a little patch of galena is found, and from level 4 down, the north side of this ore shoot carries abundant galena and sphalerite. Several distinct veins of high-grade ore of the kind found in the Piña Blanca cut the mass of low-grade pyrite. Much of this rich ore consists of soft drusy enargite and famatinite and has the appearance of secondary sulphides formed within the mass of lean primary pyritic material. Such an interpretation is contrary to the evidence of Graton and Murdoch, obtained in their study of the copper minerals in general, who say "the mineral (enargite) appears to be practically in all cases primary," and the richer shoots may simply be due, to a large extent, at least, to primary sulphide enrichment.

This sulphide-ore mass is evidently a replacement stock in a country rock of rhyolite agglomerate and tuff. About its periphery there has been also a great deal of silification, so that considerable dark cherty-looking silica occurs in places, for the most part as bands and lumps that grade outward into soft altered rhyolitic material.

Separated from the larger sulphide mass by about 100 to 200 feet of intensely sheared rock, the original character of which has been obscured by the metamorphism, but which is probably the same igneous material, is a smaller orebody known as the Noruega. This lies to the east of the south end of the Piña Blanca. It is an orebody evidently identical in character and genesis with the other. The country rock is a soft altered rhyolitic rock in places grading into the same kind of black cherty silica impregnated with more or less pyrite. The main ore mass consists of a lean pyrite that is frequently so sugary in texture as to readily disintegrate to a sand which it is almost impossible to keep from running in the stopes. Within this are the richer shoots of enargite ore.

Cross-veins.—An entirely different type of orebody is represented by the cross-veins, which are a series of veins with an east-west strike on the west side of the suphide stocks. The most important of these are found in a belt directly west of the south end of the Piña Blanca shoot. They have a northerly dip of about 67° and an average width of 5 feet. In order from south to north, the principal ones are known as the Cleopatra, the Docena, the Bolognesi, and the San Anselmo. Quartz and pyrite are the most abundant minerals in the vein filling; the principal copper minerals are enargite and famatinite; considerable tetrahedrite and some chalcopyrite occur. Luzonite, a dimorphous form of enargite, is also found. Rich pockets and shoots also occur in the veins, but on the whole the copper minerals are sufficiently well distributed to make the veins workable through practically their entire extent.

The country rock of the veins consists of the various phases of the rhyolitic rock. Near the Esperanza shaft it consists of the highly sheared rock mentioned in connection with the sulphide masses; farther west it passes into the rhyolite agglomerate; and in the vicinity of the Excelsior shaft it is the true rhyolite.

Operations.—The Cerro de Pasco Mining Company is working these orebodies through three shafts, of which the Esperanza, about 900 feet north of the railroad station, is the principal one. The sulphide stocks are worked through it and the Diamante shaft a little over a half-mile to the north, and the cross-veins through it and the Excelsior shaft about the same distance to the west. The maximum depth reached is 600 feet. An important independent mine in the belt of the cross-veins is the Docena. Several smaller mines are working veins of similar character to the north of these, among which the most important are the Rui Señor and the San Expedito.

Since the *pacos* silver ores are no longer a factor in the district, the many small *patio* plants have long been abandoned. The small copper-matte smelters were not able to compete with the two large smelting plants and have also succumbed. The presence of modern smelting works has done away with the advantage of exporting the richer ores, and consequently all the product on of the district is handled in the two works of the Cerro de Pasco Mining Company and E. E. Fernandini.

THE MOROCOCHA DISTRICT

History.—The Morococha district (188, pp. 889–892) lies on the east side of the Cordillera Occidental in the department of Junín, a short distance to the north of the Oroya railroad with which it is connected by a branch line 9 miles in length that crosses the divide at an elevation of 15,865 feet and then descends to the town of Morococha at an elevation of 14,800 feet.

Morococha is one of the old mining districts of Peru and in its earlier history furnished argentiferous lead ores with more or less gold. After the independence of Peru was established, there was but little activity in the district until the advent of L. Pflücker & Sons in about 1850. They erected an amalgamation and lixiviation plant at Tuctu and enjoyed practically a monopoly of the district until 1886, when the Monteros came in and planned developments on a large scale which only in part materialized. They erected a concentrator below Lake Huascacocha and began the construction of a narrow-gauge railroad connecting the mines, but which was never completed. The richer ores in these days carried as high as 50 per cent lead and more ounces of silver than per cent of lead.

Before 1894 the only copper ores worked in the district were sulphates from the oxidized ores of the San Miguel mine, for use in the Tuctu plant. In that year larger-scale operations were started at this mine, and from that time the district was gradually converted into a copper camp, until now the argentiferous lead ores are completely neglected. The district rivals Cerro de Pasco as the most active and important metal-mining district in Peru. Two factors have brought this about—the advent of the railroad and, to an even greater degree, the entrance of American capital a dozen years ago, the Cerro de Pasco Mining Company and the Backus and Johnston Company.

The monthly production has reached 20,000 tons of ore averaging about 12 oz. silver and 10 per cent copper. Most of this comes from the mines of the Morococha Mining Company and of the Backus and Johnston Company. That from the mines of the former company is smelted at the smelter of the parent company, the Cerro de Pasco Mining Company; and that from the mines of the latter company at their smelter at Casapalca. The remainder comes chiefly from the La Huillca and La Vieja mines of the Sociedad Minera La Huillca, a Peruvian company, and from the Alexandria mine. The ores from the former are treated at a small customs plant on the shores of Lake Huacracocha, and those from the latter at the Casapalca smelter. The ores of smaller operators, aggregating a very small tonnage, must be disposed of to the three plants already mentioned.

Geology.—The district lies in a nearly east-west trending valley with its outlet to the east, though the railroad comes in over the divide from the west, bordered by extremely rugged and high mountain ranges; those on the north side are covered by numerous glaciers and culminate in the magnificient pyramidal, glacier-covered peak of Yanaginga. In the valley are three large lakes known respectively from west to east as Huacracocha, Morococha, and Huascacocha, with elevations of 15,200, 14,800,

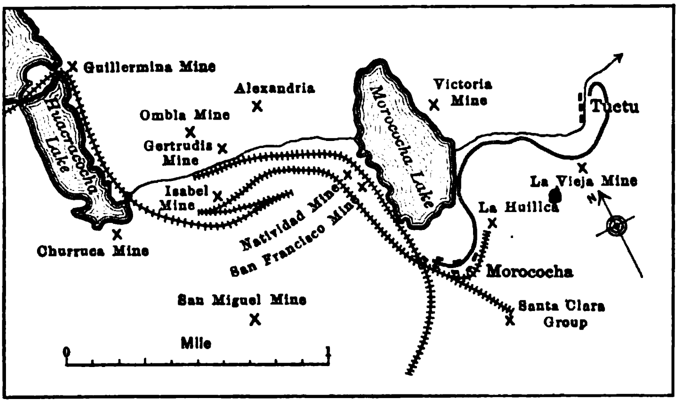

FIG. 55.—Map of central part of Morococha district.

and 14,300 feet respectively. The town of Morococha lies at the south end of Morococha Lake, and the active portion of the district centers about it. The section of greatest activity lies between Huacracocha and Morococha Lakes and is comprised within an area roughly one mile square. Another active area is above the town (Fig. 55), in the gulch opening into Morococha Lake from the south.

The geology of the district has not been worked out, but it is apparent from merely a hasty visit that it offers many interesting problems. Both igneous and sedimentary rocks occur. The sedimentaries consist of a great series of limestones and quartzites of Mesozoic age, in part, at least, Cretaceous. Two kinds of igneous rock are of importance in connection with the ore bodies, which formerly went under the names of andesite and greenstone but which have been determined by Prof. C. P. Berkey, of Columbia University, to be porphyry and peridotite. The ores occur in both the sedimentary and the igneous rocks.

Ore Deposits.—Two kinds of ore occur in the district—the silver-lead ores, which are not being worked, and the more or less argentiferous copper ores that provide the present output. The ores of the latter class average from 8 to over 10 per cent copper with a silver content in ounces somewhat greater than the percentage of copper. Under favorable conditions ores running as low as 5 to 6 per cent copper can be worked.

It is doubtful whether any other mining district of equal area possesses such a diversity of ore bodies as regards shape and geologic position as does this district. From point of output, most important are the veins in the porphyry. Where these veins reach the contact of porphyry and peridotite, if the contact is steep, they rapidly fray out, but, if relatively flat, the ore body spreads along the contact to form the flat-lying masses of considerable horizontal extent known as *mantos* (Fig. 56). The filling of the veins usually consists of quartz, pyrite, enargite, and tetrahedrite. The relative abundance of the last two minerals varies from vein to vein and even in different stopes of the same vein. In some veins sphalerite is a prominent constituent. The San Francisco mine, the most important producer of the district, illustrates admirably these features. It is working a system of branching veins with an east-west strike and variable dips ranging from 60° N to 70° S.

The other extreme is represented by veins entirely in limestone, as in the Ombla mine. These are replacement veins in which replacement has been particularly prominent along certain beds, causing local horizontal enlargements which may be repeated at several horizons. In some cases the original bedding of the limestone is preserved in the ore. The ores of these veins are characterized by the predominance of chalcopyrite with some bornite as the copper minerals, to the subordination or almost complete absence of the sulphantimonides found so abundantly in the veins in the igneous rock. The principal filling is quartz and pyrite with a little sphalerite and galena.

A closely allied type is represented by replacement veins in limestone of the same nature as the preceding, but which are terminated by a great *manto* at the contact of the limestone with overlying peridotite. The Isabel ore body is of this type (Fig. 56). A fourth type is that of *manto*-like replacements in limestone lying upon a footwall of igneous rock which is cut by narrow veins with the same filling as the *manto*. The Guillermina mine belonging to this type supplies rich silver ores characterized by the presence of rhodonite and rhodochrosite. Still another type is illustrated by the Churruca mine, which seems to be an irregular replacement in limestone. The chief copper mineral is chalcopyrite.

Chalcopyrite appears to be more characteristic of the ores in limestone, occurring in but small quantity in those in the igneous

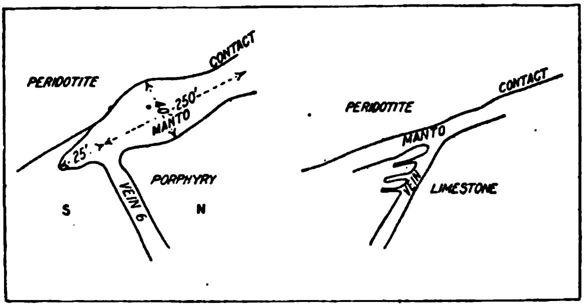

FIG. 56.—Veins terminating in *mantos*. At the left is vein 6, San Francisco mine, terminating at the flat contact of porphyry and peridotite. At the right is the termination of a vein, in the Isabel mine, as *manto* against peridotite contact, with enlargements along bedding planes on hanging-wall side.

rock. The conditions of occurrence of enargite are almost the opposite, whereas tetrahedrite is found abundantly in both. Pyrite and quartz are the most abundant minerals and are always present; rhodochrosite and rhodonite are local in their occurrence. Galena is not very abundant in the copper ores, but in some of the mines sphalerite occurs in large quantity.

THE CASAPALCA DISTRICT

The present mining activity in the Casapalca district (188, pp. 892–893) centers on the Cerro Casapalca, a mountain rising above the town on the east from an elevation of 13,600 feet at the Backus and Johnston smelter to over 17,000 feet at its summit (Fig. 57). The most important producer is the Carlos

Francisco mine. Other producing mines are the Aguas Calientes, Carmen, and San Antonio. The Chuquichuccho and Santa Rita are under development. The ore bodies are for the most part veins in andesite, but some extend beyond the igneous rock into the limestone which it intrudes. The Carlos Francisco mine has a monthly production of 6,000 tons, the average grade of which is 25 to 30 oz. silver, and 1¼ to 1½ per cent copper. This tonnage is obtained from the ore in place and by reworking the upper dumps of the mine. The crude ore is concentrated and the total product that goes to the smelter aggregates 3,000 tons monthly, averaging 40 oz. silver, 2 per cent copper, 5 per

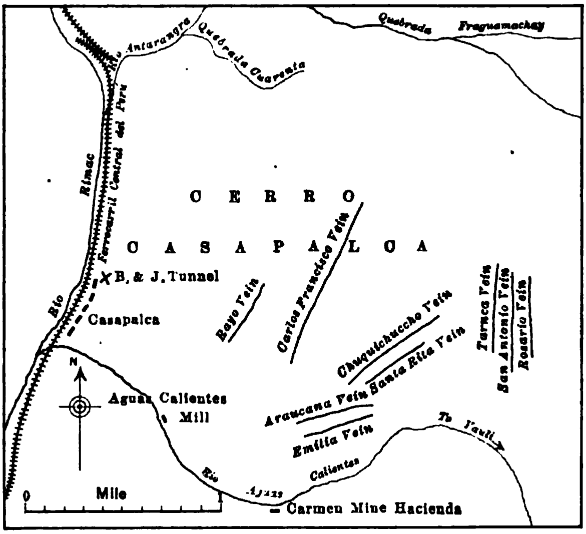

FIG. 57.—Map of active part of Casapalca district.

cent lead, 13 per cent zinc, 5 to 10 per cent iron, and 20 per cent silica.

The principal vein of the mine is the Carlos Francisco, which is cut by a tunnel from Casapalca one mile long, at a distance of 2,700 feet below the outcrop. At the time the tunnel was driven this was at a depth of 1,700 feet below the lowest workings. About 2,600 feet from the entrance, the tunnel cuts a vein known as the Rayo, but no work is being done on it. The strike of the vein is nearly north-south and it dips to the west at an angle of 60°. Though it pinches to a width of 1 foot or less and swells to as much as 12 feet, the average width of 2½ feet is maintained with considerable constancy. For a distance of about 2 km. along the strike, the country rock is a silicified andesite, but at each end the vein passes out into limestone. The present operations are confined to the vein in the andesite.

The most abundant minerals in the vein filling are quartz and pyrite with tetrahedrite as the valuable constituent. There is little chalcopyrite present, and galena and sphalerite are not abundant. The ratio of silver to copper in the ore shows a gradual decrease with increasing depth, so that, whereas in the upper levels this ratio was 1: 20, in the lower levels it is only 1:30.

The fact that this vein has been developed through a vertical distance of 2,700 feet without reaching its limits and that it is continuous throughout this extent with a fairly uniform width and character of filling marks it as truly a remarkable vein.

The Aguas Calientes mine is working the southern extension of the Carlos Francisco vein, and produces monthly 600 tons of sorted ore and mill concentrates averaging 100 oz. silver and 3½ per cent copper.

The monthly production of the Carmen mine is 600 tons of hand-sorted ore, of which one-fourth is first-grade, carrying 150 oz. silver and 2 per cent copper, and the rest second-grade, carrying 50 oz. silver and 1 per cent copper. It is working the Araucana and Emilia veins.

The only ore in the district with ruby silver and with sufficient gold to be paid for is that produced by the San Antonio mine. Its output is all hand-sorted and consists of about 10 tons of first-class ore with 200 oz. silver and 500 tons of second-class with 50 oz. silver and 1½ per cent copper.

THE COLQUIJIRCA DISTRICT

The Colquijirca silver mine is on the eastern slope of the hill on the opposite side of which, and about 1½ miles to the southwest, is La Fundicion, the Cerro de Pasco smelter (187, pp. 586–587). The mine is owned and operated by E. E. Fernandini. The daily output is 80 tons of ore averaging 70 oz. silver per ton. The lowest grade that can be profitably worked is about 50 oz. silver. The ore is treated at Fernandini's Hauraucaca smelter by concentration and smelting.

Geology.—The country rock consists of a series of limestones underlain by shales, in which are intercalated beds of coarse and fine conglomerates with a shaly matrix. Within the limestone series itself are impure shaly beds and beds of sandstone of very local occurrence. The formations have a north-south strike and a general easterly dip which has been modified by two minor synclines.

Ore Deposits.—The ore deposits consist of two beds of ore intercalated in the limestone series, which represent replacements of the limestone, and they are separated by a parting of variable thickness but averaging a little more than 2 m. Owing to the folding, the ore horizons outcrop at four points across the section. These outcrops are marked by a series of trenches on the hill-side resulting from the extraction of the gossan ores in years gone by. Similar replacements, but on a smaller scale and not resulting in workable ores, have been encountered at lower horizons by a crosscut tunnel.

The limestone has been replaced chiefly by black, cherty-looking silica and by pyrite. In some places the *manto* consists almost wholly of the chert, at others almost entirely of pyrite, and then again both minerals are present in abundance. Associated with these minerals, in subordinate amounts but in sufficient abundance to be prominent constituents of the ore, are galena and barite, and the amount of silver the ores carry seems to be closely related to the quantity of these minerals present. The smaller *mantos* referred to in the footwall consist almost entirely of pyrite and are unworkable on account of their meagre silver content. On the other hand, the quantity of galena and barite is not an invariable indication of the quantity of silver the ore carries. It is found that when these minerals are coarsely crystallized, there is less silver than when they occur in smaller crystals, a difference that is especially marked in the case of the galena. The barite in particular occurs in druses and small cavities as a network of interpenetrating tabular crystals, and it and the galena to a less extent have the appearance of having been introduced later than most of the silica and the pyrite. Associated with the minerals already mentioned, especially in the south end of the mine, a little chalcopyrite is encountered here and there. In the richest ores a little tetrahedrite and probably other sulphurets can be recognized.

The mine is remarkable for the magnificent specimens of native silver in the form of coils and clusters of wire silver that it affords. The oxidized zone is not now accessib e but n the sulphide zone are local areas that have been subjected to the action of oxidation, usually along some zone of disturbance and fracturing, and in these the partly oxidized ores frequently abound in the wire silver. Its most common habitat is in the spaces between the interlocking tabular crystals of barite, where it may be found alone or adhering to some of the sulphides, very commonly to the tetrahedrite.

The dip of the ore beds ranges from 25° to 35°. Most of the output comes from a rich ore shoot averaging over 100 oz. silver per ton. The *mantos* here have a thickness of 12 m., including a parting of 2 m. Adjoining this ore shoot on the south and continuous with it is ore of the same appearance that carries only 5 to 10 oz. silver per ton and is hence unworkable. This is a striking example of the extreme variation in the silver content of the ores, so that although the *mantos* are continuous throughout the extent of the mine, they consist of workable ore in restricted areas only.

THE MINASRAGRA VANADIUM MINE

The Minasragra vanadium deposit (99; 187, pp. 583–585) lies about 18 miles by trail west of the Hauraucaca smelter. It has been located several times for coal, but was abandoned each time on account of the high sulphur content. In 1905, Antenor Rizo Patron, the manager of the Hauraucaca smelter, had the material analyzed and found that it contained a large percentage of vanadium. The deposit was at once denounced again by E. E. Fernandini, the owner of the smelter, and Patron, and was subsequently purchased by the American Vanadium Company. Since its discovery it has furnished about 80 per cent of the world's demand for vanadium.

Geology.—The Minasragra mine lies at an elevation of 16,500 feet in a region of considerable relief between two imposing mountain ranges formed by thick series of heavy-bedded limestones. The sedimentary rocks are of Mesozoic age and in the area between the two limestone ranges consist of red and green shales with a few thin layers of limestone in the lower part. The ore deposit occurs entirely within red shales in the upper part of the series. The red shales contain abundant gypsum both as intercalated beds and as a network of stringers and veinlets filling joints and cracks in them. In a gypsum bed exposed at the south end of the mine are patches of native sulphur. Outcrops of dikes and irregular masses of igneous rocks are abundant, ranging in composition from quartz porphyry to diabase.

Ore Deposit.—The ore body is a lens-shaped mass having a length of about 300 feet and a maximum width of 30 feet, oriented with a strike approximately parallel to that of the enclosing rocks, but with a westerly dip steeper than that of the shales. It is made up essentially of quisqueite, coke, and patronite. Quisqueite is a black lustrous hydrocarbon, coke a dull-black vesicular hydrocarbon, and patronite a greenish-black mineral that is a sulphide of vanadium. Analyses of these minerals given in Hewett's paper are shown in the accompanying table:

MINERAL ANALYSES ACCORDING TO HEWETT

	Patronite Per cent	Quisqueite Per cent	Coke Per cent
Sulphur, soluble in CS_2	4.50	15.44	0.64
Sulphur, combined	54.29	31.17	5.36
Carbon	3.47	42.81	86.63
Hydrogen	.....	0.91	0.25
Nitrogen	.....	0.47	0.51
Oxygen, by difference	.....	5.39	4.64
Water, at 105°	1.90	3.01	None
Ash	.....	0.80	1.97
Vanadium	19.53		
Iron	2.92		
Nickel	1.87		
Silica	6.88		
Titanic oxide	1.53		
Alumina (phosphoric acid)	2.00		

Also small amounts of ferric oxide, manganese, chromic oxide, and alumina.

Small pockets and nests of pyrite are locally abundant, and of interest is the occurrence of a small quantity of a reddish-yellow nickeliferous sulphide of iron to which the name bravoite has been given by Hillebrand. The patronite at the surface has undergone oxidation, and the vanadium close to the surface occurs in the form of hydrous calcium vanadates, of which there appear to be red and brown varieties. At a depth of a few feet these give way to a greenish-black calcium vanadate.

Origin.—A quartz porphyry dike cutting across the shales has its outcrop shifted at the ore deposit as if it had been faulted, and Hewett regards the ore body as having been intruded along this fault plane, or fault zone, in a plastic or even liquid condition, as a mass that was probably homogeneous; and that from it the minerals now forming it segregated in a sequence which he determined from a study of polished sections to be quisqueite, coke, patronite. In the hanging wall he thinks there has been some penetration of the patronite into the shales, saying, "patronite appears to have had the peculiar property, under the conditions of temperature and pressure that existed at the time of the intrusion of the mass, of being able to permeate the porous country rock, even to the degree of saturating it." Replacement of the shales he thought has taken place only through vanadium solutions formed by the oxidation of the patronite and says, "in some places the solutions have almost entirely replaced portions of the shales, and at other places the vanadium minerals have been precipitated in the cracks and open spaces in the crushed zone."

In the brief examination made no positive evidence was seen to indicate that the ore body represents an intrusion into a definite fault. Rather it seems to represent a replacement of the shales along a zone of crushing. In the lowest tunnel, 120 feet below the surface, one can pass from shale to ore through various stages of replacement; and even where the shale is completely gone, its former pressure is indicated by the preservation in much of the ore of the network of gypsum stringers so characteristic of the shale. Where the mineralizing action has been most intense, there are no gypsum stringers. In the underground workings several gypsum beds are encountered, and even where the overlying and underlying shale is completely replaced by ore, they have persisted, but little affected by the mineralization. A few cases were seen where the gypsum has yielded to a slight extent and contains narrow lenses and stringers of ore. These observations indicate that the gypsum could not entirely resist the mineralization; and it is not surprising, therefore, that the network of narrow gypsum stringers has been removed in a large part of the main mass of the ore.

Doubtless when work first began here, the shift in the quartz porphyry dike seemed to be due to a clean-cut fault, but as exposed now in the opencut, it is practically impossible to decide whether the dike was intruded into a curved fissure or whether there was a later movement in the zone of crushing that caused an offset along the strike. Underground, the offset is less pronounced than at the surface. Consequently there appears to have been no well-defined faulting subsequent to the intrusion of the dike, but at most a slight displacement in the shear zone in which the ore body is localized. It also appears probable that the dike is later than the ore deposition. Its top has a westerly pitch so that although it outcrops at the surface on the east side of the mine, on the west side it lies some distance below the surface. Furthermore, the ore lies directly on top of the dike and at the contact has the appearance of having been baked or metamorphosed by it, and the orebody comes up to the dike on either side without increase or decrease in width. Another feature of note is that the dike does not seem to have been affected by the mineralizers. It is true that a similar phenomenon is presented by the gypsum beds, but gypsum is a chemical compound of an entirely different nature and it is conceivable that mineralizers capable of replacing the chemical constituents of shale might not be able to remove gypsum. But chemically, the quartz porphyry is similar to the shale, or at least similar enough to make it difficult to see how such widespread complete replacement of the shale could have been effected and the dike have escaped completely. The weight of evidence now available, therefore, would indicate that the dike is an intrusive across the ore deposit and deflected in that zone of crushing either at the time of intrusion or by a small later movement.

As to the nature of the mineralizers there is little that one can say, since the deposit stands in a class by itself. Not even in its vicinity has careful search revealed another deposit like it. That they were of a peculiar nature is evidenced not only by the chemical composition of the ores, but also by the fact that they acted so vigorously on the shales and produced so little effect on an otherwise comparatively soluble substance such as gypsum. Hewett regards the deposit as an extreme phase of differentiation from asphaltite under the stimulus of the igneous intrusions. Such a view is, of course, based on his belief as to the occurrence and origin of the deposits, but whether it is consistent with the mode of origin and occurrence suggested above is questionable.

The preceding account of the Minasragra vanadium deposit is based on published descriptions by D. F. Hewett, who has very carefully studied this occurrence, and by the authors. A more recent examination by Mr. Hewett has led him to modify his earlier views and to disagree in some particulars with those of the authors. In a personal communication, Mr. Hewett has kindly furnished the following summarized statement based on his observations to date:

"Explorations since 1907 show that the central lens of patronite, coke, and quisqueite, which attains a maximum thickness of nearly 30 feet, is entirely enclosed by a zone of material that is locally called *veta madre*, which is about 40 feet thick on both walls of the smaller lens and extends beyond its ends. *Veta madre* is a mixture of earthy material, disseminated sulphide of vanadium, and anhydrite, which is largely altered to gypsum on the level of tunnel No. 2, 120 feet below the surface. It represents shale that has been more or less saturated by sulphide of vanadium and replaced by the anhydrite. *Veta madre* contains from 1 to 12 per cent of vanadium.

It appears that after the intrusion of the dikes of igneous rock, the "dike"-like lens of patronite, coke, and quisqueite entered a crushed zone in the red shale. At the same time, the shale walls were partially replaced by anhydrite and sulphide of vanadium. As a result of weathering and erosion, the sulphide of vanadium was altered to sulphate, and the anhydrite to gypsum. The products of oxidation are now largely hydrous vanadates of lime, with the vanadium in several states of oxidation. The brown and red minerals are vanadates, and the purple and green minerals are vanadyl vanadates."

Treatment.—When the mine was first opened, the oxidized ores were worked in the opencut on the outcrop, and the merchantable ore carried about 20 per cent V_2O_5. Later, attention was directed to the sulphides at greater depth and a roasting plant was erected in the valley below the mine. Now the entire output comes from the sulphide ores. At the temperature of the furnace, the ore is self-burning until all but 3 per cent of the sulphur is expelled, when coal must be added to reduce this to ½ per cent. The roasted ore carries 50 per cent V_2O_5. The quisqueite is not removed in this roasting and is still present in the roasted product.

CONDITIONS GOVERNING AND AFFECTING THE MINING INDUSTRY

Labor, fuel, and transportation are the great difficulties that beset the mining industry of Peru. The high elevations of so many of the mining districts render the operator entirely dependent upon the native labor inured to working under these conditions. The situation in this respect is identical with that in Bolivia, described on pages 134 to 135. In some respects, the fuel situation is more favorable than usual in South American countries, in that coal deposits are coextensive with most of the mineralized belt and hence provide a local supply of domestic fuel. However, the quality of the coal is not always good and often not even passable for industrial and metallurgical use, and in the rugged Peruvian Andes a coal deposit may be near as measured on the map and yet practically unavailable at reasonable cost.

The most serious problem the Peruvian mining industry has to contend with is transportation. The greater part of the Andean region consists of high, rugged ranges with deep intervening valleys interrupted by frequent connecting ridges. As a result transportation from one part of the country to another is extremely difficult. There are no easy lines of travel across the country either in a north-south or in an east-west direction, hence there are few countries so inadequately provided with means of internal communication. The customary procedure is to go by steamer to the nearest port and then inland as best one can to the desired point. Two railroads have been pushed across the western range. The Ferrocarril del Sur del Perú crosses the range at 14,660 feet. The Oroya railroad, the highest in the world, climbs to an elevation of 15,865 feet.

The importance of the Oroya road to the mining industry is strikingly demonstrated by the fact that 87 per cent of the metallic production is furnished by the territory tributary to it. There is no reason to believe that it has opened up the only important mineralized area in Peru, but the facts are that with a limited amount of capital entering the country and ample opportunities along this most important line of transportation, capital has not found it necessary to open up new ways for itself, but has taken the easier course of developing the most accessible localities. There is no apparent reason why such departments as, for instance, Ancachs and Huancavelica, should not be capable of similar development. Whoever is enterprising enough to explore and develop these sections will doubtless meet with equal rewards.

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72. Fuchs, F. C.: Mineral de Vinchos y Oficina de Humaurauca. *Boletín* de Minas, Industria y Construcciones, Vol. 11, pp. 51–54, 59–62, 75–76, Lima, 1895.

Located 42 km. northwest of Cerro de Pasco. Discusses geology, mining, and economic considerations, and describes smelter and metallurgical practice. Ores are argentiferous galena.

73. Fuchs, F. C.: Estudio sobre la Region Aurífera de Santo Domingo en la Provincia de Carabaya. *Boletín* de Minas, Industria y Construcciones, Vol. 14, pp. 6–8, 11–14, 21–22, 85–86, 1898; vol. 15, pp. 6–7, 12–15, 20–21, 25–26, 35–38, 42–45, 57–58, Lima, 1899. Abst. *Eng. and Min. Jour.*, Vol. 70, pp. 9–10, 1900.

General description of region, geology, means of access, and kinds of gold deposits. Detailed description of the Santo Domingo vein and other mines. C. I. Lisson studied the ores and rocks collected by Fuchs and published results under title Minerales y Rocas de Santo Domingo, Vol. 15, pp. 58–63, 1899; and Vol. 19, pp. 4–6, 1903.

74. Fuchs, F. C.: La Region aurifera de Santo Domingo en la Provincia de Carabaya. *Boletín* de la Sociedad Nacional de Minería, pp. 289–313, Lima, 1900.

History, means of access, general and geologic description of the region, mining, and metallurgy.

75. Fuchs, Frederico G.: La Region Mineral de Poma-Grande. Boletín del Ministerio de Fomento, Año 2, Dec., pp. 52–58, Lima, 1904.

Describes geology and ores of district near Matucana. Ores are native copper and copper silicates in basic igneous rocks.

76. Fuchs, Frederico G.: La Region Cuprífera de los Alrededores de Ica y Nazca. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 29, 100 pp., Lima, 1905.

Copper veins in a belt of dioritic rocks extending from Ica to Nazca in the province of Ica. Geologic map with location of mines.

77. Fuchs, Frederico G.: Región Cuprífera de Cachi-Cachi, Provincias de Tarma y Jauja. *Boletín* de Minas, Industria y Construcciones, 2d Ser., Vol. 1, No. 4, pp. 41–46, Lima, 1907.

District situated near Oroya and Tarma. Meagre explorations have disclosed chiefly oxidized copper ores.

78. Fuchs, F. C.: Fuels. Peru Today, August, pp. 47–49; September, pp. 47–48, Lima, 1911.

Brief résumé of the various fuels available in Peru, including data on grade and price.

79. Garbin, Lucas: Apuntes sobre los Minerales de Huallanca, Chonta y Queropalca. *Boletín* de la Sociedad de Ingenieros, Vol. 6, pp. 1–17, Lima, 1904.

Brief descriptions of each of the districts.

80. García, David Pomacondor: Memoria de Excursion al Asiento Mineral del Cerro de Pasco, Marzo de 1913. *Boletín* de Minas, Industrias y Construcciones, 2d Ser., Vol. 5, pp. 114–142, Lima, 1913.

Description of mill and smelter at Hauraucaca, and notes on the Cerro de Pasco Company's coal mines.

81. Garland, Alejandro: La Industria Aurífera en el Perú. *Boletín* de la Sociedad Nacional de Minería, pp. 247–253, Lima, 1900.

Résumé of gold mining in Peru with notes on operating mines and companies.

82. Garland, Alejandro: Reseña Industrial del Peru. Ministerio de Fomento, Lima, 1905.

Section on Industria Minera, pp. 5–39, describes the occurrence of the mineral products and the mining activities directed toward each.

83. Gascuel, L.: Le Gisement de Cerro de Pasco (Pérou). *Annales des Mines*, 9th Ser., Vol. 17, pp. 660–681, Paris, 1900.

General account of the geology, ores, and mining.

84. Gastelumendi, A. C. y Días, Luis F.: Informe Anual de la Comission Minera del Cerro de Pasco en 1908 y sobre la Region Minera de Atacocha. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 74, 61 pp., Lima, 1909.

Includes brief notes on the Chuquitambo gold mines and mill, and description of the Atacocha district which yields chiefly argentiferous lead-zinc ores.

85. Gianella, Julio Ernesto: Minas de Cobre de los Alrededores de Ica. *Boletín* de la Sociedad de Ingenieros, Vol. 6, pp. 31–38, Lima, 1904.

Account of the history and geology of the region and a description of the ores.

86. Gianella, Ernesto: Yacimientos de Azufre y Halotrichita. *Boletín* de la Sociedad de Ingenieros, Vol. 8, pp. 133–138, Lima, 1906.

Near Chuquiquillán, province of Pallasca, department of Ancachs. Brief description of sulphur deposit with which is associated gypsum and alum.

87. Giessel, H. L.: Peru's Mining Industries. *Mines and Minerals*, Vol. 21, pp. 80–81, 1900.

A brief summary of the mineral resources.

88. Gonzales, Manuel C.: The Mining Industry in Peru. *Mining Magazine*, Vol. 13, pp. 549–559, New York, 1906.

A general review of the mineral resources, describing briefly each of the economic minerals.

89. Gottschalk, A. L. M.: The Mineral Resources of Peru. *Mines and Minerals*, Vol. 27, pp. 132–134, 1906.

A summary of the mineral resources.

90. Griffith, W. M.: A Rich Peruvian Mining Region. *Mines and Minerals*, Vol. 18, pp. 256–257, 1898.
Short description of the silver mines and geology of the Hualgáyoc district.

91. Griffith, William: Anthracite Coal in Peru. *Mines and Minerals* Vol. 19, pp. 121–122, 1898. *Eng. and Min. Jour.*, Vol. 66, p. 514, 1898. Abstract of paper read before Franklin Institute, Oct. 12, 1898.
Descriptions of promising anthracite coal deposits in the departments of Cajamarca and Libertad.

92. Haber, E.: Bergbau und Hütten-Industrie im mittleren Perú im Jahre 1890. *Zeitschrift* für das Berg-, Hütten- und Salinenwesen im preussichen Staate, Vol. 40, pp. 187–223, Berlin, 1892.
Introduction gives brief sketch of country, inhabitants, and means of transportation. Second part discusses in detail the ore deposits and mines of the following districts: Huarochiri, Yauli, Morococha, and Cerro de Pasco.

93. Habich, Eduardo A. V. de: Los Yacimientos de Niquel de Rapi y los de Tungsteno de Lircay. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 11, 39 pp., Lima, 1904.
General description of the De la Mar province and veins of niccolite and ullmanite. Description of tungsten veins near Lircay, capital of province of Angaraes. Topographic maps of immediate vicinities.

94. Habich, E. A. V. de: Yacimientos carboníferos del distrito de Checras. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 18, 32 pp., Lima, 1904.
District lies in province of Chancay, department of Lima. General description of the district, its geology, coal deposits, and their characteristics.

95. Haley, Charles S., and Rodegerdts, C. A.: Prospecting Conditions in Peru. *Min. and Sci. Press*, Vol. 107, pp. 922–927, 967–972, 1913.
Mainly description of routes of travel and difficulties of operations.

96. Hawley, C. E.: Notes on the Quicksilver Mine of Santa Barbara, Peru. *Amer. Jour. Science*, 2d Ser., Vol. 45, pp. 5–9, 1868.
Describes the occurrence of the quicksilver ores in sandstones and limestones at Huancavelica.

97. Herrera, Celso: Estado Actual de la Minería de la Provincia de Huarochiri. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 72, 49 pp., Lima, 1909.
Notes on the geology and ore deposits by districts and brief descriptions of mines. Ores are argentiferous lead-copper, or argentiferous lead. Description of mills and smelters.

98. Hewett, Foster: A New Occurrence of Vanadium in Peru. *Eng. and Min. Jour.*, Vol. 82, p. 385, 1906.
A description of the Minasragra deposit and the ore minerals.

99. Hewett, D. Foster: Vanadium Deposits in Peru. *Trans.* Amer. Inst. Min. Eng., Vol. 40, pp. 274–298, 861–863, 1909.
A description of the geology and the ore bodies of the Minasragra (Quisque) and Yauli vanadium deposits.

100. Hilfiker, Adolfo: Informe sobre la Zona Mineral de Ananea-Poto. *Boletín* de la Sociedad Geografica de Lima, Vol. 8, pp. 171–179, Lima, 1898–1899.

Topographic map of district. Account of history, geography, and geology, and description of vein and placer deposits.

101. Hillebrand, W. F.: The Vanadium Sulphide, Patronite, and its Mineral Associates from Minasragra, Peru. *Amer. Jour. Science*, 4th Ser., Vol. 24, pp. 141–151, 1907.

Minute descriptions of patronite, quisqueite, etc., from Minasragra.

102. Hillebrand, W. F.: The Vanadium Sulphide, Patronite, and its Mineral Associates from Minasragra, Peru. *Jour*. Amer. Chem. Soc., Vol. 29, pp. 1019–1029, 1907.

Detailed chemical descriptions of patronite, quisqueite, and bravoite.

103. Hodges, A. D., Jr.: Notes on the Topography and Geology of Cerro de Pasco, Peru. *Trans*. Amer. Inst. Min. Eng., Vol. 16, pp. 729–753, 1888.

Account of the physiographical features, geological formations, and character of ores. Several good maps and one geological cross-section.

104. Hunt, Bernard: Informe sobre el Distrito Mineral de Caylloma. *Boletín* de la Sociedad Geografica de Lima, Vol. 6, pp. 414–417, Lima, 1896–1897.

Description of geology of the district, veins, and metallurgical plant of the Caylloma Silver Mining Co., Ltd.

105. Hunt, Bernard: On the Use of Fuel at Caylloma, Peru. *Trans*. Inst. Min. and Met., Vol. 6, pp. 278–281, London, 1898. Abst. *Eng. and Min. Jour.*, Vol. 66, pp. 727–728, 1898.

Discusses value of turf, petroleum, shale, yareta, and taquia in the mining regions near Arequipa.

106. Jiménez, Juan Velásquez: Las Yacimientos de Petróleo del Departamento de Piura. Boletín del Ministerio de Fomento, Año 4, Sept., pp. 83–123, Lima, 1906.

Description of the geography and geology of the region and more detailed description of the properties and operations of the various companies.

107. Jiménez, Juan Velásquez: La Industria del Petróleo en el Perú. *Anales* de la Sociedad Científica Argentina, Vol. 73, pp. 120–154, Buenos Aires, 1912.

Outline of southern, central, and northern petroliferous regions in Peru, their development and grade of oil. Northern region described in greater detail. Paper was presented at the International American Scientific Congress in 1910.

108. Jochamowitz, Alberto: Informe relativo a las pertenencias ubicadas sobre el Yacimiento de Borax de la Laguna de Salinas. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 49, 24 pp., Lima, 1907.

Abstracts: *Min. Jour.*, Vol. 82, p. 247, London, 1907. *Eng. and Min. Jour.*, Vol. 84, p. 780, 1907.

In department of Arequipa, about 12 leagues southeast of city of Arequipa. Describes briefly the deposit and method of working it and discusses its origin. Topographic map of the lake.

109. Jochamowitz, A.: Recursos Minerales del Departamento de Apurímac. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 58, 99 pp., Lima, 1908.

Discusses the geology and mineral deposits of each province by districts.

110. Jochamowitz, Alberto: Estado Actual de la Minería en Morococha. Informe Anual de la Comision de Yauli. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 65, 67 pp., Lima, 1908.

Geology of district and description of mines. Geologic map.

111. Kemp, James Furman: Iron Ore Reserves of Colombia, Venezuela, Bolivia, Peru and Chile. Iron Ore Resources of the World, Vol. 2, pp. 801–806, Stockholm, 1910.

Brief Account of iron resource of Peru, pp. 803–805.

112. Klinge, Jermán: El Azufre de Sechura. *Boletín* de Minas, Industria y Construcciones, 2d Ser., Vol. 1, No. 5, pp. 67–76, Lima, 1907.

Located 120 km. south of Payta. Sulphur impregnates sandstone. Describes special method devised for extraction of sulphur necessary on account of peculiar character of the material.

113. Kohlmorgen, Martin: Berg- und Hüttenmännische Mittheilungen über die Provinz Tarma in Peru. *Zeitschrift* für das Berg-, Hütten- und Salinenwesen im preussischen Staate, Vol. 38, pp. 302–317, Berlin, 1890.

Geographical and geological sketch of region. Describes mines of Morococha and a few in vicinity of Yauli, including the asphalt mines at Sorao, amalgamation practice at Tuctu and Cerro de Pasco, and labor conditions.

114. Lane, Edmund: The Coal and Mineral Resources of Peru. *Trans.* Inst. Min. Eng., Vol. 3, pp. 750–772, London, 1892.

Data regarding the mineral resources. A map shows location of the economic deposits.

115. Laroza, Enrique: Gold and Copper Mining in Peru. *Min. Mag.*, Vol. 11, pp. 49–58, New York, 1905.

Brief review of the known gold and copper deposits of the country.

116. Lindgren, Waldemar: Gold and Silver Deposits in North and South America. *Trans.* Amer. Inst. Min. Eng., Vol. 55, pp. 883–909, 1917. *Proc.* Second Pan American Scientific Congress, Vol. 8, pp. 560–576, Washington, 1917.

Review of the gold and silver resources of the Americas, and the geologic features of the deposits.

117. Loveday, Santiago: La Minería en Castrovirreina. *Boletín* de la Sociedad de Ingenieros, Vol. 6, pp. 183–205, Lima, 1904.

Most important deposits are of silver and describes or gives notes on the mines. Copper veins with tetrahedrite also occur and have been worked.

118. Loveday, Santiago: La Minería en el Departamento de Huancavelica. *Boletín* de la Sociedad de Ingenieros, Vol. 7, pp. 41–44, 49–64, Lima, 1905.

Geography of the department and general notes on mining conditions. Detailed description of Huachocolpa district, where ores are argentiferous galena with some tetrahedrite.

119. Lucio, Felipe de: El Mineral de Ccochasayhuas. *Boletín* de la Sociedad de Ingenieros, Vol. 6, pp. 91–102, 109–116, Lima, 1904.

Describes geology, the veins, mining, treatment, and economic conditions.

120. Lucio, Felipe de: Recursos minerales è importancia de la provincia de Pataz. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 21, 60 pp., Lima, 1905.

Geology of province and description of mining districts. Gold veins and placers only important mineral deposits. Topographic maps of the districts.

121. Lukis, Ernesto du B.: Informe Preliminar sobre el Yacimiento Carbonífero de Huayday, Provincia de Otuzco, Departamento de la Libertad. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 64, 62 pp., Lima, 1908. Abstract: The Huayday Coal-Measures, Peru. *Trans.* Inst. Min. Eng., Vol. 38, pp. 676–677, London, 1910.

Describes an occurrence of coal of anthracite grade and its commercial aspects.

122. Lukis, Ernesto du Bois: Yacimientos Carboníferos de los Departamentos de la Libertad, Cajamarac y Ancachs. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 69, 63 pp., Lima, 1909.

Describes the coal deposits in the provinces of Pacasmayo, Cajabamba, Huamachuco and Chimbote. Hachure map.

123. Martínez, Guillermo: Contribución al Estudio del Vanadio en el Perú. Revista Universitaria, Vol. 1, pp. 157–202, Lima, 1911.

Gives description of Yauli and Minasragra vanadium deposits, and a general treatise on the discovery and chemistry of vanadium.

124. Masias, M. G.: Estado actual de la Industria minera de Morococha. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 25, 124 pp., Lima, 1905.

Historical account of mining at Morococha and description of mines.

125. Mason, Russell T.: Peru. *Eng. and Min. Jour.*, Vol. 79, pp. 1091–1093, 1905.

Summary of mining operations in Peru.

126. Marsters, V. F.: Informe Preliminar sobre la Zona Petrolífera del Norte del Perú. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 50, 150 pp., Lima, 1907.

Detailed description of the province of Tumbes, and the departments of Piura and Lambayeque, their geology, oil occurrences, and oil developments. Map of region.

127. Maza, Carlos Alvarez: La Region de Carabaya en el Perú. *Boletín* de la Sociedad Nacional de Minería, pp. 174–188, Lima, 1900.

Map of region. General description of region and routes of travel, and notes on the gold deposits.

128. Miller, Benjamin L. and Singewald, Joseph T., Jr.: Substitutes for Coal in the Andes. *Coal Age*, Vol. 9, pp. 1040–1043, 1916.

The fuel situation in the Andes is discussed and the various fuels used are described.

129. Miller, B. L. and Singewald, J. T., Jr.: The Fuel Situation in the

Andean Plateaus. *Proc.* Second Pan American Scientific Congress, Vol. 8, pp. 709–717, Washington, 1917.

Summary of fuel conditions with fuller account of Cerro de Pasco Mining Company's coal deposits.

130. Moreno, Frederico: Informe sobre los Yacimientos de Petroleo en el Departamento de Piura, su actual Explotación y otras riquezas Minerales que contiene ese Territorio. *Boletín* de la Sociedad Geografica de Lima, Vol. 3, pp. 283–343, Lima, 1893.

Extent of the oil-bearing districts, and operations. Also describes briefly coal, iron, and sulphur deposits.

131. Narducci, M.: Apuntes Retrospectivos sobre los Minerales de Cobre de la Provincia de Ica. *Boletín* de Minas, Industria y Construcciones, Vol. 4, pp. 12–14, 18–22, Lima, 1888.

Three distinct groups of copper veins in the province. Account of history of mining and method of treatment of the ores. Notes on the mines.

132. Noriega, A. Notas sobre la Mineria en la Region de Morococha. *Boletín* de Minas, Industria y Construcciones, Vol. 19, pp. 58–64, 66–72, 75–78, 84–85, Lima, 1903.

Extracts from studies of the mines of Morococha made by students of the Peruvian mining school under the direction of Prof. A. Noriega.

133. Ochoa, Nicanor G.: Recursos minerales de la Provincia de Huánuco. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 9, 43 pp., Lima, 1904.

General description of each district of the province, and of its geology and metaliferous deposits; the latter are chiefly gold veins and placers. Map of province.

134. Olaechea, Teodorico: Apuntes sobre el Departamento de Apurimac. *Anales* de la Escuela de Construcciones Civiles y de Minas del Perú, Vol. 6, 57 pp., Lima, 1887.

General description of the province and remarks on the mining industry. Fuller notes along routes of travel followed by author. Mining is chiefly placer though other types of deposits are also described.

135. Olaechea, T.: Ligera Relacion del Viaje á la Provincia de Ica. *Boletín* de Minas, Industria y Construcciones, Vol. 4, pp. 37–39, 42–46, Lima, 1888.

General notes on the occurrence of copper in the province of Ica.

136, Orton, James, The Silver Mines of Peru. *Eng. and Min. Jour.*, Vol. 17, p. 83, 1874.

Brief description of Cerro de Pasco, Hualgáyoc, and other districts.

137. Paz Soldan, D. D. Mateo: Geografia del Peru. Publicada a expensas del Gobierno Peruano, Vol. 1, 745 pp., Paris, 1862.

Contains many geologic descriptions and notes on mines.

138. Pearse, Arthur L.: Mining in Peru. *Trans.* Inst. Min. and Met., Vol. 1, pp. 344–367, London, 1894.

General paper on mining conditions in Peru.

139. Peele, Robert, Jr.: A Peruvian Salt Mine. *School of Mines Quart.*, Vol. 15, pp. 219–221, 1894.

Description of a salt deposit a short distance south of Huacho. Some nitrate of soda occurs with the sodium chloride.

140. PEPPER, CHARLES M.: Economic and Commercial Situation in Peru. *Iron Age*, Vol. 92, pp. 1097–1100, 1913.

Contains general descriptions of the copper, vanadium, and coal deposits.

141. PFLUCKER, GERMÁN E.: Apuntes sobre la Región Aurífera del Alto Haullaga. (Placeres en las Provincias de Ambo y Huánuco.) *Boletín* de la Sociedad de Ingenieros, Vol. 14, pp. 530–543, Lima, 1912.

General description of the region and its geology, of the placers, and their mode of formation.

142. PFLÜCKER, LUIS: Informe sobre los Yacimientos Auríferos de Sandia. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 26, 40 pp., Lima, 1905.

Describes the different types of gold deposits and their occurrences. Topographic map of Poto district.

143. PFLÜCKER, LUIS: Yacimientos de Fierro de Aija y Calleycancha. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 36, 33 pp., Lima, 1906.

In province of Huaraz. At Aija are deposits of magnetite with a little pyrite at contact of andesite and slates; at Calleycancha veins of micaceous hematite in sandstone and quartzite. Other mineral deposits occur but are not important.

144. PFLÜCKER Y RICO, LEONARDO: Apuntes sobre el Distrito Mineral de Yauli. *Anales* de la Escuela de Construcciones Civiles y de Minas, Vol. 3, 78 pp., Lima, 1883.

Gives account of the orography and geology of the district. Veins now worked are chiefly silver and argentiferous galena, though copper veins also are found. Describes mining industry.

145. PFORDTE, OTTO F.: The Cerro de Pasco Mining Industry. *Trans.* Amer. Inst. Min. Eng., Vol. 24, pp. 107–121, 1894.

Mainly a description of mining and metallurgical methods.

146. PICKERING, J. C.: Transportation, Costs and Labor in Central Peru. *Eng. and Min. Jour.*, Vol. 85, pp. 589–591, 1908.

Discussion of economic conditions affecting mining in the Central Peruvian Andes.

147. PICKERING, J. C.: Recent Developments at Cerro de Pasco, Peru. *Eng. and Min. Jour.*, Vol. 85, pp. 760–763, 1908.

Brief description of history of region and character of ore bodies with account of recent improvements in mines and smelter.

148. PICKERING, J. C.: The Mining Districts of Central Peru. *Eng. and Min. Jour.*, Vol. 85, pp. 997–1001, 1908.

Descriptions of the mining districts of Morococha, Pacococha, Oyón, Chanca, Raura, and Pumahuain. Map of Morococha district and analyses of the Oyón coal.

149. PINZAS, ESTENIO J.: La Mineria en la Provincia Dos de Mayo. Boletín del Ministerio de Fomento, Año 1, Nov., pp. 32–44, Lima, 1903.

Notes on geology and ores of the province.

149½. Preumont, G.: Antimony Mining in Peru and Bolivia. *Min. Jour.*, Vol. 83, p. 282, London, 1908.

Brief descriptions of localities in northern Bolivia and southern Peru where antimony ores have been mined.

150. Puente, J. R. de la: La Industria Minera en el Cerro de Pasco. *Boletín* de Minas, Industrias y Construcciones, 2d Ser., Vol. 3, pp. 53–58, Lima, 1911. *Boletin* de la Sociedad de Ingenieros, Vol. 13, pp. 201–207, Lima, 1911.

Brief description of the mines of the La Docena group at Cerro de Pasco.

151. Raimondi, A.: El Departamento de Ancachs y sus Riquezas Minerales. Imprenta de El Nacional por Pedro Lira, 651 pp., Lima, 1873.

Describes the geography and geology of the department. Part 3 deals with general distribution of mines and description of mines in each district. Hachure map of the department.

152. Raimondi, A.: Minas de Oro de Carabaya. *Anales* de la Escuela de Construcciones Civiles y de Minas del Perú, Vol. 3, 32 pp., Lima, 1883.

Geography of the region and the discovery of gold. Notes on Aporoma, Poto, and Challuma districts. Descriptive geology of the auriferous region and manner of occurrence of the gold, grade of the ore, and methods of mining, and special method of washing the auriferous gravels.

153. Raimondi, A.: Minas de Oro del Peru. *Anales* de la Escuela de Construcciones Civiles y de Minas del Peru, Vol. 6, 96 pp., Lima, 1887. *Boletín* de Minas, Industria y Construcciones, Vol. 1, pp. 27–29, 36–37, 45–48, 55–56, 68–71, 77–80, 1885; Vol. 2, pp. 3, 13, 22, 28, 1886, Lima. *Boletín* de la Sociedad Nacional de Minería, Año 4, pp. 721–723, 730–731, 736–739, 745–748, 755–756, 762–764, Santiago de Chile, 1887.

Describes the gold deposits of Peru by departments.

154. Raimondi, Antonio: El Peru. Estudios Mineralógicos y Geológicos (Vol. 4). Publicado por la Sociedad Geográfica de Lima, 515 pp., Lima, 1902.

Publication of part of Raimondi's geologic notes written during the years 1860 to his death in 1890. Contains description of his collection of rocks, a paper on the mineral waters of Peru, and papers on the Cerro de Pasco district, the salt deposits of Huacho, and the Hualgáyoc district. The last three are listed separately in this bibliography.

155. Raimondi, Antonio: Memoria sobre el Cerro de Pasco y la Montaña de Chanchamayo. El Perú. Estudios Mineralógicos y Geológicos, Vol. 4, pp. 444–488, Lima, 1902.

Paper was written in 1885. Gives account of geography, history, geology, and metallurgy of the silver ores and description of the coal deposits.

156. Raimondi, Antonio: Informe sobre las Salinas de Huacho. El Perú. Estudios Mineralógicos y Geológicos, Vol. 4, pp. 496–506, Lima, 1902.

Paper was written in 1867. Describes the salt deposits and method of working them, and discusses their origin.

157. Raimondi, Antonio: Apuntes sobre el Mineral de Hualgáyoc. El

Perú. Estudios Mineralógicos y Geologícos, Vol. 4, pp. 506–515, Lima, 1902.

Paper was written in 1861. Describes the geology of the district and its veins and mines. Veins of argentiferous galena and sulphurets and their oxidation products.

158. Rammelsberg, C.: Der gegenwärtige Zustand des Berg- und Hüttenwesens auf dem Cerro de Pasco. *Zeitschrift* für das Berg-, Hütten- und Salinenwesen im preussischen Staate, Vol. 32, pp. 111–126, Berlin, 1884.

Translation of article by M. Du Chatenet in "*Anales* de construcciones civiles y de minas del Peru," Vol. 1, 1880.

159. Remy, G. L.: Estudio sobre el Cerro Mineral de Pomasi. *Boletin* de Minas, Industria y Construcciones, Vol. 6, pp. 5–7, Lima, 1890.

Located 50 km. southwest of Lampa, Puno. Veins of argentiferous galena, but some also carry tetrahedrite.

160. Remy, Pedro Felix: Estado Actual de la Mineria en el Distrito de Yauli. *Anales* de la Escuela de Construcciones Civiles y de Minas del Peru, Vol. 6, 60 pp., Lima, 1887.

General description of the district, its ores, mines, and metallurgy. Deposits are veins of argentiferous galena. Brief notes on the mines in operation. Topographic map of region.

161. Remy, P. F.: Excursiones Científicas. Viaje al Departamento de Ayacucho. *Boletin* de Minas, Industria y Construcciones, Vol. 6, pp. 13–15, 17–19, 52–55, Lima, 1890.

Brief notes on the geology and some of the mining districts of the department of Ayacucho.

162. Remy, Pedro Felix: Distrito Mineral de San Miguel. *Boletin* de la Sociedad de Ingenieros, Vol. 6, pp. 270–282, Lima, 1904.

Province La Mar, department of Ayacucho. Includes veins of argentiferous nickel and cobalt.

163. Rivero, M. de: Sketch of the Rich Mine of Pasco. *Am. Jour. Science*, 1st Ser., Vol. 17, pp. 43–63, 1830.

Description of the geology of the region and of the mines.

164. Rivero, M. de: Mèmoire sur les Mines d'Argent de Pasco, au Pérou. *Anales des Mines*, 3d Ser., Vol. 2, pp. 169–198, 1832.

An account of the geography and geology of the region, and exploitation of the mines, method of treating the ore, and statistics of production since 1774.

165. Romaña, Eduardo A. L. de: Una Inspeccion de los Yacimientos de Estaño de Bolivia y una exploracion por el mismo metal en el Perú. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 57, 99 pp., Lima, 1908.

Describes explorations for and failure to find tin deposits in the provinces of Huancané and Chucuito of the department of Puno, territory adjacent to the Bolivian tin belt. Map of provinces.

166. Rosell, R. G.: Mineral de Cerro de Pasco. *Boletin* de la Sociedad Nacional de Minería, Vol. 14, pp. 110–121, 168–179, 249–253, 289–298, 332–345, Santiago de Chile, 1897.

Geography of the region, history of the district, description of the geology, mining, metallurgy, and production. Reprint of a report made by the author in 1892.

167. Rosell, R. García: Informe sobre el Reconocimiento dé la Region Aurifera de Sandia y Carabaya. *Boletín* de la Sociedad Nacional de Minería, 1900, pp. 419–429, 462–471; 1901, pp. 507–512, 553–559, 595–600, 619–625, 662–668, Lima.

Treats of geography, geology, history of the region, and gives more detailed account of Poto, Phara, Sandia, and Carabaya.

168. Ross, F. E.: Mining Operations in Peru in 1910. *Eng. and Min. Jour.*, Vol. 91, pp. 463–465, 1910.

Discusses progress in the different mining regions.

169. Sample, Clarence C.: The Cerro de Pasco Mining District, Peru. *Eng. and Min. Jour.*, Vol. 85, pp. 155–158, 1908.

General description of a trip to the district.

170. Sample, Clarence C.: Mining and Smelting at Cerro de Pasco, Peru. *Eng. and Min. Jour.*, Vol. 85, pp. 206–208, 1908.

Good historical account of the mining industry of the region with descriptions of the ore bodies and mines.

171. Santolalla, F. Malaga: ElAsien to Mineral de Hualgáyoc. Boletín del Cuerpo de Ingenieros de Minas del Peru, No. 6, 111 pp., Lima, 1904.

Describes geography, geology, ore deposits, mining, and metallurgical activities of the province. Coal also occurs. Hachure map of province.

172. Santolalla, Fermín Málaga: La Provincia de Cajatambo y sus asientos minerales. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 10, 78 pp., Lima, 1904.

Department of Ancachs. Geologic description of the province, mineralogy of the ores, description of the mining districts, and metallurgical processes in use. Ore deposits are argentiferous galena veins characterized by presence of tetrahedrite and silver sulphurets. Coal deposits also described. Hachure map of province.

173. Santolalla, Fermín Málaga: La Provincia de Cajabamba y sus asientos minerales. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 19, 90 pp., Lima, 1905.

Department of Cajamarca. Geographic and geologic description of the province and its mineral deposits, mining and metallurgical operations. Metallic deposits are veins in sandstone and shale carrying chiefly silver values. Also coal deposits. Hachure map of province.

174. Santolalla, F. Málaga: La Provincia de Otuzco y sus asientos minerales. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 22, 70 pp., Lima, 1905.

In department of Libertad. Description of geology of the province, mineralogy of the ores, the ore deposits, and mines by districts, and the methods of treatment. Ores are highly argentiferous base metal sulphides. Also describes coal deposits. Hachure map.

175. Santolalla, F. Málaga: Importancia Minera de la Provincia de Cajamarca. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 31, 83 pp., Lima, 1905.

Geology of province and description of mineral deposits by districts. Include sulphur and coal. Hachure map of province.

176. SANTOLALLA, F. MÁLAGA: Los Yacimientos Minerales y Carboniferos de la Provincia de Celendin. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 32, 50 pp., Lima, 1905.

In department of Cajamarca. General description of province, its geology, and its mineral deposits by districts. Argentiferous copper ore characterized by presence of tetrahedrite. Description of coal deposits. Hachure map of province.

177. SANTOLALLA, FERMÍN MÁLAGA: Monografia del Departamento de Cajamarca. *Boletín* de la Sociedad Geografica de Lima, Vol. 20, 319 pp., Lima, 1906.

Map of the department. Third chapter, pp. 23–68, gives general account of geology and résumé of mineral deposits by provinces with brief descriptions of the districts.

178. SANTOLALLA, F. MÁLAGA: Informe Preliminar sobre los Lavaderos Auríferos del Rio Tablachaca. *Boletín* de la Sociedad de Ingenieros, Vol. 8, pp. 199–206, Lima, 1906.

An affluent of the River Santa which empties into the Pacific at Santa. Describes the geology of the region through which it flows, the gold content of the sands, and mining operations.

179. SANTOLALLA, F. MÁLAGA: La Provincia de Contumazá y sus asientos minerales. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 38, 57 pp., Lima, 1906.

Department of Cajamarca. Description of geology, geography, mineralogy of the ores, and ore deposits by districts. Ores are principally argentiferous lead and copper ores. Coal is also found.

180. SANTOLALLA, F. MÁLAGA: Riquezas Minerales de la Provincia de Santiago de Chuco. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 46, 120 pp., Lima, 1906.

Description of geology and ore deposits by districts and of metallurgical plants. Most important district, Quiruvilca, described more fully. Coal deposits also described.

181. SANTOLALLA, FERMÍN MÁLAGA: Monografia Minera de la Provincia de Huamachuco. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 51, 66 pp., Lima, 1907.

Description of geology and ore deposits by districts and of metallurgical plants. Coal also occurs. Map of province.

182. SANTOLALLA, F. MÁLAGA: Estado Actual de la Minería en Quiruvilca. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 75, 48 pp., Lima, 1909.

Department of Libertad. Veins of argentiferous copper ores in andesite country rock.

183. SCHAFER, F. J.: Mining in the Department of Ancachs, Peru. *Eng. and Min. Jour.*, Vol. 64, pp. 274, 663–664, 1897.

Describes the various mining projects of the region.

184. SEWELL, HENRY: On the Mineral Caves of Huallanca, Peru. *Am. Jour. Science*, 3d Ser., Vol. 15, pp. 317–318, 1878.

Describes marvelous tetrahedrite crystals lining caves and vugs.

185. SINGEWALD, JOSEPH T., JR., AND MILLER, BENJAMIN LEROY: The

Mining Industry of Peru. *Eng. and Min. Jour.*, Vol. 101, pp. 845–850, 1916.

A general review of the mineral wealth of Peru.

186. SINGEWALD, JOSEPH T., JR., AND MILLER, BENJAMIN LEROY: The Cerro de Pasco District, Peru. *Eng. and Min. Jour.*, Vol. 101, pp. 1015–1018, 1916.

Describes geology and ore deposits and operations of Cerro de Pasco Company.

187. SINGEWALD, JOSEPH T., JR., AND MILLER, BENJAMIN LEROY: Prominent Mines of Junin, Peru. *Eng. and Min. Jour.*, Vol. 102, pp. 583–587, 1916.

Describes Minasragra vanadium, Colquijirca silver, and San Gregorio bismuth deposits.

188. SINGEWALD, JOSEPH T., JR., AND MILLER, BENJAMIN LEROY: The Morococha and Casapalca Districts in Peru. *Eng. and Min. Jour.*, Vol. 102, pp. 889–893, 1916.

Describes geology and ore deposits of Morococha and Casapalca districts with account of mining operations.

Translation by MICHEL FORT; *Boletin* de Minas, Industria y Construcciones, Series II, Vol. 9, pp. 8–19, Lima, 1917.

189. STRAUSS, LESTER W.: Quicksilver at Huancavelica, Peru. *Min. and Sci. Press*, Vol. 99, pp. 561–566, 1909.

Gives a history of the region, the occurrence, origin, and exploitation of the ores; and methods of smelting.

190. STRAUSS, LESTER W.: The Casapalca Smelter, Peru. *Min. Mag.*, Vol. 5, pp. 59–66, London, 1911.

Contains a description of the ore bodies in the Natividad Mines, Morococha.

191. STRAUSS, LESTER W.: The Chuichos Coal Mine, Peru. *School of Mines Quart.*, Vol. 34, pp. 24–25, 1912.

A brief description of a vein of asphaltite

192. STRAUSS, LESTER W.: Mining in Peru in 1913. *Min. and Sci. Press*, Vol. 108, pp. 482–486, 1914.

A general review of the mining industry of the country.

193. TARNAWIECKI: The Huaura Wolfram Mines. *Min. Jour.*, Vol. 94, pp. 687–689, London, 1911.

Description of the ore bodies accompanied by sections.

194. THURSTON, E. COPPÉE: Bedded Gold Quartz Veins near Poto, Peru. *Eng. and Min. Jour.*, Vol. 90, pp. 597–598, 1910.

Gold-bearing quartz veins between beds of slate are described.

195. TORRES, J. LEOPOLDO: Guia Bibliografica. Descripcion de la Minas i Oficinas Metalurgicas en el Peru clasificadas por Departamentos. Litografia i Topografia Nacional de P. Berrio, 2d Ed., 85 pp., Lima, 1908.

Bibliography of literature on mining in Peru contained in the library of the Peruvian Mining School arranged by departments.

196. TORRICO Y MESA, JUAN: Breves Apuntes sobre el Asiento Mineral de Huallanca. *Anales* de la Escuela de Construcciones Civiles y de Minas del Perú, Vol. 6, 31 pp., Lima, 1887.

In province Dos de Mayo, department of Huánuco. General account of the district and notes on the three mines in operation.

197. Torrico y Mesa, Juan: Memoria acerca de las Riquezas Minerales de la Provincia de Cajatambo y Especial de los Cerros de Chanca. *Anales* de la Escuela de Ingenieros de Construcciones Civiles, de Minas e Industrias del Peru, 70 pp., Lima, 1901.

Description of the geography and geology of the province, kinds of ore found, and of the ore deposits.

198. Tweddle, H.: The Gold-Fields of Sandia, Peru. *Eng. and Min. Jour.*, Vol. 63, pp. 449–451, 479–480, 1897.

Description of the gold placers in the northeastern part of the Department of Puno.

199. Umlauff, A. F.: La Turba en el Perú. *Boletín* de la Sociedad de Ingenieros, Vol. 5, No. 5, Ingenieria de Minas, pp. 31–38, Lima, 1903.

Description of occurrence, use, and value of peat at Caylloma.

200. Umlauff, Augusto F.: El Cinabrio de Huancavelica. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 7, 62 pp., Lima, 1904.

Description of geology and mercury deposits and discussion of mining and metallurgical industry of the district. Geologic map.

201. Velarde, Carlos E.: Apuntes sobre el Asiento Mineral de Yauli. *Boletín* de la Sociedad Nacional de Minería, 1899, pp. 418–425; 1900, pp. 8–16, 53–58, 87–93, Lima.

Résumé of mines in subdistricts and their production, old and present methods of ore treatment, transportation, and labor.

202. Velarde, Carlos E.: La Region Minera de Huancavelica, distrito de Huaillay, Provincia del Cerro de Pasco. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 44, 40 pp., Lima, 1906.

Describes geography, geology, and veins of district. Veins occur in dacite and sedimentaries. Former are argentiferous copper veins characterized by enargite and tennantite, latter carrying galena and sphalerite more abundantly.

203. Velarde, Carlos E.: La Minería en el Perú. Publicación del Ministerio de Fomento, Direccion de Fomento, 366 pp., Lima, 1908.

Part I. Description of metalliferous deposits in geographic sequence from north to south. Part II. Description of mills and metallurgical plants taken up in same order. Part III. Description of petroleum districts in same sequence.

204. Venturo, Pedro C.: Excursiones Cientificos. Viaje al Asiento Mineral del Cerro de Pasco. *Boletín* de Minas, Industria y Construcciones, Vol. 13, pp. 27–30, 36–39, 43–47, 50–54, 58–62, Lima, 1897.

Description of the geology and discussion of the genesis of the deposits, description of nearby deposits, of metallurgical plants and general considerations.

205. Venturo, Pedro C.: Los Yacimientos de Fierro de Tambo Grande. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 8, 37 pp., Lima, 1904.

Description of a large deposit of siliceous red hematite, supposedly deposited in a lacustrine or marine basin.

206. Villa, Emilio G.: Asiento de Ancash. Mineral de Colquipocro.

Boletín de Minas, Industria y Construcciones, Vol. 5, pp. 66–69, Lima, 1889.

Notes on the mines, mills, labor, and transportation. Produces oxidized silver ores and argentiferous sulphides.

207. WECKWARTH, EUGEN: Los Metales Raros y sus existencia en los Minerales del Peru. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 63, 128 pp., Lima, 1918.

Describes chemical behavior and occurrence of each of the rare metals and states whether found in Peru or not.

208. WECKWARTH, EUGEN: El Antimonio en el Perú. Boletín del Cuerpo de Ingenieros de Minas del Perú, No. 68, 97 pp., Lima, 1908.

General treatment of antimony-bearing minerals, metallurgy and production of antimony with description of occurrences in Peru.

209. WEST, H. E.: Vistas del Peru. *Min. and Sci. Press*, Vol. 112, pp. 704–706, 1916.

Some data regarding the silver mines of Calloma, gold-silver mines near Trujillo, and molybdènum deposits near Jauja.

210. ————: Estudio Técnico de las Salinas del Perú. Imprenta de "El Pais," Edicion Oficial, 2 Vols., Lima, 1896.

Vol. 1 text, vol. 2 maps. Contain map showing localities at which salt is produced and description of salt deposits in Peru by a commission appointed to make a study of the salt industry.

211. ————: 5ª Memoria del Directorio, Compañia Administradora del Guano, Limitado. Librería y Imprenta Gel, 105 pp., Lima, 1914.

Contains map showing distribution of the guano deposits, description of localities and of guano-depositing birds, and statistics of production.

212. ————: The Cerro de Pasco Mines, Peru. *Eng. and Min. Jour.*, Vol. 103, pp. 351–353, 1917.

Official statement by Cerro de Pasco Copper Corporation giving brief outline of ore occurrence and operations of company at Cerro de Pasco and Morococha.

213. ————: *Boletín* de Minas, Industria y Construcciones. Publicado por la Escuela Especial de Ingenieros de Lima.

Contains many articles and notes on mining districts of Peru. Only a few of these receive separate citation in this bibliography.

214. ————: *Boletín* de la Sociedad de Ingenieros, Lima.

Contains abstracts of many of the bulletins of the Cuerpo de Ingenieros de Minas del Peru, and a number of short articles on mines and mining districts that have not been listed in this bibliography.

215. ————: *Boletín* de la Sociedad Nacional de Minería, Lima.

Contains many extracts of the bulletins of the Cuerpo de Ingenieros de Minas del Peru, and also brief descriptive articles that have not been listed in this bibliography, only the more important ones being here cited separately.

216. ————: Estadística Minera del Perú. Boletín del Cuerpo de Ingenieros de Minas del Perú.

Beginning with 1903 the annual statistics of the mineral production of Peru are published in a number ot this series of bulletins. Frequently also include descriptive notes on many of the districts.

217. ————: Estadística del Comercio Especial del Perú. Superintendencia General de Aduanas, Lima.

Published annually and gives exports of mineral products by customs ports.

218. ————: Peru Today, Lima.

Published monthly from 1909 to 1914. Mining section contains many brief articles and notes on Peruvian mines and mining and in addition there are a number of other articles in the general section of the paper. Though they contain much information, they are in general short and are so numerous as to make individual citation in this bibliography impossible.

CHAPTER XI

URUGUAY

RÉSUMÉ OF MINERAL PRODUCTION

The mineral production of Uruguay is less than that of any South American country with the exception of Paraguay. Contrary to the status of the mining industry in the other countries of this continent, the mining of non-metallic products is more important than the metal-mining industry. Gold is the only metal produced at present and the output comes entirely from the department of Rivera. In the past the department of Minas has also been a producer. During the last decade the gold output has fluctuated between $50,000 and $111,000 annually.

Copper has been worked in Maldonado and Minas, the most extensive operations having been conducted at La Constancia in Maldonado where there was a smelter. Lead mining was carried on in the department of Minas, and at the Ramallo or Reus mine, which was abandoned in 1901, there are remains of smelting works. Manganese ore was mined at Guaycurú in San José until 1876. There are no statistics of production of these ores.

The only fuel produced is a small quantity of peat in Maldonado.

Uruguay has long been noted for its production of the semi-precious stones, amethyst, agate, and chalcedony, which are found in the states of Salto, Artigas, and in the western part of Tacuarembó and Rivera. Statistics of production are very incomplete, but in 1909 the total exports of amethysts amounted to 6,000 to 7,000 kgs. worth from 10¢ to $12 per kg., with exceptionally fine stones bringing as high as $40 per kg. (7, p. 74).* Practically the entire production of amethysts and agates has gone to Germany.

* Numbers in parentheses refer to articles in bibliography at close of chapter.

Talc is mined near Las Conchillas in Colonia, and in seven years of operation the mine has produced 7,000 tons, of which 5,000 was exported to Buenos Aires and 1,000 tons sent to Montevideo. A small amount of graphite has been produced at Isla Mala in Florida.

Limestone, marble, granite, slate, and sandstone are quarried at a number of localities, but there are no figures as to amount. Most of the limestone quarries are in Minas, others are operated in Maldonado and Cerro Largo. The greater part of the output is used for lime-burning. The largest granite quarries are in Colonia where an English company exports considerable stone to Buenos Aires, and quarries are worked in Maldonado and Minas. Curbstones, paving stones, and building stones are made. Slate is produced in small quantity in Minas and Maldonado. Near San Fructuoso in Tacuarembó is a sandstone quarry which produced grindstones.

GEOLOGIC SKETCH

A broad belt of crystalline rocks traverses eastern Uruguay in an approximately north-south direction, forming the extension of a similar belt in Brazil, and encounters at its southern end in the department of Minas a belt of the same kind of rocks stretching along the south coast of the country in an east-west direction. These rocks consist of gneisses, schists, and slates with intercalations of limestones and marbles, and widely distributed eruptive rocks, especially granite, syenite, and diorite.

The north-south crystalline belt is bordered on each side by younger sediments which have suffered practically no disturbance. They consist of sandstones, sandy clays, sandy shales, shales, and dolomitic limestones. Interbedded with these sediments are porphyries and cutting them are numerous melaphyre intrusions in the form of small knobs and dikes. The age of this series ranges apparently from Permo-Carboniferous, through the Mesozoic, and possibly into the Tertiary.

Both of these series of rocks are overlain to a greater or less extent by the *pampa* formation. It consists for the most part of terrestrial, and chiefly eolian deposits, composed of sands, sandy conglomerates, clayey sands, clays, and occasionally fresh water quartzose material and limestone. In places abundant mammalian remains are found. The series seems to extend from Tertiary to Recent time.

Except for the semi-precious stones and the fuels, the mineral deposits are confined almost entirely to the region of the crystalline rocks.

DESCRIPTION OF MINERAL DEPOSITS

GOLD

The gold occurrences of Uruguay are of two types—quartz veins in dioritic dikes and stocks and greatly shattered quartz

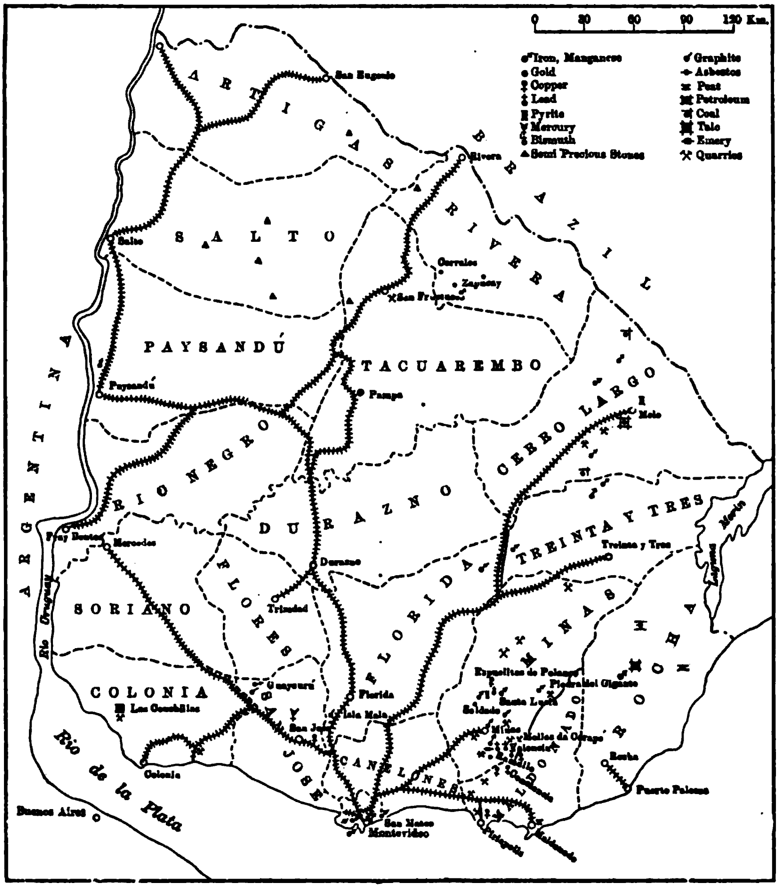

FIG. 58.—Map of Uruguay with locations of mineral deposits.

intercalations in the schists, of which the former have proved the more productive. The only districts of importance have been Corrales in Rivera and Soldado in Minas. Alluvial gold has also been found in a number of streams in Minas, and gold veins and placers near Pampa in Tacuarembó.

The gold ore at Corrales, near Cunapirú, occurs in quartz veins cutting dioritic rocks. The most extensively worked vein has been the San Gregorio which consists of a large body of low-grade ore within which are shoots of higher grade. The average annual gold content of the ore has ranged from $2.40 to $9.20 with the average during the past twenty years about $5.70. The cost of extraction has been brought down to $4 to $6 per ton. The annual production from 1894 to 1909 was about $33,000. In the first half of 1911 it was increased to $51,000, but in July, 1913, work was practically suspended. The property has a mill equipped for amalgamation and cyanidation. About 60 per cent of the gold is recovered by amalgamation. The cyanide product carries 30 to 40 per cent silver. The mine has changed hands a number of times, having been owned by a French company and several English companies, and the operations have never been remunerative as can be surmised from the above figures.

At Zapucay, 20 km. to the southeast, gold occurs in mashed quartz layers in highly folded siliceous chlorite and amphibole schist, and also impregnating the schist, and has apparently resulted from the oxidation of auriferous pyrite.

The Soldado veins are quartz veins in dioritic rock, carry auriferous pyrite and chalcopyrite, and are characterized in the oxidized zone by the presence of shoots containing considerable free gold. The copper content of some of the ore is so high that in the middle of the last century it was worked by an Uruguayan company for its copper and the veins are said to have yielded an ore assaying $5 to 6.50 gold and 20 per cent copper. Several concessions have been worked at various times in this district.

COPPER

Copper ores are found in Maldonado, Minas, and San José. The best known copper mine is the Oriental or Constancia, located about 30 km. south of Minas in Maldonado. The ore consists of pyrite, chalcopyrite, and a little bornite, and is said to contain 8 to 19 per cent copper. Three parallel veins with a thickness of 0.80, 2.10, and 1.80 m. respectively are separated by 1.2 and 1.5 m. of rock. The mine has not been regularly worked for 30 years. About 7 km. west of this locality is a vein of malachite and cuprite mixed with hematite which is 10 cm. wide at the surface but at a depth of 10 m. has widened to 50 cm. The details in regard to other occurrences in Maldonado are even more meagre. The copper content of some of the gold veins of the Soldado district in Minas has been referred to. Further northeast in the same state, at Las Espuelitas de Polanco, several deposits have been worked that show a gossan of oxides of iron with carbonate of copper in granite, schists, and limestones.

LEAD

Lead deposits are known only in Minas. At the Ramallo or Reus mine, 10 km. south of Minas, occurred lenses or pockets in black shale consisting of quartz, galena said to be rich in silver, and a small amount of copper minerals. The maximum width of the masses was 40 cm. The remains of the old plant and the size of the dump indicate extensive work here in former years. During the Civil War in 1842–1851 the mine furnished lead for bullets, and later was worked even more extensively, but was abandoned about 1901. The Valencia mine, 6 km. east of the Ramallo, is on a quartz vein cutting a reddish limestone which has a width of 30 to 40 cm. with several parallel veins 2 to 12 cm. wide. The ore mineral which is galena occurs disseminated through the limestone. Work was stopped at this mine in 1868.

MANGANESE

The most important manganese occurrence is that at Guaycurú in San José where the ore covers a large area on both sides of the Guaycurú River and is said to extend in an east-west direction for 50 to 70 km. The deposit is apparently a surficial one somewhat similar to bog iron ore. Six or seven mines were in operation here until the deposit was abandoned in 1876. The only other occurrences of manganese ore are in the department of Montevideo. At San Mateo, 15 km. east of Montevideo, are small and scattered outcrops of ore containing 30 to 40 per cent manganese, 10 per cent silica, 2 to 3 per cent iron, and practically no sulphur or phosphorus. The deposit extends along a contact of granite and schist for a distance of 150 to 200 m. with a width of 50 m. and consists of the schist saturated with manganese minerals, of which wad is most abundant at the surface. On a small island in Montevideo Bay is a vein carrying 34 per cent manganese which has a width of only 5 to 10 cm. at the surface, but which is said to widen in depth.

Deposits of highly manganiferous iron ores are known in Rivera, Florida, and Rocha. Of considerable promise is that at Zapucay in Rivera. The two hills Cerro Ymán and Cerro Papagay are made up almost entirely of ore, and branches extend for 3 km. into the neighboring hills. At the surface the ore is a mixture of wad, psilomelane, and magnetite, and carries 34.8 per cent iron, 22.7 per cent manganese, 9.0 per cent silica, .03 per cent phosphorus, and .05 per cent sulphur. Marstrander says 80,000,000 tons can be taken out by open cuts (7, p. 10). Considerable preliminary prospecting has been done and a 120-km. branch railroad to the deposits is projected.

IRON

Iron ores are reported from Minas, Florida, Montevideo, Paysandú, Treinta y Tres, and Cerro Largo, but most of these occurrences are of no economic promise. In the northern part of Cerro Largo are several layers of clay ironstone that are reported to extend over a large area and to contain a high percentage of iron. Most numerous are the localities in Minas, where the ores are hematite and magnetite with or without quartz gangue associated with the schists either as veins or intercalations. The largest deposit is at Piedra del Gigante, where a vein 4 to 10 m. wide can be traced over 1,000 m. on the surface. The ore is a mixture of magnetite and hematite accompanied by varying amounts of quartz. A large sample across the vein contained 46 per cent silica, but analyses of pure ore gave a content of about 66 per cent iron. A similar vein 2 to 6 m. wide and traceable for 700 m. outcrops in the Minas Viejas Valley southeast of the city of Minas. A little work has been done at Santa Lucia on deposits of specular hematite occurring as nearly pure masses and small veins of different widths alternating with the rock.

FUELS

Coal in workable quantity has not been found. An occurrence of coal is reported in the southern part of Cerro Largo and the probability is that the coal beds of the adjoining Brazilian state of Rio Grande do Sul extend into the department of Cerro Largo. The extensive peat swamps of Rocha, Maldonado, and Canelones offer the greatest promise of a domestic fuel supply. Some of the peat beds cover large areas and have a thickness of 5 m. Evidences of oil and bituminous shales are found in Rocha and Cerro Largo, but no occurrences of commercial value have yet been discovered.

SEMI-PRECIOUS STONES

The amethysts, agates, chalcedonies, carnelians, and other varieties of the silica minerals are found in the northwestern part of the country widely distributed over the surface and in stream gravels and occur in all sizes up to boulders 10 cm. in diameter. They represent materials weathered out of the melaphyres and other amygdaloidal igneous rocks of this region.

TALC

An excellent deposit of talc is being worked 15 km. from Las Conchillas in Colonia. It occurs in chloritic and quartzitic rocks with large masses of younger granites and porphyries nearby, and is supposed to have been formed as a result of hydrothermal action of waters carrying magnesium silicates or silica only on dolomitic limestone, intercalated in the schistose rocks. The talc occurs in large lenticular, nearly vertical masses. Though frequently stained near the surface, in depth it is extraordinarily pure and of a dazzling white color with a greenish or bluish tinge due to a small amount of chloritic minerals. Lenticular quartz nodules up to 1 m. in length are found embedded in it and are considered remnants of siliceous inclusions of the original dolomite. Most of the product has been used in the paper and soap industries in Buenos Aires and Montevideo, but on account of its purity, its use for pharmaceutical purposes is increasing.

OTHER MINERALS

Occurrences of mercury and bismuth minerals are of mineralogic interest only. Emery has been found in the San Francisco Valley in Minas in an isolated conical hill 60 m. high and 250 m. in diameter and in a smaller outcrop nearby. It grades into the enclosing schists and is supposedly the result of pneumatolytic processes accompanying the intrusion of a large granite mass west of the deposits. The emery is fine-grained, and contains only a small amount of magnetite and no pyrite or other injurious minerals. Unimportant occurrences of graphite have been noted at a number of localities. At Isla Mala in Florida there is a deposit that has been worked on a small scale for some time. Unsuccessful attempts have been made to mine asbestos at the Mólles de Carapé in Minas. The deposit consists of white, long-fibred, but brittle tremolite in dolomite which is so intermingled with the latter that a separation of the two is not commercially feasible.

BUILDING STONES

It is hardly necessary to say anything further in regard to the building stones. Many deposits of marble and granite of exceptional quality suitable for building and ornamental purposes occur in the country, and with such markets as Montevideo and Buenos Aires and other important cities of eastern Argentina near at hand a still greater development of this industry is possible. The locations of the principal quarries are given on the map.

CONDITIONS AFFECTING AND GOVERNING THE MINING INDUSTRY

Compared with other South American countries, the facilities for the development of a mining industry are peculiarly favorable in Uruguay, and the fact that it ranks next to last among them as a mining country, seems almost certain evidence of a lack of important and extensive mineralization. No part of the country is far removed from water or rail transportation, and there are no great climatic or topographic difficulties to be overcome. The government is one of the most stable, and the country, as a whole is the most highly developed on the South American continent. Unmistakable evidence of this is the relative importance of the production of the non-metallic products as compared with the metallic.

Though it is not to be expected that Uruguay will ever become an important mining country, the mineral industry is undoubtedly capable of a far greater development than it has yet attained a result that is being greatly furthered by the work of the Instituto de Geología y Perforaciones established by the government in 1912 under the direction of Dr. M. A. Lamme. This bureau is making a careful examination of the more promising mineral deposits, even to the extent of prospecting by drilling and in other ways.

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CHAPTER XII

VENEZUELA

The Republic of Venezuela occupies the northernmost part of South America and contains an area estimated at 594,000 square miles. From east to west the country has an extent of about 1,000 miles and 750 miles from north to south. There are 70 navigable streams, of which the great Orinoco River is the most important, and several hundred lakes, one of which—Lake Maracaibo—is of large size, covering about 6,755 square miles.

TOPOGRAPHICAL DIVISIONS

Venezuela contains varied types of topography ranging from coastal plains to high mountain peaks continually capped by snow even though well within the Tropics. Four fairly well-defined topographic divisions can be readily distinguished, each of which is peculiar in its geological features and the economic mineral products which it contains. These are commonly designated as (1) The Coastal Plains, (2) The Northern Mountain Ranges, (3) The Llanos, and (4) the Guayanan Highlands.

1. **The Coastal Plain.**—The Coastal Plain is the smallest of the topographical divisions of Venezuela. It occupies the extreme northwestern portion of the country and includes an area of about 28,000 square miles, or less than one-twentieth the entire area of the country. It includes practically all of the State of Zulia and a part of Falcon. Lake Maracaibo, one of the largest lakes of the South American Continent, occupies the center of the region. It is a brackish-water shallow lake into which empty numerous streams having their sources in the high Cordillera of Western Venezuela and Colombia. The lake is connected with the Gulf of Maracaibo (also called Gulf of Venezuela) by four channels. A bar prevents heavy-draft vessels entering the lake, but small steamers ply back and forth to various small settlements on the shores and on the tributary streams.

The topography of the Coastal Plain is low and comparatively level and contains numerous small lagoons and salt pans. Only a small part of the land is utilized. Agriculture and cattle raising are the principal occupations of the people.

The geology of the Coastal Plain has only been worked out in a general way. Cretaceous and Tertiary strata outcrop in many places, especially about the shores of Lake Maracaibo, but the greater portion is covered with alluvial deposits of Quaternary age. It is supposed that the Cretaceous and Tertiary strata form a great syncline with the axis extending through Lake Maracaibo, which was at one time much larger but is being gradually silted up by the alluvium brought into it by the streams from the bordering mountains.

With the exception of some salt, obtained from the salt pans, practically no use has been made of the mineral deposits of the Coastal Plain. Deposits of coal and asphalt are known in several places, and there is considerable evidence of petroleum.

2. **The Northern Mountain Ranges.**—A spur of the Colombian Andes enters the western portion of the Republic of Venezuela and runs in a northeasterly direction. It is continued by other ranges that extend to the coast, several ranges parallel the coast to the delta of the Orinoco River in the eastern part of the country. As these ranges possess many different features, it is advisable to describe them separately as (*a*) the Andes or Cordillera of Merida, (*b*) the Coro ranges, and (*c*) the Caribbean or Venezuelan Coast ranges.

The continuation of the Colombian Andes in Venezuela is usually designated as the Sierra Nevada Mountains or the Cordillera of Merida from the name of the principal town of the section. These are the highest of the Venezuelan mountains and contain several peaks perpetually covered with snow. The range culminates near the town of Merida in La Columna Peak, whose height is variously given from 14,885 feet to 16,423 feet. The Andes extend through the three states of Tachira, Merida, and Trujillo, terminating not far from Barquisimeto. The valleys in these mountains are utilized in the cultivation of coffee and cacao while valuable forests cover the steeper slopes. Abundance of water power is available in the numerous mountain streams.

The Cordillera of Merida contain a central core of gneisses, micaceous schists, and phyllites, with much granite which is believed to be considerably younger and to have been intruded into these old metamorphic rocks, which are probably of Archean age. Cretaceous and Tertiary strata outcrop on both the eastern and western flanks of the range, dipping away from the range in a manner to suggest the uplift of the mountains after these beds had been formed.

Gold, silver, copper, iron, and antimony have been found in the crystalline rocks, and coal and petroleum in the Cretaceous and Tertiary strata of the lower slopes. Gypsum and sulphur have also been reported. Thus far the mineral resources of the Venezuelan Andes remain practically untouched, no mines of any consequence having ever been developed.

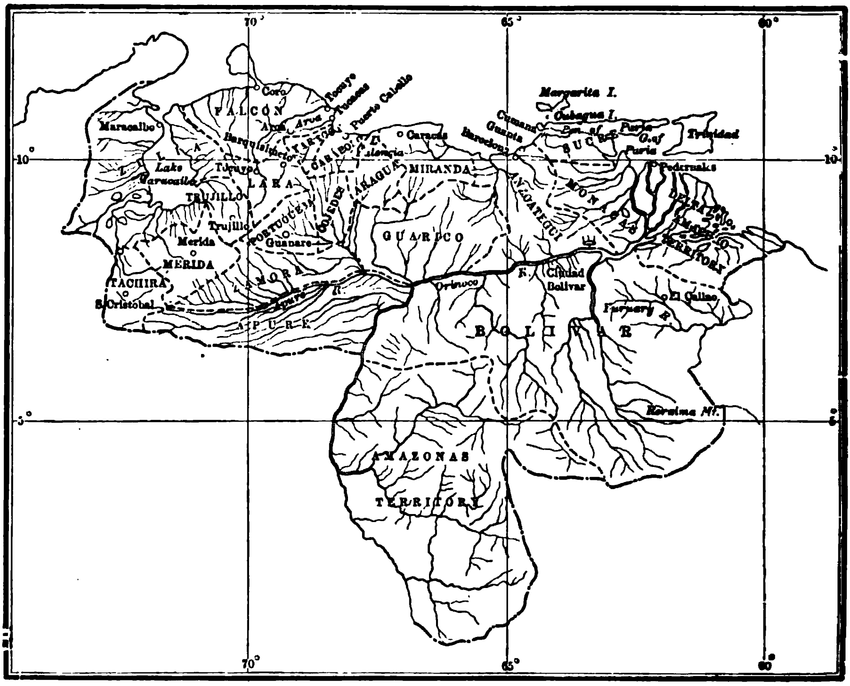


FIG. 59.—Map of Venezuela.

The second division of the northern mountain ranges lies mainly in the State of Falcon, although extending into the states of Lara and Yaracuy, and is known as the Coro ranges. They lie between Barquisimento and Coro. They have an east-west trend and consist of several parallel ranges separated by wide valleys. The highest peaks are scarcely 5,000 feet above sea level. Different portions have received different names; Sievers distinguishes the two principal ranges as the Northern System, including the Cordillera de San Luis, and the Southern System, including the Cordillera de Buena Vista, the Cordillera de Agua Negra, etc. The Sierra de Baragna, the Sierra de Matatere, and the Sierra de Aroa are short ranges lying to the south of the Southern System.

The Coro ranges are composed mainly of Lower and Upper Cretaceous strata with the valleys between occupied by Tertiary or Quaternary deposits. In the southern ranges, however, some of the ancient metamorphic crystalline rocks are exposed.

The principal occupation of the region is farming and stock raising. The western portion is, in general, too dry to produce much but the rainfall of the eastern part is sufficient for farming. Silver, lead, bismuth, antimony, and copper occur in the Coro ranges, but the last-mentioned is the only one thus far worked to any extent. The copper mines of Aroa have long been operated.

The Caribbean or Venezuelan Coast ranges extend from the State of Yaracuy eastward to Trinidad. They are separated from the Coro ranges by a broad depression drained by the Yaracuy River. The Caribbean ranges, with an east-west trend, are composed of two parallel ranges, one bordering the coast called the Coast Range, and the other somewhat farther south designated as the Interior Range. Both are interrupted twice in their course. In the vicinity of Barcelona, the Llanos of the Orinoco valley come to the coast, and the Gulf of Paria, which separates Trinidad from the mainland, also cuts across the ranges.

West of the Barcelona depression, the highest peaks are in the Coast Range, Naiguáta Mountain rising to an elevation of 9,127 feet; east of Barcelona the Interior range contains the highest point, Turumquire Peak, with an elevation of 6,562 feet above sea level.

Lake Valencia and many ancient lake beds occupy the hollow between the two ranges in the western portion, and the Gulf of Cariaco and various swamps and lagoons are located between the eastern ranges. Caracas, Cumana, and Carupano are located in the Coast range, and Barcelona is within the Interior range.

Geologically, the Caribbean ranges consist of ancient metamorphic rocks, with Cretaceous, Tertiary, and Quaternary rocks in the depressions and along their flanks.

Deposits of gold, silver, copper, iron, manganese, lead, coal, asphalt, petroleum, salt, sulphur, opals, and iron sulphate occur in the Caribbean ranges.

3. **The Llanos and the Delta of the Orinoco River.**—Extending in a broad belt across the entire country from west to east are the plains known as the Llanos which terminate in the delta of the Orinoco River. This region, lying mainly north or northwest of the Orinoco, is a plain, with few irregularities, and has in the western and northern portions a maximum elevation of about 800 feet. The western part is partially forested but the central and eastern portions are largely covered by a growth of coarse grass. Although many streams cross the Llanos, most of them are dry during the dry months so that portions are practically deserts. The Orinoco delta is low, flat, and unhealthy.

The Llanos and the Orinoco delta have, in the main, Quaternary rocks at the surface but are probably everywhere underlain by Cretaceous and Tertiary strata.

The mineral products of this district are few. Asphalt deposits are known at a few places, and probably petroleum and coal may be obtained by boring.

4. **The Guayanan Highlands.**—The great areas lying south and southeast of the Orinoco River are known as the Guayanan Highlands. They are embraced in the State of Bolivar, the Territorio Amazonas, and a part of the Territorio Delta-Amacuro. The greater portion of the region is unexplored.

The Guayanan Highlands consist of numerous hills or short mountain ranges separated by broad valleys. There are several peaks exceeding 8,000 feet. Dense forests cover certain portions and other sections have luxuriant growths of grass and shrubs. The streams are interrupted by numerous rapids which have interfered with exploration work.

The geology of the Guayanan Highlands is almost unknown, but apparently is exceedingly complicated. The principal rocks are granites, gneisses, and schists of various kinds, believed to be of Archean age. Overlying these are horizontal beds of sandstones, conglomerates, and shales at one time continuous over the entire region but now occurring as isolated patches of variable extent. The greatest known thickness is about 2,000 feet. Several writers have correlated these strata with the pre-Cambrian Torridonian beds of Scotland, whereas Sievers considers them of Cretaceous age. They are undoubtedly a continuation of similar beds which are extensively developed throughout Brazil and believed by Derby to be of Mesozoic age probably Triassic. Dikes of various kinds of igneous rocks cut both the crystalline rocks as well as the overlying sedimentaries.

The mineral deposits of the Guayanan Highlands have been investigated in only a few localities but the fact that the country's richest known gold and iron deposits occur here leads one to believe that it may contain other valuable mineral products.

THE MINING INDUSTRY OF VENEZUELA

That mining in Venezuela has not prospered as in several of the other South American countries is evident. The cause for this state of affairs is undoubtedly due to lack of transportation facilities mainly, in part to climatic reasons, and partly to lack of capital. The asphalt and petroleum resources are now receiving the attention they merit and the other economic products will doubtless be exploited in time.

The mineral products of importance are gold, copper, iron, coal, asphalt, and petroleum. On Dec. 31, 1913, the Government reported the following mineral concessions:

	Gold mines	Copper mines	Iron mines	Copper and iron mines	Lead mines	Asbestos mines	Coal mines	Asphalt deposits	Petroleum properties
Concessions in force.....	74	20	47	1	1	1	7	20	47
Concessions being worked	15	6	......	......	......	......	3	8	?

GOLD

Ever since Raleigh searched the northern part of the South American Continent for the mythical El Dorado, gold has been sought in Venezuela. There probably has been not a year since the earliest occupation of the country when there has not been some gold produced. During the first 6 months of 1916, gold to the value of nearly $700,000 was exported according to the Bulletin of the Pan-American Union for August, 1917.

Gold has been found in nearly all the mountainous states, and gold mines have been operated at a number of places in the

Andean and Caribbean mountain ranges. However, for one reason or another, no extensive mining has been done in these districts nor have any of the small operations proved especially profitable.

The region of the Guayanan Highlands has long been considered the most important, and probably two-thirds of all the gold mining operations have been in that section. The principal region is the Caratal District in the State of Bolivar, about 150 miles south of Ciudad Bolivar. The district is known because of the famous El Callao mine which was at one time the richest mine in the world. Scores of other mines have been worked in the same general region, although none compared with this famous bonanza. The success of this mine stimulated activity in gold mining, and, between 1860 and 1883, 42 companies were organized to work gold mines in Guayana; of that number, 29 imported considerable machinery for the equipment of mills. The heavy costs of transportation and high costs of working in a region remote from towns and supplies has always interfered with the success of the projects and many failures have resulted. However, a number of companies have been highly successful.

The El Callao mine is near the Yuruary River in a forested region of low hills adjoining the *savannas*. The region is one of metamorphic gneisses, mica and hornblende schists, granites, and diorites, with later intrusions of diabase. The gold-bearing veins are true quartz fissure veins closely associated with the diabase. At the Callao mine the veins were in diorite but not far from the diabase. They had an almost north-south strike and dipped to the west. The main bonanza vein scarcely exceeded 2 feet in width, but on account of the great value of the ore, from $75 to $90 a ton, was worked with extremely profitable results.

The mine was discovered in 1853 as a rich placer deposit. After the surface placer sands were exhausted, mining was started on the decomposed vein, and later the hard ore was found. In 1885 the mine produced about 12,000 ounces of gold a month. Altogether the mine is believed to have produced about 1,438,638 ounces of gold. The main vein was worked throughout a distance of 1,000 feet and to a depth of 1,100 feet. Although the quartz vein continued farther the values became so low that in 1895 the mine was closed. Considerable money was expended during the last few years the mine was in operation in exploratory work to try to find another rich ore shoot but without success.

Except that most of the other gold lodes of the district have a northeast-southwest strike and a south dip and also are of lower tenor, the various gold veins of the Caratal district are similar. One writer states that there are northerly dipping veins also, but these are usually poor.

Many placers have been worked in the Guayanan Highlands, but they are almost all restricted in area and the deposits thin. They have been worked with profit by means of shovel and *batea* but scarcely justify dredges except in a few places. The placers of the states of Carabobo and Lara have furnished considerable gold.

It is the general opinion of those familiar with the Guayanan region that with the improvement in transportation conditions, as the population of the country increases and its agricultural development continues, gold mining may again become as important as it was during the balmy days of the El Callao prosperity.

COPPER

Copper minerals have been reported from many places in the northern ranges of mountains, yet in only one district have profitable mines been developed. At an early date the Spaniards are said to have worked copper mines at Vargas (or El Cobre), in the Andes, and copper ores have been found near Caracas and near Carupano. During the first half of 1916, 8,435 tons of copper ore valued at $184,532, were exported.

The most important copper district is known as the Aroa region in the State of Yaracuy, about 67 miles west of Puerto Caballo, at an elevation of 1,165 feet above sea level. A railroad 53 miles in length connects them with the seaport of Tucacas. These deposits are said to have been discovered in 1605 and first mined in 1632. They were at one time owned by Simon Bolivar. The history of mining in the district is a long and eventful one; many times have the mines been abandoned for long periods of time and then re-opened. The mines are now owned and operated by a British company, the South American Copper Syndicate, Ltd.

The rocks of the region consist of slates and limestones cut by dikes of igneous rocks. The ore bodies are irregular lenticular masses within slates. In the upper levels, oxidized ores containing malachite, azurite, melaconite, and cuprite were abundant but for many years most of the ores have been sulphides—chalcopyrite and pyrite. The vein at the Aroa mine is said to have been from 50 to 75 feet in width at the surface, with an outcrop of 2,000 feet in length.

From 1880 to 1894, when the mine was closed, about $6,000,000 of ore was mined. Since the re-opening in 1907 the annual production has amounted to about $35,000. The best grade sulphide ore containing about 9 per cent of copper, is shipped to England or Wales, and the oxidized and low-grade ores are smelted to a copper matte on the property.

Within recent years another promising copper mine, La Cumaragua, has been opened up near the famous Aroa mines. At Seboruco, in the State of Tachira, copper is present in gray sandstones and conglomerates about 250 feet in thickness, constituting a part of a red sandstone formation. Eight beds varying from 1½ to 2½ feet in thickness, carry chalcocite, cuprite, malachite, and azurite. The tenor of the ore is low. Considerable lignite is present in the sandstone as is true in so many other parts of the world where similar ores occur.

Within recent years a copper mine has been worked at Pao in the State of Cojedes. Copper deposits are also known near Coro and near Barquisimeto.

IRON

Iron ore has been reported from many places in the crystalline rock belts in the Caribbean Mountain ranges and the Guayanan Highlands, particularly the latter. Practically nothing is known concerning them except those situated close to the Orinoco River (Fig. 60).

The Imataca or Manoa deposits, located in the foot-hills of the Imataca Mountain range, in the Territory of Delta-Amacuro, are the only ones that have been exploited to any extent. These hills, which have an elevation of about 500 feet above the alluvial plains of the Orinoco, are one-half mile distant from the Carosmo River which is a branch of the Orinoco and navigable for vessels of about 14-foot draft. The deposits are about 75 miles from the mouth of the Orinoco.

The country rock is a banded hornblende gneiss dipping

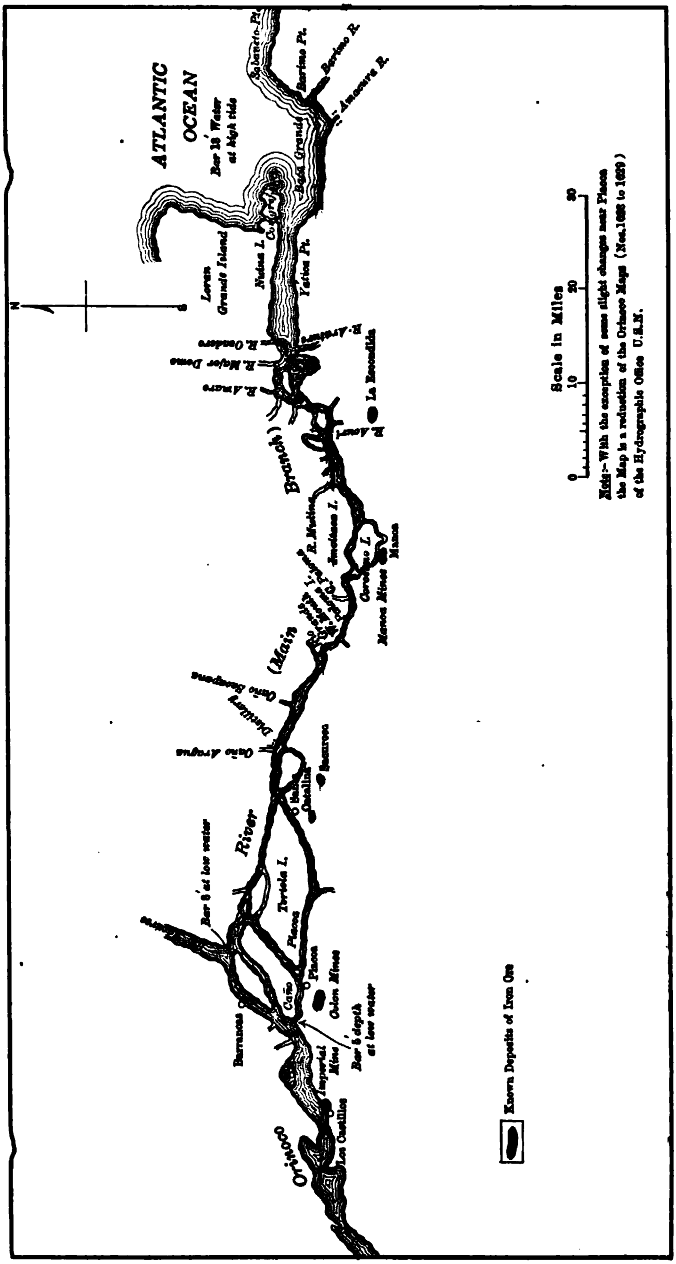


FIG. 60.—Map showing the principal iron ore-deposits along the Orinoco River.

to the north at angles of 60° to 90°. In many places the rock contains some magnetite and hematite but in too small quantities to be of commercial value. The ore, which is a mixture of magnetite and hematite, occurs in a vein about 8 feet wide that outcrops along the hills about 140 feet above the river. The vein dips to the south at an angle of 40°, cutting across the bands of gneiss. Its outcrop has been traced for a distance of 1,000 feet. A quartz vein, almost vertical, outcrops above the ore vein. It contains bunches of iron ore, especially on the sides, and rubble ore on the hill slope have come from this source.

The deposits were first investigated about 25 years ago by a New York party and subsequently by British and Canadian companies. Several cargoes have been shipped to the United States. Twelve thousand tons were exported in 1912 and 56,975 tons in 1913. The mines have been closed during the past few years.

The ore is of excellent quality, as shown by the analysis below. The deposit has been estimated to contain 10,000,000 tons, but according to some observers this is an exaggerated estimate.

Average Analysis of the Three Cargo Shipments

	Per cent
Metallic iron	66.53
Silica	1.81
Phosphorus	0.031
Sulphur	0.045
Titanium	0.139

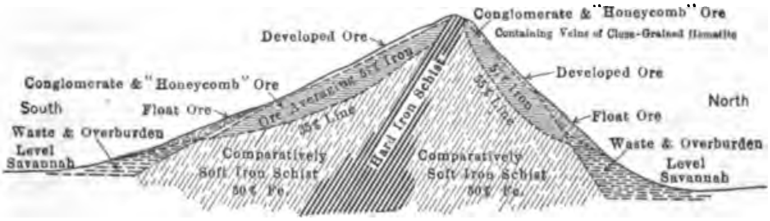
About 60 miles farther up the Orinoco River, near Piacoa, are the Colon iron mines that have been prospected. They are located in a hill rising about 450 feet above the level of the *savannas*. The entire hill is composed of the iron formation (Fig. 61) which consists of an aggregate of hematite and quartz. It is schistose in character and similar to the itabirite ores of Minas Geraes, Brazil. In places there are small lenses or veins of hard dense iron ore a few inches thick.

The slopes of the hill are covered with partially hydrated and leached ores, cemented fragments of the original iron schist, forming a kind of conglomerate, analogous to the *canga* ores of Brazil.

Analyses of the different ores made by P. W. Shimer are as follows:

	Fe	Mn	P	S	SiO_2	TiO_2	Loss on ignition
Conglomerate surface ore from northeast part of hill, representing a width of 75 feet....................	57.66	.072	.213	.070	8.50	.43	
Conglomerate surface ore representing a width of 150 feet.................	62.55	.050	.191	.055	2.51	.57	
Conglomerate surface ore representing a width of 22 feet..................	60.55	.065	.190	.103	3.63	.87	8.02
Hydrated schistose ore.....	61.30	.072	.193	.071	3.74	.93	
Non-hydrated schistose ore.	63.65	.070	.175	.063	2.55	1.40	
Rubble ore, boulders up to 1 foot in diameter........	50.54	....	....	....	22.55		
Average of 6 samples......	59.37	.066	.192	.072	7.25	.84	

A conservative estimate is that there are on the hill about 500,000 tons of the conglomerate ore averaging 60 per cent



Width Approximately, ¾ Mile
Elevation, 450 Feet

FIG. 61.—Cross-section showing the character of the iron-ore deposit, Colon Claims, Piacoa.

Fe and 5,000,000 tons of 50 per cent Fe ore, with the probability of even much more. Some drilling has been done in the deposit, but the results are not available. The character of the ores and their occurrence strongly suggest the same origin as those of Minas Geraes, Brazil, which seem to be of sedimentary origin.

Other deposits of iron ore are known along the south side of the Orinoco River near Los Castillos, Santa Catalina, Sacuroco, and La Escondida. Little is known concerning these deposits. Samples from the Imperial Mine near Los Castillos and Santa Catalina have yielded the following analyses:

	Fe	Mn	P	S	SiO_2	TiO_2
Imperial Mine Ore	59.00	.10	.112	.052	6.50	.90
Santa Catalina Ore	64.00	.07	.140	.022	1.20	.30

Iron ores of promise are also reported in the Parima Mts. and in the mountains near Coro, Barimas, Barcelona, and Cumana.

Manganese.—Manganese is reported from near Tinaquillo in the State of Carabobo.

Bismuth.—Bismuth occurs near Tocuyo in the State of Lara.

Antimony.—Antimony ores have been found near San Jacinto in the State of Trujillo and near Tocuyo in the State of Lara.

Lead.—Lead ores are found near Carupano, State of Sucre, and near Tocuyo, State of Lara.

Silver.—Silver-bearing minerals occur near Carupano, State of Sucre, in the State of Carabobo, near Tocuyo, State of Lara, and near San Cristobal, State of Tachira.

Asphalt.—The most important non-metallic mineral product which Venezuela has thus far produced and second only to gold in the country's mineral resources is asphalt. During the first six months of 1916, 16,686 tons of asphalt valued at $112,631 were exported.

The asphalt deposits of the country occur at the surface and represent the residue of oil seepages in which the volatile substances have passed into the atmosphere. In many of them petroleum is still seeping out of the sandstone strata, in others inflammable gases are given off, and others represent ancient seepages, perhaps as early as the Miocene period.

Asphalt has been reported from a number of localities in the country, all of which, however, lie to the north of the Orinoco and Apure rivers; but, so far as known, it has only been worked in three places, which will be described. It is not improbable that small areas covered with asphalt may be found in almost every place where oil springs are found. The three principal deposits are (1) the Pedernales, (2) the Bermudez pitch lake, and (3) the Lake Maracaibo deposits.

Pedernales Asphalt Deposit.—The Pedernales asphalt deposit is located a short distance from the port of Pedernales, on an island formed by two of the distributaries of the Orinoco River. It is the only mineral deposit of importance known on the Orinoco delta.

A German company worked the deposit for a short time about 20 years ago, but the property has long been idle. The asphalt is of good quality, somewhat more liquid and purer than that of Trinidad. It was refined by boiling, by which process the more volatile materials were eliminated.

Bermudez Asphalt Lake.—The Bermudez pitch lake is the most widely known and also the most extensive asphalt deposit of the country. It is this deposit, owned by the New York and Bermudez Company, that was confiscated by the Venezuelan Government in 1904 and caused a great amount of diplomatic controversy between the governments of Venezuela and the United States. The following descriptions of the deposits and those about Lake Maracaibo are mainly taken from accounts by Richardson (34).

The Bermudez pitch lake is located in the State of Sucre (formerly Bermudez) near the Guanaco River, which is a branch of the San Juan River. In a direct line it is about 30 miles from the coast of the Gulf of Paria, but by the winding San Juan and Guanaco River is about 65 miles inland. It is situated at the edge of a swamp and adjoining a low range of hills. The region is low and flat, and the deposit is frequently flooded during the rainy season.

The lake is 1.8 miles long and 1 mile wide and covers 1,100 acres. It is 600 feet above sea level. The greatest depth of the deposit is about 9 feet with an average of 4 feet. A layer of soil covers the surface, and high grass, shrubs, and palms grow luxuriantly. Beneath the soil in many places there is a hard substance resembling coke, and so called, which is formed by the heat produced when the dry vegetation occasionally burns during the rainless months. At several places soft pitch is coming to the surface from springs and these areas are free from vegetation. One of these covers 7 acres. Some inflammable gas is given off in these places.

The fresh soft asphalt has the following composition:

	Per cent
Carbon	82.88
Hydrogen	10.79
Sulphur	5.87
Nitrogen	0.75
	100.29

The hardened asphalt after being exposed to the sun has a somewhat different composition and the material obtained from different parts of the lake varies considerably both in its physical and chemical characteristics.

The asphalt is dug and hauled 6 miles over a narrow-gauge railroad to Guanaco, where it is loaded on boats for shipment to New York for refining. Its use for roads and roofing purposes is continually increasing.

Lake Maracaibo Asphalt Deposits.—Deposits of asphalt have been reported in many places near Lake Maracaibo in the State of Zulia. The only ones thus far worked are located near the Limon River about 50 miles west of the town of Maracaibo. The asphalt is partially refined and then sent down the river to Toas where it is shipped on steamers to the United States. The region, where the deposits occur, is flat and lies only about 75 feet or less above sea level. The asphalt varies in thickness up to 20 feet.

The asphalt from the Limon River deposits contains hydrocarbons of objectionable odor and does not melt at as low temperatures as the Bermudez material.

It is not improbable that there are other asphalt deposits besides these described that will eventually be exploited, as several others have been reported. One on the Rio Caribe, one near Porto Cabello near Cumana, and another in the State of Merida, have received some attention. It is believed that active search in the Lake Maracaibo region might result in the discovery of other valuable deposits.

PETROLEUM

The petroleum resources of Venezuela are little known at present, although during the past five years extensive explorations by oil geologists have been carried on in various parts of the country and several wells have been drilled. Up to the present, all information thus obtained has been withheld. It seems, however, that the Venezuelan petroleum resources are extensive and that they will be properly exploited in the near future.

Some petroleum has for many years been obtained from shallow wells in the State of Tachira. It is refined and sold for local consumption. Petroleum springs are known from many places in the Andine states of Trujillo and Merida, in numerous places about Lake Maracaibo in the state of Zulia, near the asphalt deposits of the State of Sucre, on the delta of the Orinoco and extending about 40 miles up the river, on the Peninsula of Araya, and on the Island of Cubagua, once famous as the great pearl fisheries locality. The petroleum seems to come from strata of different ages ranging from Lower Cretaceous to the Miocene.

In 1912 an American company, the Caribbean Petroleum Company, obtained a 2-year concession from the Government for the location and exploration of the oil fields and began an elaborate study of the geological conditions of the entire northern part of the country. As a result of these studies, in 1914 they denounced claims of 500 hectares (1,235 acres) each as follows:

	No. of Claims
State of Zulia	707
State of Monagas	188
State of Sucre	45
State of Merida	28
State of Falcon	25
State of Trujillo	24
State of Tachira	5
State of Nueva Esparta	4
Territorio Delta-Amacuro	2
Total	1,028

Drilling was started promptly at different places in the State of Zulia, and although it is known that oil has been obtained, the quantity is not known. Production will start as soon as the pipe lines have been constructed.

An English company, the Venezuela Oil Concessions, has extensive concessions in the State of Zulia, where some wells have been drilled and oil obtained. The oil at 60°F. has a specific gravity of 0.947 to 0.956, contains from 1.98 to 2.065 per cent sulphur, and possesses a heating value of 18,300 to 18,425 B.t.u.

There seems to be little doubt but that Venezuela will within a few years, become an important producer of petroleum.

COAL

The coal deposits of Venezuela are confined to those sections lying to the north of the Orinoco and Apure rivers and the Llanos. Coal has been discovered in many places in the Andes (Cordillera of Merida), in the Coro ranges, in the Caribbean Coast ranges, and in the Coastal Plains of the State of Zulia. The deposits are not continuous but occur in separate basins, some of which extend over several hundred square miles.

The age of the coal-bearing strata is in question, as some observers have referred them to the Lower Cretaceous, others to the Upper Cretaceous, and still others to the Tertiary. It is probable that they are not all of the same age, and both Cretaceous and Tertiary coal measures may be present in different parts of the country.

All of the coal of the country is soft and properly classified as lignites or semi-bituminous coals, with the exception of one locality in the State of Falcon where some semi-anthracite coal occurs.

The coal industry has never attained much prominence although many small mines have been opened up in various sections. Up to the present only two localities are worthy of description. These are the Barcelona or Naricual District of the State of Anzoategui, in the northeastern part of the country, and the Coro District of the State of Falcon, in the northwestern portion.

The Barcelona District.—The Coal Measures of the Barcelona District are said to extend over an area of more than 300 square miles. They are composed of alternating strata of sandstones and shales in which are numerous coal beds of variable thicknesses up to 10 feet. The sandstones are either arkosic or micaceous. Shales enclose the coal beds in most places. The region where the coal is found has been subjected to intense folding, and in general the strata dip at high angles up to 80°, although 20 miles to the south the strata are practically horizontal. The prevailing strike is northeast-southwest with a southeasterly dip.

The principal operations are centered along the Quebrada de Araguita, a tributary of the Naricual River. A Government railroad line, 22 miles in length, connects the mines with the shipping port of Guanta.

Six coal beds have been worked here as follows: No. 1, 3.28 feet thick, No. 2, 1.64 to 3.94 feet, No. 3, 3.28 to 9.18 feet, No. 4, variable thickness up to 10.17 feet, No. 5, 4.10 to 6.56 feet, and No. 6, which is very irregular. The first three named are the important beds.

The coal varies considerably in composition as shown in the following table representing 19 analyses.

	Range, per cent	Average, per cent
Water	0.95 to 10.20	3.03
Volatile matter	25.70 to 45.33	36.15
Fixed carbon	45.00 to 66.25	57.63
Ash	1.18 to 6.20	3.38
Sulphur	0.43 to 2.16	1.42

The calorific value of the coal varies from 5,866 to 9,303 calories, the average of 15 analyses being 7,599 calories. The sulphur content, occurring as thin layers of pyrite between the cleavage planes of the coal, decreases with depth according to Jiménez. The coal has been proved to be serviceable for the production of illuminating gas and the resulting coke is compact and of good quality.

The greatest objection to the coal of this district is its extreme friability. In mining, about 33 per cent of coarse coal is obtained; the remainder consists of very fine fragments and dust. Some of it has been satisfactorily briquetted at Guanta, and this seems to be the solution for its effective utilization.

In the mining of the coal, considerable timber is necessary because of the poor roof. The mines must be well ventilated on account of the presence of considerable gas, and, in addition, safety lamps are used.

Jiménez states that the cost of the coal at the port of Guanta is 21.60 bolivares a ton but if the output could be increased and an aerial tram be constructed to take the coal from the mines to the railroad, instead of transporting it by burros, as at present, the cost at the port should not be more than 16.42 bolivares.

The State of Falcon Deposits.—In the State of Falcon, there are many places where coal has been worked. The center of most active mining is about 7 miles south of the city of Coro, where the El Isiro Mine is located. The coal measures there have an east-west strike and dip to the south at angles of 19° to 36°. Some distance to the south are coal beds dipping to the north, probably the same beds, which would mean that the coal measures here occur in a broad synclinal basin.

At El Isiro Mine several veins are worked as follows: El Isiro, 1.64 to 1.80 feet in thickness, El Hatillito, 1.64 to 1.80 feet, Angoleta 1.31 to 1.64 feet, El Semuruco, 1.31 feet, El Saladillo, 1.64 to 1.97 feet, and Aloncico, 1.64 feet.

The coal beds of El Isiro Mine are not as thick as those of the Barcelona district, although it is said that coal beds over 3 feet thick have been found elsewhere. The maximum output from this mine is about 77 tons a day.

The Falcon coals are harder, blacker, and more brilliant than those of the Barcelona district. They have a specific gravity of 1.25. They are also less friable and only about 20 per cent crumbles to a powder during the mining.

The composition is shown by the range and average of 16 analyses of Falcon coals.

	Range, per cent	Average, per cent
Water	1.10 to 7.00	3.81
Volatile matter	12.62 to 52.72	40.18
Fixed carbon	37.25 to 79.75	53.56
Ash	0.64 to 6.80	3.16
Sulphur	0.15 to 8.90	3.50

The calorific value of the Falcon coals in a series of 10 analyses ranges from 4,823 to 7,240 calories with an average of 6,054 calories.

The operation of El Isiro Mine began in October 1904. The cost of the coal on board vessels at La Vela is about 34.56 bolivares a ton, but it is believed that with improved equipment this could be reduced to 25 bolivares. Some coal beds located nearer the coast should be worked for even less.

SULPHUR

Deposits of workable sulphur are known from several different sections of the country. The most important are the deposits near Carúpano, near Pedernales, near Tariba (State of Tachira), and near San Jacinto (State of Trujillo). Gypsum is also reported from most of these localities, indicating the probable origin of the sulphur.

About 9 miles southeast of Carúpano, a German company controls a deposit which is said to cover an area of 9,113 square yards. Samples from the deposit average 62½ per cent sulphur.

SALT

Salt is one of the important mineral products, and as it is a Government monopoly it has been a source of great revenue to the country.

All of the salt occurs in salt pans in the arid portions, where lakes or arms of the ocean have disappeared by evaporation.

On the Peninsula of Araya, opposite Cumana, there is an extensive deposit of practically pure sodium chloride which has been worked ever since the earliest settlement of the country. On the Island of Coche, a short distance away, near Barcelona, at Sinamaica in the northern part of the State of Zulia, and in the State of Falcon, salt deposits of less purity are also worked. Pits dug in the salt pans fill with salt water and on evaporation deposit the salt. The salt obtained from Coche Island is said to be of unusually high quality.

POTASSIUM NITRATE

Valuable deposits of potassium nitrate, iron sulphate, and iron chromate are reported to occur near Guanare in the State of Portuguesa. Other deposits of iron sulphate occur near Pedernales and near Nirgua (State of Carabobo).

Urao (sesquicarbonate of calcium) and gaylussite (sesquicarbonate of sodium and calcium) are obtained from the bottom of the small Lake Lagunillas near Merida. The former is mixed with tobacco for chewing and is extensively used by the natives.

PRECIOUS STONES

Opals have been found near Tinaquillo in the State of Carabobo, and amethysts and garnets near Caracas.

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