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Travelling in Chile

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TRAVELLING IN CHILE

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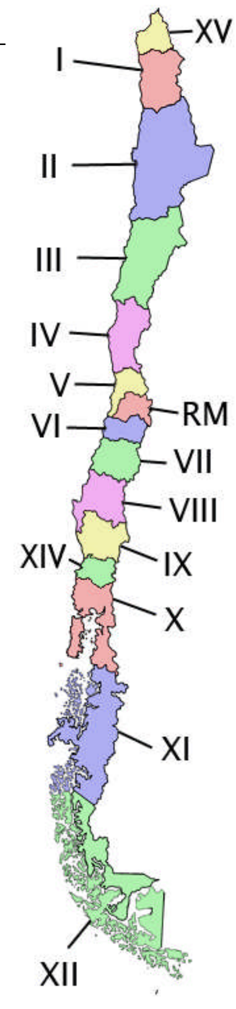
ABSTRACT[1]

Chile is at present the largest copper and rhenium producer and was before World War I the largest nitrate producer. She is also an important producer of lithium carbonate and molybdenum oxide. An important event in the history of the country is the Pacific War of 1879-1883 in which she acquired the northern provinces initially belonged to Bolivia and Peru. In 1888 Chile annexed Easter Island. The Chilean mineral and cultural history is briefly reviewed together with the people who contributed to her development. The present report is the result of a number of academic and industrial visits to Chile during the period 1992 to 2009.

Chile is divided into 15 regions, each is headed by an Intendant

Regions and their capitals

Region	Name	Capital
XV	Arica and Parinacota	Arica
I	Tarapacá	Iquique
II	Antofagasta	Antofagasta
III	Atacama	Copiapó
IV	Coquimbo	La Serena
V	Valparaíso	Valparaiso
RM	**Santiago Metropolitan**	**Santiago**
VI	O'Higgins	Rancagua
VII	Maule	Talca
VIII	Biobío	Concepción
IX	Araucanía	Temuco
XIV	Los Ríos	Valdivia
X	Los Lagos	Puerto Montt
XI	Aisén	Coihaique
XII	Magallanes and Antártica Chilena	Punta Arenas



HISTORICAL BACKGROUND

Pre-colonial period

The Indian empires in the Americas were founded thousands of years after those in the Middle East or in the eastern river valleys. Metal working civilizations developed only in Central America (the Mayas), in what is now Mexico (the Toltecs and the Aztecs), and in the present-day Colombia, Peru, and Bolivia (the Tihuanacas and the Incas). It is believed that metal-working was introduced from the south to the north (Figure 1). Most of the American Indians perished as a result of disease contacted from Europeans, were killed, or died as a result of hard work and torture. Those who escaped to the inaccessible areas in the mountains were able to survive.

[1] Dedicated to Dr. Raul Ibarra, former professor at Universidad Catolica del Norte in Antofagasta, who was the first to introduce me to Chile.

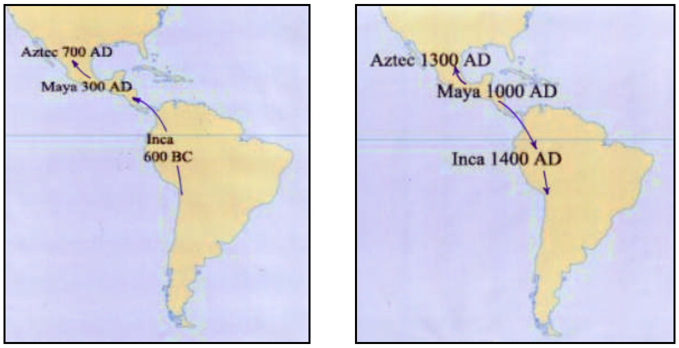


Figure 1. Spread of metalworking from the south to the north and spread of civilization from the Mayas to the Aztecs and to the Incas.

The Inca Empire which the Conquistadores confronted in what is now Chile was a religious despotism; the ruler was an emperor-god. The Incas were the last and the greatest of all the Indian cultures of the Americas. More than ten million Indians were living in the mountain valleys between Colombia and Chile. Under the leadership of a succession of brilliant rulers, they extended the area of their control from northern Ecuador to south-central Chile, a distance of over 3000 km. It was the largest empire ever known in the Americas.

The Incas were organizers and administrators. They built cities and a network of roads through jungle and desert, over which messengers moved constantly in relays to deliver information vital to the business of the state. They controlled a well organized army but they never used the wheel. But the Inca nation had just been emerging from a devastating civil war caused by a dispute over the succession to the Inca throne when Francisco Pizarro (1476–1541) arrived in 1532. Treachery, Spanish gunpowder, and disease managed to extinguish the Inca civilization in the space of 40 years.

Metals Gold was abundant in South America. In most of the important mining centres, the placer, or alluvial mines were worked by slaves who were usually prisoners of war from neighbouring tribes. The ancient artisans obtained much of their gold by panning. They also dug shafts into the ground and vein gold was worked in certain regions. At the time of the conquest only gold, silver, copper, and platinum were known in South America. Gold was one of the most important trade items and the mining areas became centres from which the trade routes radiated.

The value that the Western world ascribes to gold, as a symbol of material riches, is different from that which the American Indians conferred on the metal. Gold was treasured by the most eminent individuals of a tribal society, but, it was an essential element in the votive offerings made to their gods. Most communities had temples where group offerings were made The most common offerings were small flat representations of human beings known as tunjos, face masks, animals, and objects of daily use (Figures 2- 5).

Figure 2. A typical Inca gold flat religious figure, known as tunjos.

Figure 3. A typical Inca gold mask.

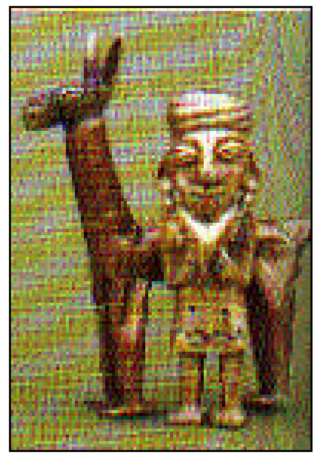


Figure 4. Llama in gold.

Figure 5. Inca copper knife.

Some lakes, mountains, rocks, and caves, were holy places for the Indians. When the chief made his offerings in the centre of the lake, his subjects gathered at the edge and cast offerings of gold, emeralds, and ceramics into the water. Gold was also given to the gods in the form of votive offerings buried with the dead. Peruvian stone masons were able to cut and fit building stones so accurately that their temples and palaces could be put together without mortar.

The American Indians did not construct furnaces for smelting ores, they used only small clay crucibles for this purpose. They did not use bellows when making fire but used blowpipes. The goldsmiths made alloys of gold, silver, and copper, probably unintentionally, but gold–platinum alloys were certainly deliberately prepared. When the Spaniards arrived, the Indians had already mastered all gold working techniques, including "lost wax" casting, known in the Old World.

Guano. Guano is the Spanish for the Indian word, *huanu*, meaning excrement. To increase the land's productivity, the Incas gathered guano and brought it from three small Chincha Islands 20 km off the coast of Lima where a great number of seabirds nest and used it as fertilizer (Figures 6 - 9). Alexander von Humboldt was the first to introduce it to Europeans in 1804. Guano is formed from the excrement and carcasses of sea-fowl. The fresh excrements are highly nitrogenous and consist mainly of uric acid and calcium phosphate. Because of the hot and dry, the excrements are desiccated and the nitrogenous matter protected. These are the conditions on the Chincha Islands. Guano from these regions contains 13–17% nitrogen and a similar amount of phosphoric acid. A million birds usually occupies an area of about one hectare, and consume about 180 tons of fish per day to produce about 10 000 tonnes of guano per year. The supplies were mostly exhausted by 1874.

Figure 6. Chincha Islands in 1863.

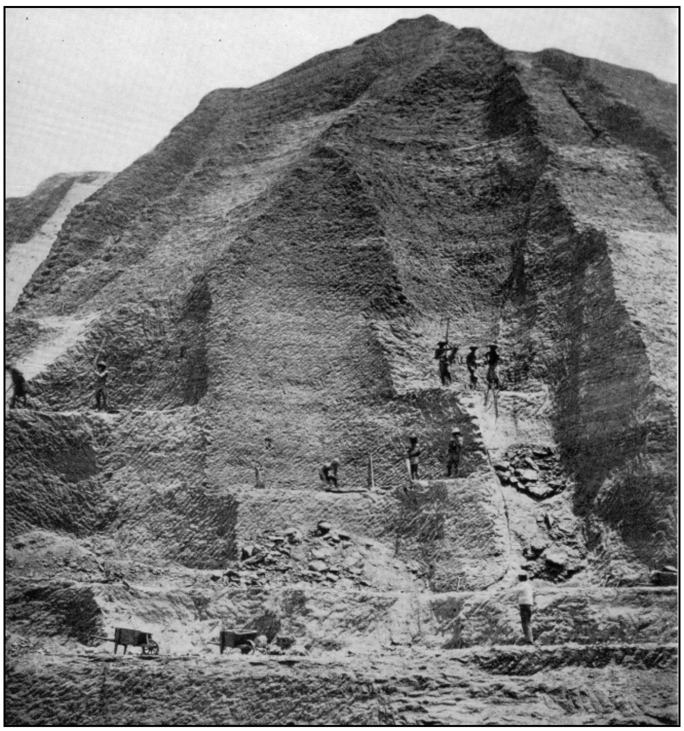


Figure 7. A mountain of guano on Chincha Islands.

Figure 8. A colony of birds responsible for the guano.

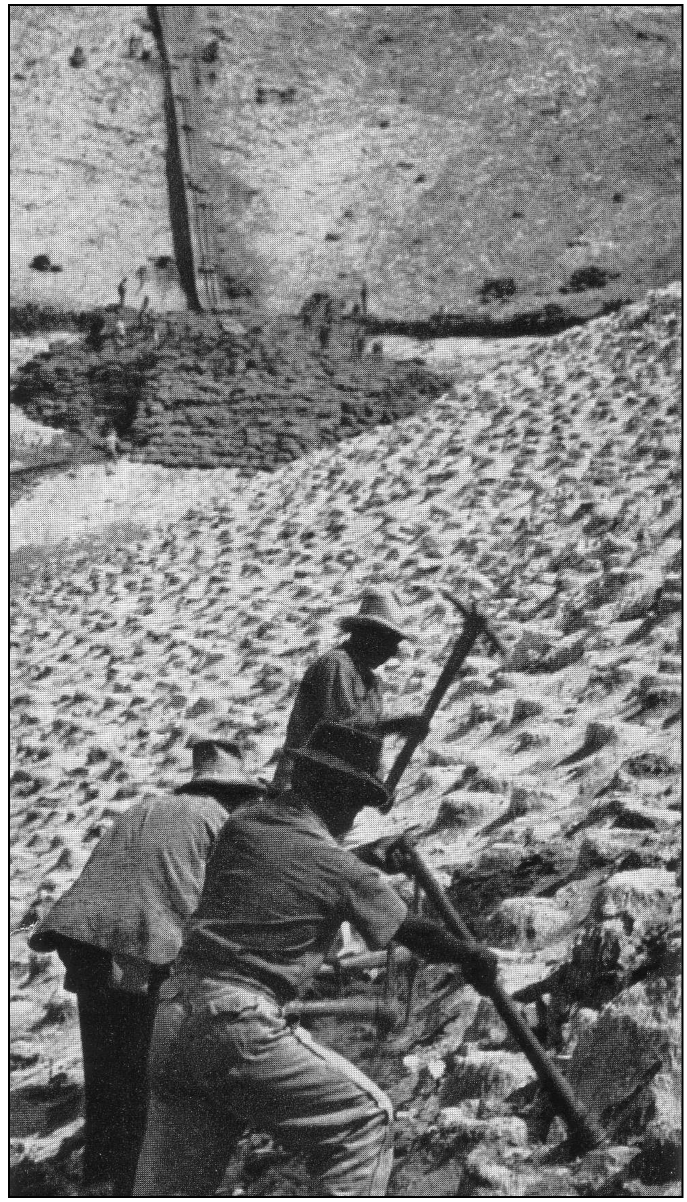


Figure 9. Mining of guano

The colonial period (1545-1810)

In 1536, Diego de Almagro (1475-1538) (Figure 10), accompanied by 500 Spanish and 1,500 native men, came from Peru down to Chile searching for gold similar to that discovered by the Incas. They crossed the Copiapó Valley and instead found copper minerals in the Chuquicamata area. De Almagro returned to Peru but due to a conflict with Pizzaro he was executed. Pedro de Valdivia (ca.1500-1553) (Figure 11, 12) led an expedition in 1540 with 150 people and in 1541 founded the city of Santiago where gold was found nearby.

Gold mining was the only mining activity in Chile during the first decade of the conquest, mainly, in areas such as Margamarga near Viña del Mar, Imperial (presently Carahue), Valdivia, Angol, Tucapel, Villarrica, and Osorno. In 1544, the city of Serena was founded and gold was discovered nearby, as well as in Ponzuelos, Illapel, and Choapa. Native slaves mined the gold. Gold production was two tons/year between 1545 and 1560. By the end of the sixteenth century, Chile had a Spanish population of only 3,600 while the natives amounted to about 600,000; half of them lived in the Arauco region in southern Chile, resisting the Spanish occupation. As a result, they replaced mining activities with raising animals for export to Peru.

Figure 10. Diego de Almagro (1475-1538) conquerer of Chile

Figure11. Pedro de Valdivia (ca. 1500-1553) founder of Santiago

Figure 12. Founding of Santiago.

At the beginning of the eighteenth century, Spanish reforms allowed an increase in the trade of raw materials between Spain and its colonies. Once again, mining became the main activity. The gold ores were milled using a *maray*, a traditional Chilean mill used by the natives before the Spanish expedition. It consisted of two stones, one fixed at the base, and the other handled manually (Figure 13). In 1730s, this equipment was replaced by *trapiches* in which the milling action was caused by an animal (Figure 14). At the end of the eighteenth century, there were 130 *trapiches* in operation in Chile producing approximately three tonnes of gold per year. Gold production began with alluvial gold which could be recovered easily by washing. A small amount was in the form of quartz veins, which were crushed and beneficiated, then treated by gravitational concentration or amalgamation. In 1743, the Royal Mint was founded in Santiago (Figure 15).

Figure 13. Crushing of ore during colonial period using a *maray.*

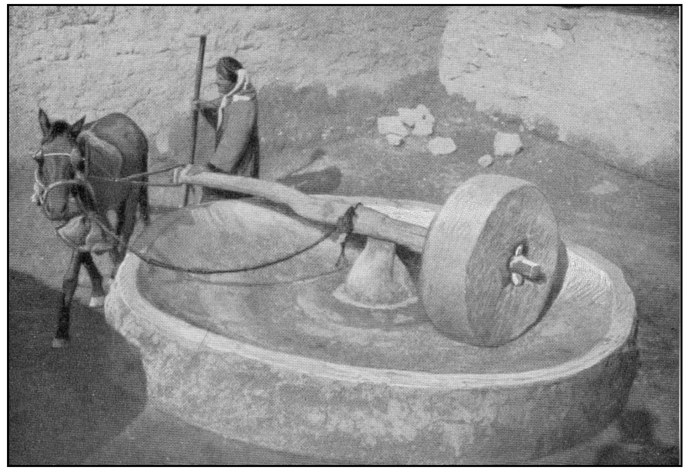


Figure 14. An animal operated trapiche in Chile.

An annual silver production of seven tonnes was obtained from nine amalgamation plants. The amount of mercury consumed was two to three times the amount of silver recovered. Copper was still recovered in small clay furnaces, which were filled with oxidized ore and charcoal. At the end of the eighteenth century, there were 61 mines operating with this system in Copiapó, Huasco, Coquimbo, and Rancagua that produced 1,500 tonnes/year. In 1787, mining laws of New Spain were applied in Chile, thus allowing for the founding of the Royal Administration of Mining which included the Miners' Union. In 1778, it financed the construction of a gunpowder plant and a mining bank in Santiago.

Figure 15. Casa de la Moneda in Santiago established in 1743 - - Presidential Palace and Mint.

The governor of Chile, Ambrosio O'Higgins (1716-1801), solicited the help of foreign experts. Thus, between 1789 to1795, an expedition headed by Alejandro de Malespina of Spain arrived in Chile. Thaddaeus Haenke (1761-1817) (Figure 16), a German scientist accompanying the expedition, visited the central and southern zones of Chile and wrote *Descripción del Reyno de Chile*, a report on geology and on the life of miners. In 1794, Jorge Passler, a German mineralogist, arrived and established a chemical laboratory and taught at the Royal Academy of San Luis in Santiago. The Academy was founded on September 6, 1797, by Chilean lawyer Manuel de Salas y Corbalán (1754-1841) (Figure 17) to teach grammar, drawing, and arts; arithmetic, geometry, chemistry, and mineralogy were added a few years later. In 1813, the academy merged with the newly-founded National Institute in Santiago.

Figure 16. Thaddaeus Haenke (1761-1817) wrote *Descripción del Reyno de Chile*

Figure 17. Manuel de Salas y Corbalán (1754-1841) founder of the Academy

El Dorado

El Dorado is Spanish meaning “the Gilded Man”; it became a general term referring to various places of possible treasure. The origin of the term “El Dorado” stems from the following:

- The Spanish conquistadores found a large amount of gold and silver treasures in Indian temples. They melted it down and shipped it home in form of ingots.
- Folklore holds that Colombia’s Muisca Indians, who lived in the highlands near present-day Bogotá, installed their kings by dusting their naked bodies with gold and then washing them in nearby Lake Guatavita. To complete the ritual, they dropped gold into the holy waters as offerings to their god.
- A Mayan religious ceremony consisted of throwing art work made of gold into a sacred well, a custom that resembles today’s tradition of throwing coins into a fountain to bring good luck. At the beginning of this century, archaeologists dredged wells near Chichen Itza, in Yucatán, and recovered part of this treasure. The treasure is housed in the Peabody Museum of Harvard University.
- The American Indians believed in life after death and, accordingly, the dead were buried by treasures which had belonged to them while alive.

Consequently, expeditions were sent to find the source of these treasures whether they were in graves or in lakes. Fortunately, many of these ancient gold objects have survived because the Indians buried their treasures in hidden tombs that escaped detection until recent times. Lakes were the most common sites of communal ceremonies.

Independence

The great Spanish empire in South America which lasted for centuries came to an end when Napoleon invaded the Iberian Peninsula in 1808. The Spanish colonies became independent between 1811 and 1830. Chilean independence was gained in 1818 under José de San Martín (1778-1850) (Figure 18) and Bernardo O’Higgins (1778-1842) (Figure 19).

Figure 18. José de San Martín (1778-1850)

Figure 19. Bernardo O’Higgins (1778-1842)

WAR OF THE PACIFIC

In 1879 there started a conflict between Chile and the alliance of Bolivia and Peru regarding taxation of the companies exploiting the caliche deposits in the Atacama Desert. This resulted in what became known as the War of the Pacific which lasted until 1884. The conclusion of the conflict ultimately led to the Chilean acquisition of the Peruvian territories of Department of Tarapaca and Province of Arica, as well as the Bolivian Department of Litoral (Figure 20).

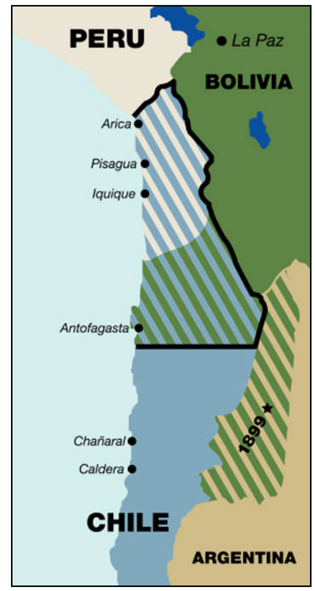


Figure 20. Map showing the areas acquired by Chile from Peru and Bolivia after the War of the Pacific.

MODERN CHILE

The natural wealth of Chile is mainly from her porphyry copper deposits (Figure 21) and its by-products molybdenum, rhenium, gold, and silver as well as from nitrate deposits containing iodine and lithium solutions in the Atacama Desert. After independence foreign investors were invited to re-open closed mines and to explore for the mineral wealth. In 1875, at the request of the Chilean government, a French engineer prepared a geological and mineralogical map of the Chilean territory. In 1883, the National Society of Mining was founded to bring together Chilean mining producers. The Government created in 1927 the Caja de Crédito Minero to endorse the construction of ore treatment plants and to buy and sell minerals to the miners. The Caja de Fomento Carbonero and the Superintendencia del Salitre y Yodo were created in 1928, and Corporación de Fomento de la Producción in 1939. In 1953, the Ministry of Mines was founded. Gradually coal mines were opened and iron and steel production started.

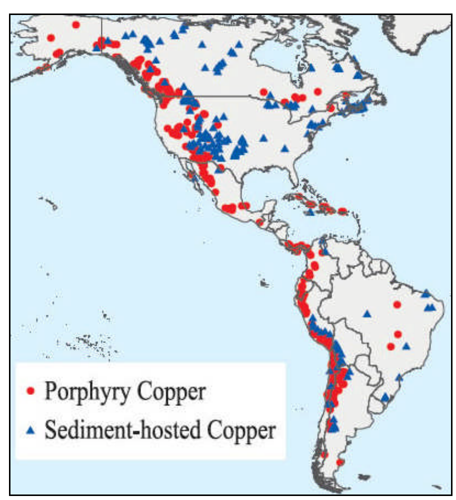


Figure 21. Porphyry copper in the Americas.

THE FIRST METALLURGISTS IN CHILE

Carlos Santiago Lambert (1793-1876) was born in Strasbourg in an Alsatian family (Figure 22). He studied mining and metallurgy at the School of Mines in Paris. After working in a number of mines in France he was sent to Chile in 1824 as manager of the Compañía Minera Sudamericana in La Serena - - a British company interested in the Chilean copper. During this period, only copper oxide ores were smelted to produce metallic copper. In 1831, Lambert decided to apply the Welsh process used in Swansea to sulfide ores from a mine near Coquimbo. In 1841, the process was used in other smelters. Sulfuric acid was produced from the smelter gases. Charcoal, and later coal, imported from England were used in this furnace. He installed the first copper and brass rolling mills in La Serena to supply the national demand, principally shipbuilding for the the Chilean Marine. It was Lambert who recommended hiring Ignacio Domeyko.

Figure 22. Carlos Santiago Lambert (1793-1876)

Figure 23. Ignacio Domeyko (1802-1889)

Ignacio Domeyko (1802-1889) (Figure 23) was born in Niedzwiadka, Poland. In 1817 he attended the University of Vilna to study mathematics and physical sciences. In 1832, he left Poland because it was occupied by the Russians and went to Paris to attend the School of Mines. In 1837, he obtained a degree in mining engineering, then went to Chile to teach chemistry and mineralogy at the College of Coquimbo. During the summer of 1839, wrote a report on the geology of Chile to help promote mining in the country. Based on his report, entitled the University of Chile was founded in 1842. In 1844, he published a book on mineral analysis and in 1845 another on the mineralogy in Chile, entitled *Elementos de Mineralogía*, which was the first book on the subject published in the country. In 1847, he was appointed professor of mineralogy and natural sciences at the University of Chile. In 1867 he was named rector of the University of Chile, a position he held until his retirement in 1882.

José Tomás Urmeneta (1808-1878) (Figure 24) was born in Santiago. In 1852, he discovered a rich copper deposit near Ovalle. In 1858, he installed smelters in Guayacán and in Tongoy which produced bars of 97% Cu and ingots of 99.5% Cu. In 1925, the smelters closed due to financial problems and were bought by the Compañía Minera del Pacífico, who re-opened it in 1929. However, the same problem persisted forcing its closure in 1934.

Figure 24. José Tomás Urmeneta (1808-1878)

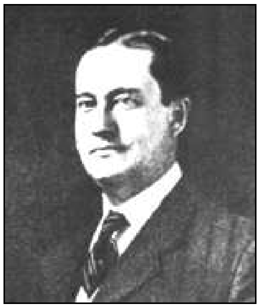


Figure 25. William Braden (1871-1942)

William Braden (1871-1942) (Figure 25) was born in Indianapolis, Indiana, USA. He graduated from the Massachusetts Institute of Technology. Between 1893 and 1898, he worked in a number of smelters across the United States, Canada, and South America. He was commissioned in1904 by American Smelting and Refining to go to Chile to purchase the El Teniente deposit. He founded the Braden Copper Company, becoming its general manager until 1912.

SANTIAGO

Santiago (Figure 26) is the capital and largest city of Chile founded in 1541 by the Conquistadores Pedro de Valdivia along the Mapocho River. Of the 20 million Chileans about 40% live in the Greater Santiago area.

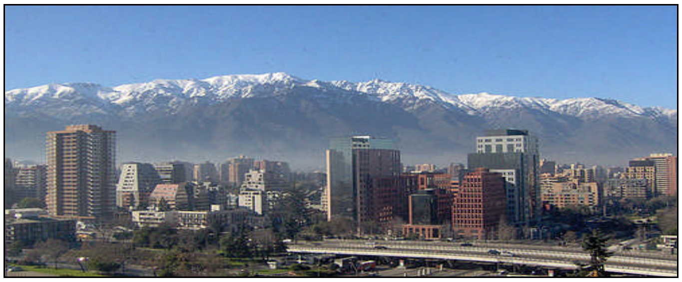


Figure 26. View of Santiago.

University of Santiago

The first university in Chile, Santo Tomás de Aquino, was founded in 1622. In 1738, its name changed to Real Universidad de San Felipe, in honor of King Philip V of Spain. After independence it was replaced in 1842 by the Universidad de Chile which was formally opened on 17 September 1843 (Figure 27-29).

Figure 27. University of Chile at Santiago.

Figure 28. University of Chile at Santiago. From left to right: Gerardo Fuentes, Roughette Araneda (Guide), Augusto Millan [Photo by Nadia Habashi, 1993].

Figure 29. With faculty members Mining Department, University of Chile, Santiago. Standing from left: Armando Valenzuela, Fathi Habashi. Jesus M.Casas de Prada, Luis Cifuentes , April 2005.

CIMM

Centro de Investigacion Minera y Metalurgica in Santiago was founded in 1970 and housed in a modern building located in a pleasant environment (Figure 30). Director Dr. Ricardo Badilla

Figure 30. Centro de Investigacion Minera y Metalurgica in Santiago.

Museo Nacional de Historia Natural

There was a display on the history of copper and its importance in society at the Museo Nacional de Historia Natural (Figure 31). Two illustrated books on this topic were available (Figures 32, 33)

Figure 31. Museo Nacional de Historia Natural.

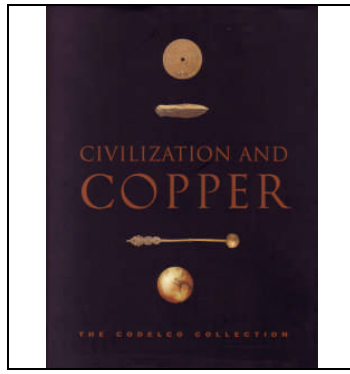


Figure 32. Civilization and Copper, The Codelco Collection, 2001.

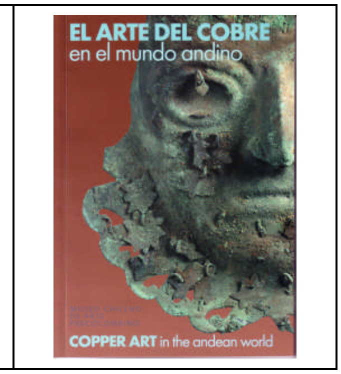


Figure 33. Copper Art in the Andean World.

Chilean Mining Society

Presentation entitled “Milestones in the History of Metallurgy” was given at the Society of Geography and History in Santiago organized by the Chilean Mining Society and sponsored by Acorga (Figure 34). It was translated by Armando Valenzuela into Spanish, “Hitos en la Historia de la Metalurgia,” and published in *Minerales* [Santiago] **56** (240), 13–17 (2001).

Figure 34. Meeting with members of the Chilean Mining Society in Santiago [Photo by Nadia Habashi, 2001].

Comision Chilena del Cobre

Chilean Copper Commission known as Cochilco safeguards government interests in Codelco and Enami by auditing, assessing, and reviewing their operations and investment decisions. Cochilco also advises the Ministries of Mines and Finance on related budget development and review. A seminar was held with the staff discussing recent advances in copper metallurgy organized by Armando Valenzuela a former graduate of Laval University (Figure 35 - 38).

Figure 35. Cochelco, April 2005 [Photo by Armando Valenzuela].

Figure 36. Cochelco, April 2005.

Figure 37. With Armando Valenzuela at Cochelco, April 2005.

Figure 38. At Cochelco, April 2005.

O'HIGGINS REGION

El Teniente

The El Teniente and La Fortuna mines, located near Rancagua (Figure 39), were worked since Colonial time. In 1903, William Braden purchased the deposit and founded the Braden Copper Company, together with E.W. Nash and Barton Sewell, president and vice-president of the American Smelting & Refining Co., respectively. In 1904, construction began on a 250 ton/day concentrator in Sewell. The ore having 3.34% Cu was concentrated to a product having 20% Cu at a copper recovery of 45% to 55% using gravity methods. The tailings ranged between 0.8% and 1.5% Cu. In 1907, the smelter began operation with six roasters and two shaft furnaces producing a matte having 50% Cu. A second smelter, which had two shaft furnaces, agglomeration furnaces, and a Peirce-Smith converter, was built in 1909 to replace the first because it was damaged by a fire.

Labour conflicts and other difficulties in 1909 led Braden to mortgage the company to the Guggenheim Exploration Company, which took financial control. Braden continued on as general manager until 1912. In 1915, the Guggenheim brothers sold the Braden Copper Company to the Kennecott Corporation.

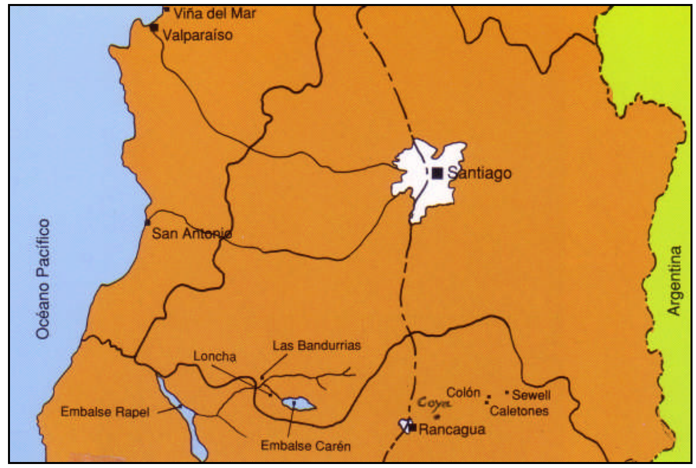


Figure 39. Location map of Santiago and its environment: Valparaiso, Viña del Mar to the northwest and the mining district El Teniente [Sewell, Colón, Catelones, and Coya] to the south.

In 1911, the company processed 49,650 tons of ore having 2.97% Cu producing about 6,000 tons of blister copper. In 1912, to flotation process was introduced. The processing capacity was increased to about two million tons of ore in 1918. Wedge furnaces to roast the concentrate were installed in 1915. The SO_2 produced was used to make about 30 tons/day sulfuric acid, which was sold in the local market. By 1919, the shaft furnaces could smelt about 500 tons/day and two new Peirce-Smith converters with a capacity of 40 tons each were installed. Copper production ranged between 40 to 50 tons/day. In 1922, a third smelter was built in Caletones (7.5 km east of Sewell) to replace the one in Sewell. The new smelter had three agglomeration plants, a shaft furnace, two Peirce-Smith converters, and two casting machines. In 1958, the Caletones smelter began to treat metallurgical gases to produce sulfuric acid.

In 1967, copper production increased from 180,000 to 280,000 tons/year. In 1985, a solvent extraction and electrowinning plant began producing copper cathodes from the acid mine waters from the mine. In 1992, a semi-autogenous grinding (SAG) plant began its operation. Today, El Teniente is the largest underground copper mine in the world producing about 340,000 tons/year Cu (Figure 40, 41).

Figure 40. Transportation of tailings at El Teniente.

The most significant improvement has been the El Teniente technology, which consists of two furnaces, the Teniente converter for smelting and converting dry copper concentrate, and the slag cleaning furnace to recover copper contained in the produced slag. The first prototype for the Teniente converter furnace was tested in 1977. Today, there are seven furnaces operating in Chile, and others in Zambia, Peru, and Mexico.

Figure 41. One of many tailings ponds at El Teniente.

Sewell

Sewell, the largest underground mine in the world at 2000 m above sea level (Figures 42, 43).

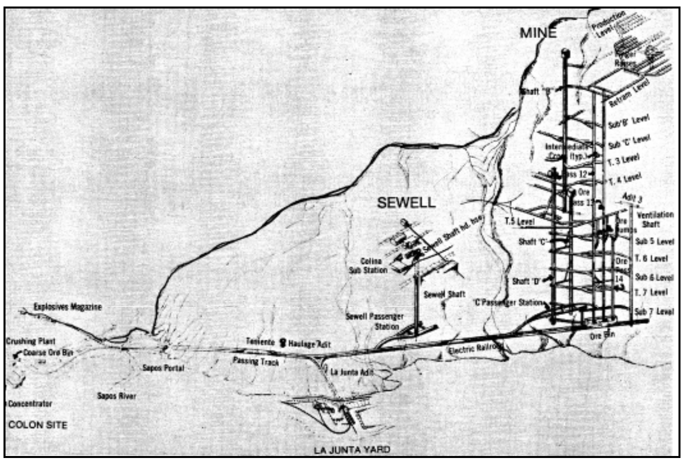


Figure 42. Sewell, the largest underground mine in the world.

Figure 43. Sewell at 2000 m above sea level is the world's largest underground mine.

Colón

Copper concentration plant at Colón (Figure 44)

Figure 44. Concentration plant at Colón.

Río Blanco

The Río Blanco deposit, located 80 km northeast of Santiago, was discovered in 1850, however, climate conditions and its remote location (3,700 m above sea level) made its exploitation expensive. In 1955, the Cerro Corporation, an American company, decided to exploit the deposit. Eleven years later, a joint venture was formed by the Chilean government and Cerro Corporation, which operated the mine until 1971; a concentrator was then built underground. Today, the Andina Division of Codelco-Chile exploits the mine and the open pit mine which produces about 218,000 tons of Cu.

VALPARAISO REGION

Valparaíso (Figure 45) is one of the country's most important seaports and where the National Congress of Chile and Technical University Federico Santa Maria are located.

Figure 45. Valparaiso harbour, 1993.

Technical University Federico Santa Maria

Federico Santa María Carrera (1845-1925) (Figure 46) was born in Valparaíso in one of the most influential Chilean families of the 19^{th} century. He made a huge fortune in the sugar markets of Paris, in which he arrived when he was very young. His importance in the sugar market was considerable: he became a major power in the French economy. During World War I he closed down all his businesses, declaring that he did not want to profit from war. He also supported the French Army, donating clothes and weapons for an entire regiment. Because he had no descendants, he gave his entire fortune to his hometown Valparaíso for the founding of a technical and engineering school. The result of his legacy was the Federico Santa María Technical University founded in 1926. In 1960 the Graduate School was created. In 1963 the university became the first higher-education institution in Latin America to confer a doctorate (Figures 47 - 49).

Figure 46. Federico Santa María Carrera (1845-1925).

Figure 47. Technical University Federico Santa Maria.

Figure 48. Professor David Fuller [third from left], Washington Alyaga and staff at Technical University Federico Santa Maria in Valparaiso, 1993.

COQUIMBO REGION

La Serena is the capital of Coquimbo Region. It has a School of Mines (Figure 50) and is the home of Nobel prize winner Gabriela Mistral (Figure 51).

La Serena School of Mines

The School of Mines in La Serena was founded in 1887. Manuel Buenaventura Osorio (1833-1907), who was a pupil of Ignacio Domeyko's first class at the College of Coquimbo, was appointed director. In 1952, the school was incorporated in the newly founded State Technical University. In 1981, it became the Faculty of Engineering of the University of La Serena that offered programs in mining, mechanical, food, and civil engineering.

Figure 49. Professor David Fuller and staff at Technical University Federico Santa Maria in Valparaiso Jorge Pontt at the extreme right [Photo by Nadia Habashi, 1994].

Figure 50. University La Serena. From left to right: Rector, Caudio de Bon Canus, Fathi Habashi, Federico Brunner [Photo by Nadia Habashi, 2001].

Figure 51. Museum of Nobel literature prize Gabriela Mistral in La Serena [Photo by Nadia Habashi, 2001].

Gabriela Mistral

Chile has two Nobel prize winners for literature: Gabriela Mistral (1889-1957) in 1945 (Figure 52) and Pablo Neruda (1904 –1973) in 1971. Mistral was the pseudonym of Lucila de María del Perpetuo Socorro Godoy Alcayaga, a poet, educator, and diplomat who was the first Latin American to win the Nobel prize. She was of Basque and

Amerindian descent. Her father was a school teacher who abandoned the family before she was three years old. By age fifteen, she was supporting herself and her mother by working as a teacher's aide in the seaside town of Compañia Baja, near La Serena. About 1906 she met a railway worker who killed himself in 1909. The profound effects of death were already in the poet's work. In 1914 she won a prize for her work The Sonnets of Death. She worked in Mexico and USA and toured Europe before returning to Chile in 1925. She served as a consul in different countries from 1932 until her death.

Figure 52. Gabriela Mistral (1889-1957).

ATACAMA REGION

Copiapó is the capital of the Atacama Region (Figure 53). It was founded in 1744 by the governor José Antonio Manso de Velasco along the Copiapó River which is now dried up due to mining activities. The University of Atacama is located there. The first railroad in Chile was constructed in1851 from Copiapó to Caldera on the ocean coast. This first locomotive is on display at the University of Atacama (Figure 54).

Figure 53. A view of Copiapó.

Figure 54. The first railroad in Chile was constructed in1851 from Copiapó to Caldera on the ocean side. This first locomotive is on display at the University of Atacama.

University of Atacama

The discovery of silver deposits in the Atacama region in 1832 resulted in the creation on April 11, 1857 of the Copiapó School of Mines in Copiapó the capital of the Atacama region. In 1864, the “Engineers of Mines” program was created, and the students took their exams at the University of Chile in Santiago. As of 1875, a mining engineering degree could be obtained directly from Copiapó. In 1885, the school adopted the name Practical School of Mining. Casimiro Domeyko, son of Ignacio Domeyko, a mining engineer, was its director. In 1952, with the creation of the State Technical University, the two schools merged. In 1957, the extractive metallurgy department was created leading to a degree in metallurgy as an industrial technician. From 1969 to 1983, the degree was entitled practical engineer in extractive metallurgy, and since 1983, civil engineer in metallurgy. Since 1981, it is the Faculty of Engineering at the University of Atacama that offers programs in mining and metallurgical engineering, as well as technology in geology and metallurgical plants (Figures 55, 56).

Figure 55. University of Atacama, Copiapó.

Figure 56. Rector Jose Palacios [Photo by Fathi Habashi, April 2005].

Congreso Internacional de Ingeneria de Minas

The International Congress of Mining Engineers was held in August 1993 in Copiapó and was organized by the faculty members of the University of Atacama. It followed immediately another local conference III Jornadas de Metalurgia del Norte Grande held few days earlier in Antofagasta (Figure 57, 58).

Figure 57. With students at the University of Atacama, 1993. From right to left: Armando Valenzuela, Mauricio.

Figure 58. From right to left: Jean Frenay from University of Liege, Germán Cáceres from University of Atacama, ??, Mario Sanchez from University of Concepcion, ? ? [Photo by Nadia Habashi, 1993].

Paipote

Construction of the Paipote smelter, located 9 km south of Copiapó, began in 1949 using a reverberatory furnace and two. Peirce-Smith converters. Production of sulfuric acid started in 1969, which was used in the oxide processing plants.

Punta del Cobre

Sociedad Punta del Cobre is engaged in the exploration, mining, and exploitation of copper in the Atacama region. The Company recovers copper from the Punta del Cobre mine. Its facilities also include the San Jose plant, which produces copper concentrates, and the Biocobre plant, where the production of copper cathodes is performed (Figures 59 - 62).

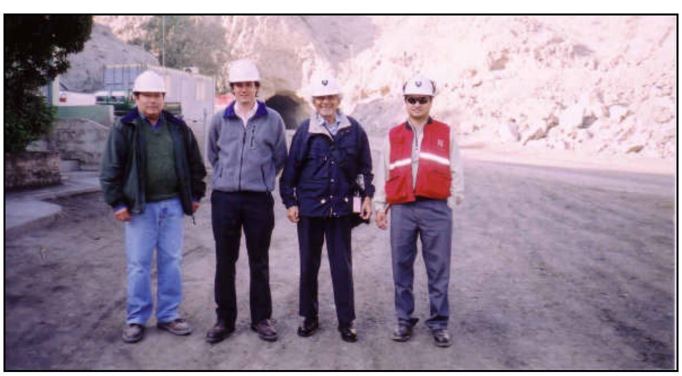


Figure 59. Entrance to the chalcopyrite mine Punta del Cobre, April 2005.

Figure 60. Heap leaching operation at Punta del Cobre, April 2005.

Figure 61. Chalcopyrite concentrator at Punta del Cobre, April 2005.

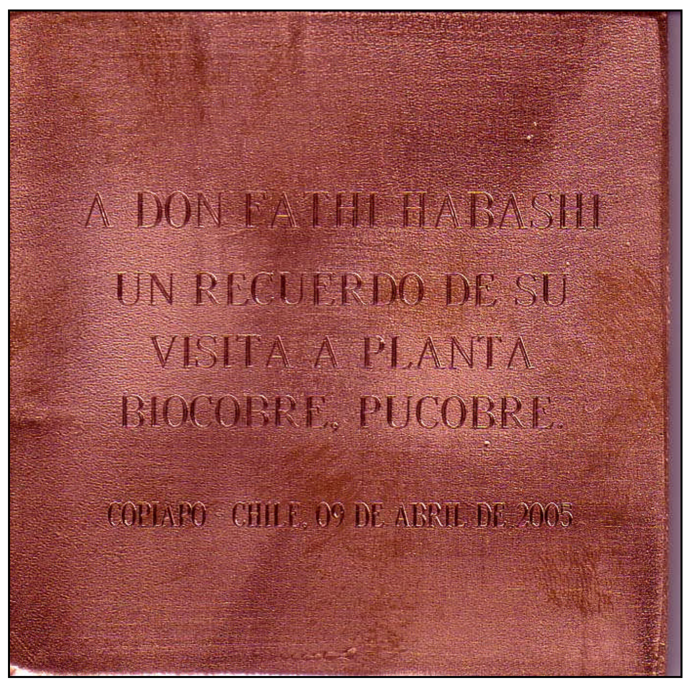


Figure 62. A copper plaque souvenir from Punta del Cobre, April 2005.

ANTOFAGASTA REGION

The city Antofagasta is the capital of Antofagsta Region and is a port city about 1,130 km north of Santiago located in the Atacama Desert on the Tropic of Capricorn (Figures 63 - 65). It is the seat of the

Universidad Católica del Norte and is characterized by Portada de Antofagasta (Figure 66).

Figure 63. Location map of Antofagasta and its environment.

Figure 64. Plaque at Antofagasta marking the Tropic of Capricorn [Photo by Raul Ibarra, 2009].

Figure 65. Monument at Antofagasta marking the Tropic of Capricorn [Photo by Raul Ibarra, 2009].

Figure 66. Portada de Antofagasta.

Universidad Catolica del Norte

The Universidad Católica del Norte (Catholic University of the North) is a Catholic and pluralistic university founded in 1956 in the city of Antofagasta (Figures 67 - 70).

Figure 67. Universidad Catolica del Norte.

Figure 68. Right: Teodoro Politis Jaramis, Dean of Engineering Faculty, left: Hugo Carcamo Chairman Metaluurgy Department, Universidad Católica del Norte.[Photo by Nadia Habashi, 1993].

Figure 69. With metallurgy faculty members at the Universidad Católica del Norte [Photo by Nadia Habashi, 1993].

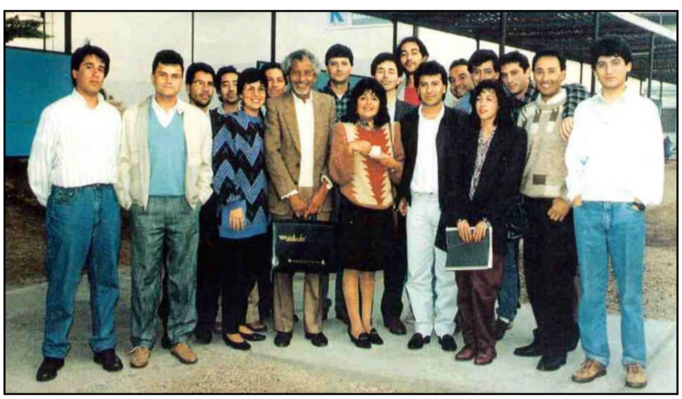


Figure 70. With students at the Universidad Católica del Norte, 1993.

Escondida process

Minera Escondida, which means 'hidden' in Spanish, is a mining company that operates two open pit copper mines in the Atacama Desert, 170 km southeast of Antofagasta. It is currently the highest producing copper mine in the world. Production in 2007 was 1.483 million tons of copper mainly as metal in concentrate but some as cathode. The concentrate is shipped at the port of Coloso. A cross section of the ore body is shown in Figure 71 and the concentrator is shown in Figure 72. The Escondida process was developed by Wilem Duyvesteyn and coworkers at the Minerals Laboratory of BHP in Sunnyvale, California in 1991 and was closed few years later. The 600 kg/day plant was constructed at Coloso near Antofagasta in Chile. The ore was mainly chalcocite, Cu_2S, and it was intended to extract only half of the copper to produce a CuS concentrate for shipment (Figure 73).

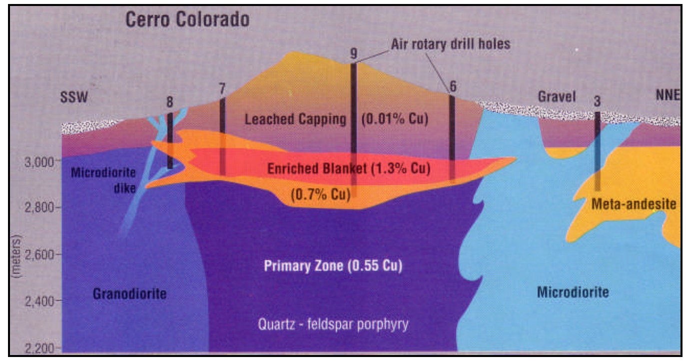


Figure 71. Cross section of the Escondida ore body.

Figure 72. View of Escondida concentrator.

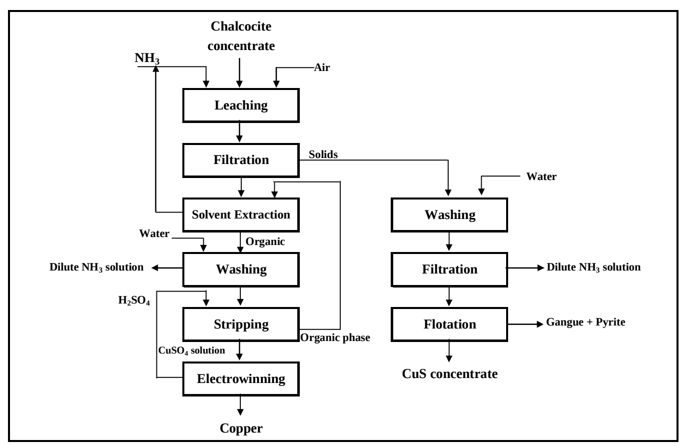


Figure 73. Escondida process.

An ammoniacal solution under mildly oxidizing conditions at atmospheric pressure was used to leach half of the copper in the concentrate. The mild leaching conditions also prevent the dissolution of unwanted impurities. Solution purification is carried out by solvent extraction with LIX-54 which is selective for copper ions. Stripping is conducted by sulfuric acid. Copper cathodes of high purity were produced in a conventional sulfuric acid-based electrowinning system. Ammonia was regenerated from the solutions by distillation and recycled for leaching. One scrubbing step was needed between the ammoniacal and acid circuits. The residue is a high-grade copper concentrate ready for shipment.

Chalcocite behaves in leaching as if it were a mixture of metallic copper and cupric sulfide:

$$Cu_2S \approx Cu + CuS$$

$$Cu + 4\ NH_3 + ½\ O_2 + H_2O \rightarrow [Cu(NH_3)_4]^{2+} + 2\ OH^-$$

Conditions were so chosen that CuS was not attacked. The reaction is slow but accelerated when NH_4^+ ion is present. There are some problems, however, with ammonia leaching:

- Absorbing CO_2 from the atmosphere. Thus an appreciable amount of ammonium ion builds up
- Partial oxidation of NH_3 to nitrite, Cu^{2+} ion acting as catalyst:

$$2\ NH_{3(aq)} + 3\ O_2 + 2\ OH^- \rightarrow 2\ NO_2^- + 4\ H_2O$$

- Transferring the extraction system from ammoniacal to acid generates a dilute ammoniacal solution which necessitates recovery
- Washing of residue also generates a similar solution

Recovery of NH_3 from such solutions requires boiling with lime to distill off NH_3 and form calcium carbonate for disposal. If some sulfides go in solution, then a corresponding amount of gypsum will also form for disposal. Recovery of ammonia from ammonium salts is not economical and losses of ammonia cannot be tolerated.

Mantos Blancos

Empressa Minera de Mantos Blancos is located 45 km northeast of Antofagasta owned by the German magnate Mauricio Hochschild who owns also mineral properties in Bolivia. The plant was designed by Lurgi, and is presently operated by about 1000 workers. There is an open pit mine since 1961 (1% Cu oxide ore) and an underground mine since 1981 (1.2% Cu sulfide ore). Guide: Jorge Arias Parra, Chief Metallurgist. Flowsheet is shown in Figure 74.

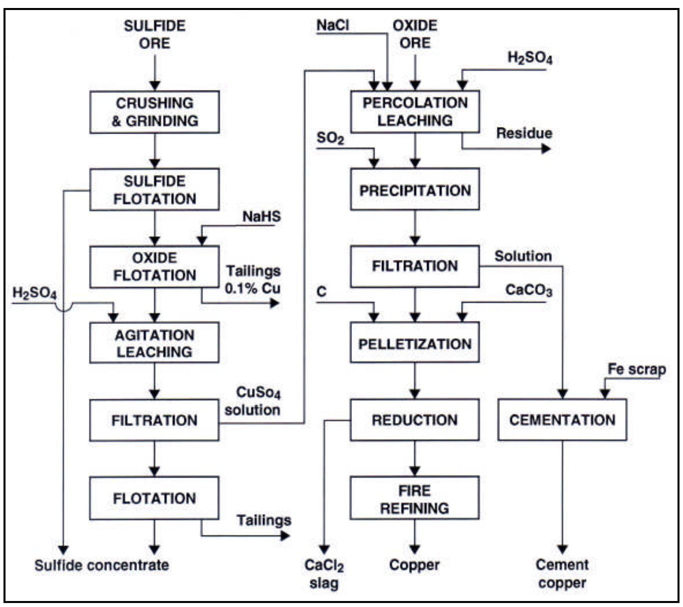


Figure 74. Mantos Blancos process.

Sulfide Plant. After crushing and grinding, sulfides are floated to obtain a concentrate containing 45% Cu and 500 g/t Ag for shipping. The remaining oxide minerals are then treated with NaHS solution and floated to get an oxide concentrate containing 20% Cu which is leached in agitated tanks by H_2SO_4 and CCD to get a $CuSO_4$ solution and a residue still containing some sulfides which are recovered by flotation and added to the concentrate destined for shipping.

Oxide Plant. The ore contains 1% Cu mainly as atacamite (10 000 t/day), is crushed to -1/4" and leached in 10 vats, 4 000 t each by H_2SO_4 for 100 hours. $CuSO_4$ solution from Sulfide Plant is added together with some NaCl. The solution obtained contains 30 g/1 Cu at Cr/Cu' ratio = 1. Copper (I) chloride is precipitated from this solution by reduction with SO_2 gas (prepared by burning imported elemental sulfur) in a series of towers (counter-current, no packing) (Figure 75). It is thickened, centrifuged, then pelletized with 4% coke and 36% limestone (pellets contain 36% Cu), then heated in small rotary furnaces (Kurz Trommel Ofen) (Figure 76) to get crude copper 99.5-99.9% and a $CaC1_2$ slag. This is then refined to ingots 99.96% Cu (25 000 t) by blowing and poling (Figure 77). Solution after Cu precipitation contains Cu^+ ion in solution is treated with scrap iron in rotating drums to get cement copper (5 000 t). Figure 78 shows the reaction and refining plant outline.

Figure 75. Sulfur dioxide towers for precipitating Cu_2Cl_2.

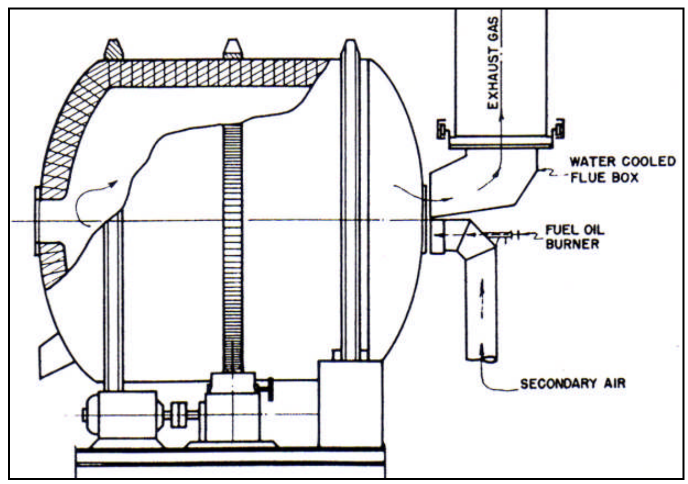


Figure 76. Lurgi short drum reaction furnace.

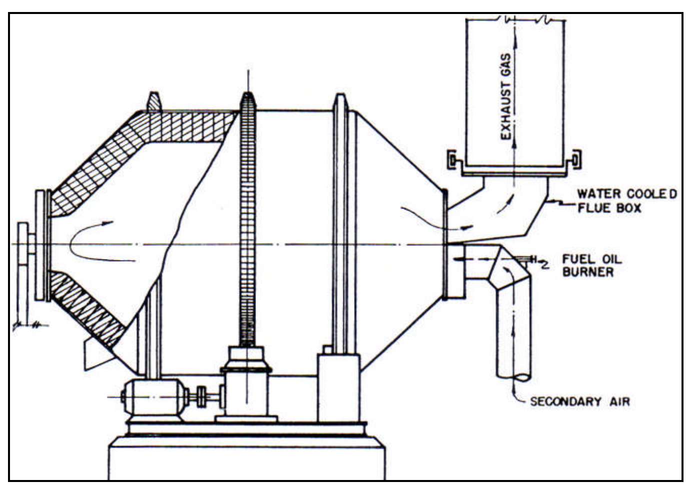


Figure 77. Lurgi copper refining furnace.

The plant will be shut down in the next few years because it is highly polluting and inefficient. For example:

- Large amounts of $CaC1_2$ are produced; they contain 1% Cu.
- Six small rotating reduction furnaces are highly inefficient (heat loss by radiation) and no provision for collecting the dust emitted.

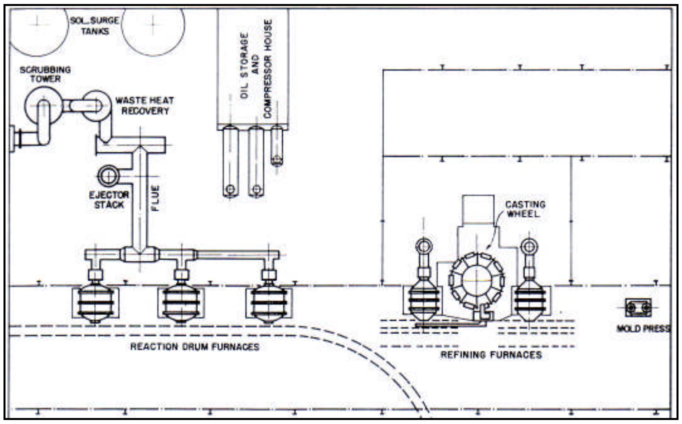


Figure 78. Mantos Blancos plan of reaction and refining furnaces.

New Oxide Pilot Plant. The chloride precipitation technology will be replaced by solvent extraction-electrowinning. A pilot plant is presently in operation treating 10 t/d ore, washing to remove Cl ion before electrowinning; SX 11 1/min, 80 kg/d cathodes.

Compania Minera Carolina de Michilla

Chief metallurgist and guide: Ing. Gustavo Fuentes. The mine and plant is located 110 km north of Antofagasta. The minerals are mainly atacamite, chrysocolla, chalcocite, and bornite. Average grade 2.5% Cu oxide-sulfide. Flotation concentrate obtained 1600 t/month at 44-54% Cu. Tailings contain 0.16% Cu is leached in agitation tanks and **CCD** system to throw away a residue containing 0.10% Cu. Copper recovered from solution by cementation with scrap iron in large rotating drums.

Thin layer leaching process. An oxide ore containing 2.3 - 2.5% Cu mainly as atacamite and chrysocolla is ground to 3/8" then sprayed with concentrated H_2SO_4 , 30 kg/ton in rotating drum; the temperature rises. The material is then transported in trucks and dumped to form pads 2.6 m high. Sea water is then spayed at the top of the dump at a controlled rate, and the strong $CuSO_4$ solution 25-50 g/1 is collected at the bottom. In about a week, 87% of the copper is recovered. The pad is then removed and discarded, while the solution is treated with pig iron ingots to get cement copper for sale to copper smelters. The process is therefore not a dump leaching process but rather acid curing and vat leaching (without vats).

New pilot plant. All cementation processes will be discontinued in the next few years, to be replaced by solvent extraction-electrowinning. A pilot plant is at present in operation using L1X622N and stainless steel cathodes. Engineer: Gabriel Araya Garrido.

Huanchaca Silver Refinery ruins

In 1888, The Huanchaca Company of Bolivia established a large silver refinery at Playa Blanca in Antofagasta that became the largest in South America (Figures 79-81). It was built by the American engineer C. W. Wendt who brought all the necessary equipment from the USA. The building material for the plant was the stone which was obtained from an existing quarry to the south of the Universidad Catôlica del Norte in Antofagasta. Silver ore was mined from the Pulacayo Mine in Potosi which was owned by the company. It was transported 500 kilometers to Antofagasta for smelting. The plant was recognized as the most modern of its time, crushing more than 100 tons of ore daily and producing 20 tons of silver per month. The plant was characterized by its enormous pumps that raised water from the sea for cooling purposes and the huge steam engine whose flywheel was 7 meters diameter

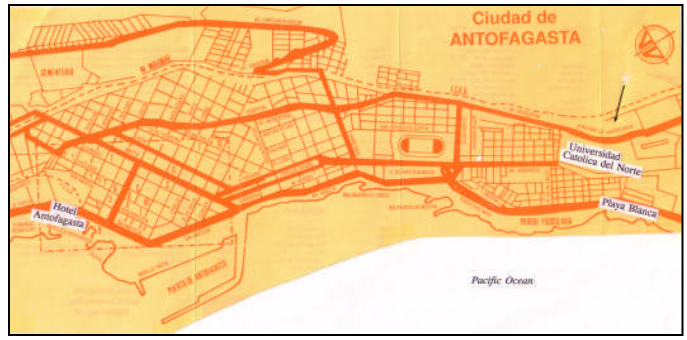


Figure 79. The arrow refers to the location of the silver refinery ruins in Antofagasta.

Figure 80. Huanchaca Silver Refinery ruins in Antofagasta.

Figure 81. With Professor Hugo Carcamo of the Catolica Univerisdad del Norte, Antofagasta.

At the Huanchaca refinery a variety of silver-bearing sulfides were treated by amalgamation and by cupellation. A number of roasting furnaces were used prior to both operations. When the ore was refractory chloridizing roasting was used in the Stetefeldt furnace. The material charged to this furnace must have a sulfur content of about 8 %. If the ore contains higher than this, then excess sulfur must be first removed in the rotary kilns. The purpose was to transform all the silver mineral to a chloride and as little as possible of the other metals, with the exception of copper, using NaCl. The chloridized residue as well as the chloridized dust collected from the escaping gases were combined and treated with mercury.

After 12 years in operation, management decided to close and sell the property because the technology used was already outdated. The cyanidation process for treating silver ores, invented in 1888, was already successful and rendered amalgamation methods uneconomical.

III Jornadas de Metalurgia del Norte Grande

The Third Conference of Metallurgy in the North was attended in 1993 (Figures 82-83).

Figure 82. With conference organizers [Photo by Nadia Habashi, 1993].

Figure 83. Souvenir from the conference [Photo by Nadia Habashi, 1993].

CONAMET 94

The VIII Congresso Nacional de Metalurgica known as CONAMET was held in Antofagasta jointly with the III Congresso de la Asociacion Latinoamericaa de Metalurgia y Materiales in August 1994 (Figure 84).

Figure 84. CONAMET 94. From left: Aljandro Morales, Maria Cecilia, Fathi Habashi, and Alonso Arenas [Photo by Nadia Habashi, 1994].

Calama

Calama, the second-largest city in the Antofagasta Region, is 213 km northeast of the regional capital.

Chuquicamata

Various Chilean miners sporadically worked the Chuquicamata mine after the Pacific War. In 1903, there were 300 operations producing 18,000 tons of concentrate and 3,325 tons of copper. Several attempts were made in the early 1900s to develop the mine however, it was the Boston-based businessman Albert Burrage who saw the potential in a mountain of low-grade ore. The oxide ore had about 2% Cu, which was considered barely economic at the time. He employed the newly developed Bradley process to leach the oxide ores with sulfuric acid and succeeded in persuading the Guggenheim family of New York to help finance construction. In 1912, a geological team was sent to determine the mineral reserves; these were estimated at 690 million tons having 2.58% Cu and were divided as follows:

- Oxides 329 million tons at 1.91% Cu
- Sulfides 210 million tons at 1.84% Cu
- Mixed 151 million tons at 2.98% Cu

In 1913, the American company established the Chile Exploration Company and bought all the operations in the Chuquicamata district. The mine was operated using large-scale open-pit mining techniques, which were first demonstrated in 1906 by Daniel C. Jackling at Bingham Canyon in Utah as well as in Cananea, Mexico.

Oxide exploitation began in 1915 sulfuric acid vat leaching then copper electrowinning. In 1923, Anaconda Copper acquired a controlling stake in the Chile Exploration Company. In 1929, Daniel Guggenheim sold his remaining interest to Anaconda. Concentration by flotation began in 1952 together with concentrate smelting. In 1967, the Chilean government purchased 51% of the Anaconda property to form the Company of Copper Chuquicamata S.A. Currently, about 180,000 tons/day of ore having about 1% Cu are processed at Chuquicamata producing about 600,000 tons/year Cu.

Codelco is the main copper company in the world. In 2009 produced 1.700.000 tonnes. Codelco is one the largest molybdenum producer. In 2008 the production was 21.000 ton. It also produces gold (5,5 tpy), silver (130 tpy), and selenium as by-products. A recent view of Chuquicamata mine is shown in Figure 85. Director of Research at Chuquicamata in 1993 was Gustavo Cartagena (Figure 86).

Figure 85. Chuquicamata copper mine.

Alliance Copper

Bacterial leaching has been successfully applied for heap leaching of copper ores. It was extended to treat auriferous pyrite concentrates to liberate gold and render it amenable to cyanidation by a process known as BIOX. In the past few years there has been interest to apply bacterial leaching to treat chalcopyrite concentrates. For example, Engineering of BacTech Mining Corporation operated a continuous small scale bioleach pilot plant in 1998 at Mt. Lyell in

Tasmania. A demonstration scale plant was constructed in 2001 by the joint technology partnership of BacTech and Mintek in conjunction with Peñoles in Monterrey in Mexico. The plant operated for a year with a capacity of 200 tpa copper cathode production using commercial equipment. It is interesting that in 2002, Alliance Copper, which is a joint venture between BHP Billiton and Codelco built also a 20,000 tonnes/year demonstration plant 30 km from Calama for US $ 50 million. The plant is composed of six large reactors, mechanically agitated, and lined with acid-resisting brick. Since a thermophilic bacteria is used in the system it is possible to operate at a temperature of about 90ºC and this accelerates the reaction.

Figure 86. Gustavo Cartagena, Director of Research, 1993.

In spite of this enthusiasm for bioleaching technology, one cannot recommend its use for leaching chalcopyrite concentrates because it cannot be economical for the following reasons. The leaching reaction for chalcopyrite is as follows:

$$CuFeS_2 + 4\ O_2 \rightarrow CuSO_4 + FeSO_4$$

From this it can be seen that a large amount of oxygen will be consumed, a large amount of lime will be needed to precipitate ferrous sulfate, and there will be an excessive disposal and material handling problem of ferrous hydroxide – gypsum mixture:

$$FeSO_4 + Ca(OH)_2 + 2\ H_2O \rightarrow Fe(OH)_2 + CaSO_4{\cdot}2H_2O$$

The reaction is slow - - it is complete in 4 – 5 days when conducted and in addition, some bacterial nutrients such as phosphate and ammonium ions must be supplied to the reaction mixture. In the recovery step by electrolysis, acid will be generated and must be disposed of. When bioleaching technology is compared with pressure leaching, the reaction that takes place in one autoclave at 150ºC and 4000 kPa oxygen partial pressure is as follows:

$$2\ CuFeS_2 + 4\ H^+ + 5/2\ O_2 \rightarrow$$
$$2\ Cu^{2+} + Fe_2O_3 + 4\ S + 2\ H_2O$$

The advantages of this route are the following:

- The reaction is fast - - complete in 20 – 30 minutes
- Oxygen consumption is $1^1/$□ moles per mole chalcopyrite as compared to 4 moles in the case of bioleaching, that is less than one third that required for bacterial leaching
- One reactor is enough
- Cu^{2+} is already separated from Fe^{2+} since Fe_2O_3 is precipitated during the reaction
- All the sulfur in the concentrate can be obtained in the elemental form
- When copper is recovered from solution by electrowinning, the acid generated at the anode is equal to that required for leaching hence no acid disposal problem
- There is no material handling and disposal problem involving lime addition
- Any arsenic present in the concentrate will remain in the residue as ferric arsenate

No wonder that the plant was shut down few months after my visit in 2005.

Potrerillos and Salvador

The Potrerillos deposit, located in the Atacama region, was exploited until 1913 by the Potrerillos Mining Company, a small Chilean company. It was then purchased by William Braden and, in 1916, it was sold to Anaconda, which through its subsidiary, Andes Copper Mining, began exploitation. In 1921, the reserves reached 137 million tons having 1.5% Cu; 48 million tons were oxides and 89 million tons, sulfides. In 1924, for the first time in Chile, the block caving method was used to exploit the mine. In 1927, a 17,000 ton/day concentration plant and a smelter began operation; oxide ore was leached by sulfuric acid then copper electrowinning, recovering 86% Cu.

The concentrate obtained from the flotation process was roasted in seven roasters. Calcine was smelted in three reverberatory furnaces having a 1,200 ton/day capacity. The matte having 50% Cu was fed into converters to obtain blister copper having 99.3% Cu and 1.2 ppm Au. The off-gas allowed for the producing of sulfuric acid, which was used in the leaching process.

In 1939, the company processed about 5 million tons/year of ore having 1.45% Cu, producing 50,000 tons/year Cu. In 1959, the reserves were exhausted and the company began developing the Salvador deposit near Potrerillos (340 million tons having 1.5% Cu), where a new concentrator was built with a production capacity of 85,000 tons/year of copper concentrate. In 1960, the company built an electrolytic refinery in Potrerillos. Today, the Salvador Division produces about 70,000 tons of copper.

Saltpeter

During the colonial period, saltpetre (el salitre), also know as caliche, was used by the natives as fertilizer. In the 17th and 18th centuries, it was used to make gunpowder for the military and for mining operations. Important deposits were exploited in Peru in the Tarapacá region. In 1809, sodium nitrate was converted to potassium nitrate to produce gunpowder using the Thaddaeus Haenke method. In Europe, research on plant nutrition had shown the advantage of using nitrogen in the harvests, thus the demand for natural compounds of this element increased. From 1810 to 1813 about ten plants, known as paradas, began operation in the Tarapacá region at that time in Bolivia. The paradas consisted of a container to leach the saltpeter containing 50% to 70% nitrate, with hot water, a pond to clarify the slurry, and a vat for crystallization.

In 1856, Petro Gamboni (1825-1895) (Figure 87) improved the recovery of nitrates by using superheated steam instead of heating by burning fuel. He also extracted iodine from the mother liquor. The solution was mixed with sodium bisulfite, $NaHSO_3$, to reduce the iodate to iodide, and was then mixed with another pregnant solution where iodine was obtained, then separated, washed, and dried:

$$IO_3^- + 3HSO_3^- \rightarrow I^- + 3SO_4^{2-} + 3H^+$$

$$5I^- + IO_3^- + 6H^+ \rightarrow I_2 + H_2O$$

One kilogram of iodine was produced per ton of saltpeter processed.

Figure 87. Petro Gamboni (1825-1895).

Gamboni was born in Valparaiso in an Italian family from Sardinia. He studied chemistry and engineering in Europe and USA. He worked in Iquique's saltpetre industry and in 1853 introduced the use of high-temperature steam as a thermal and leaching agent instead of using direct heat via tubes. In 1856, he devised a method to extract iodine from the pregnant solution of saltpeter which is still in use today with minor modifications.

Santiago Humberstone (1850-1939) (Figure 88) was an English chemical engineer went in 1875 to Chile to work for the Compañía Salitrera de Tarapacá. In 1878, at the Agua Santa operation, he increased the production and processed low grade deposits. In 1925, he retired after 50 years of working in the saltpeter industry.

Figure 88. Santiago Humberstone (1850-1939).

In 1857, Domingo and Máximo Latrille discovered saltpeter in a salar near Antofagasta, on the Bolivian coast. In 1860, José Tomás Ossa (1827-1878), a Chilean miner, discovered saltpeter in Aguas Blancas on the same coast. Following the Pacific War, Chile took possession of the Tarapacá and Antofagasta saltpeter deposits. There were about 80 saltpeter plants that employed approximately 25,000 people. Production increased from 500,000 tons in 1884 to 1,060,000 tons in 1890, and was mainly intended for export to Europe. In addition to iodine, the deposits also produced borates, sodium chloride, and chlorates.

Production was reduced during World War I when synthetic ammonia was produced in Germany by the Haber-Bosch process, which was used to make nitric acid, and took the place of the Chilean saltpeter. In 1924, the Guggenheim family acquired the María Elena saltpeter plant in the Antofagasta region and formed the Anglo Chilean Consolidated Nitrate Corporation, developing the Guggenheim crystallization system. This method allowed for the mechanization of the operations. Nitrate crystallization from the solution was achieved by cooling and later by solar evaporation. The final product was melted and granulated for handling.

Elias Anton Cappelen Smith (1873-1949) (Figure 89) was born in Trondheim in Norway, son of founder and owner of the trading companies E. A. Smith AS. Smith was related to the Cappelen family originally from Cappeln in Oldenburg in Northern Germany. The family immigrated to Norway in 1653. Elias Anton Cappelen Smith received his education at the Polytechnic Institute at Trondheim. He migrated to USA in 1893 to work with the Chicago Copper Refining Company, the Anaconda Company, the Baltimore Copper Smelting & Rolling Company, the American Smelting & Refining Company, and then became one of the partners of Guggenheim Brothers in New York.

In 1911, Guggenheim bought Chuquicamata and developed the copper mine, under the leadership of Elias Anton Cappelen Smith. He developed the leaching process for copper extraction from the low grade ore and devised with William H. Peirce what became later known as the Pierce – Smith converter (1909).

During more than a decade, Smith was appointed first administrator of the Chacabuco Saltpeter Refinery built in 1924. He studied the technology of the saltpeter industry and designed a new method for extracting and purifying the sodium nitrate. All activities were halted in 1940 when synthetic ammonia became a substitute of natural nitrate. In 1965, the company handed the management over to Soquimich Chemical and Mining Society of Chile. The community's name was given by Elias Anton in honour of his wife Mary Helen who died at the young age of 54. Figures 90 to 93 shows some views of the Salar.

Figure 89. Elias Anton Cappelen Smith (1873-1949).

Figure 90. Salar de Atacama [Photo by Nadia Habashi, 1993].

Figure 91. Salar de Atacama [Photo by Nadia Habashi, 1993].

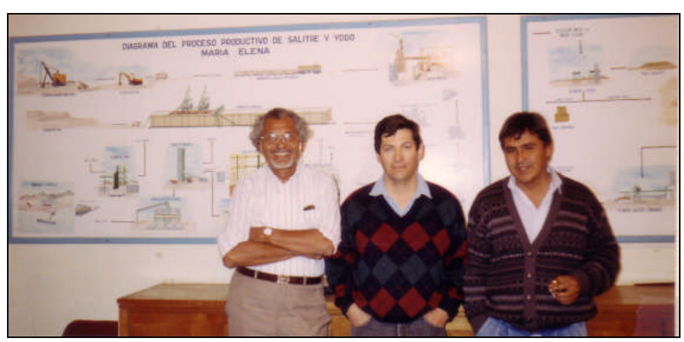


Figure 92. Maria Elena. From right: Dr. Patricio Araya Director of Research, Ing. Bernardo Araya Production Manager [Photo by Nadia Habashi, 1993].

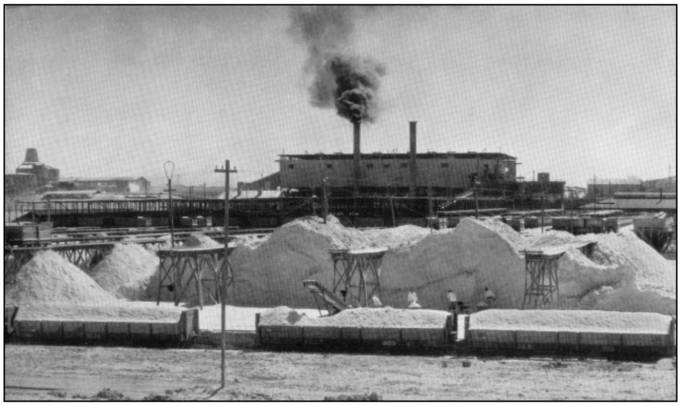


Figure 93. A nitrate plant in Tarapaca.

San Pedro de Atacama

San Pedro de Atacama is located east of Antofagasta, some 106 km southeast of Calama and the Chuquicamata copper mine, overlooking the Licancabur volcano. It features a significant archeological museum, the Archaeological Museum founded by Gustavo Le Paige, with a large collection of relics and artifacts from the region related to pre-Columbian cultures. Father Gustavo Le Paige (1903-1980) was born in Tilleur near Liege in Belgium, studied Philosophy and Theology at the University of Lovaine, then went to Belgium Congo as missioner from 1936 to 1952 before coming to Chile in 1953 where he was assigned to San Pedro de Atacama church. Figures 94-98 shows some details of the region.

Figure 94. Location map of San Pedro de Atacama.

Figure 95. San Pedro de Atacama Museum.

Figure 96. Museum director of San Pedro de Atacama Museum.

Figure 97. San Pedro de Atacama Volcano Licancabur.

Figure 98. San Pedro de Atacama volcano on the background.

Lithium

In 1980 the Sociedad Chilena del Litio, a joint venture between Corporación de Fomento de la Producción de Chile known as CORFO and Foote Mineral Co., began to produce lithium carbonate from Atacama brines (Figures 99, 100). The process included a solar evaporation to increase lithium concentration of the salar brine from 0.23% to 5.8%. The product was sent to a chemical plant where it was purified to eliminate the magnesium, and then treated by Na_2CO_3 to precipitate lithium carbonate.

In 1968, the Sociedad Química y Minera de Chile S.A. (SQM) was created as part of a plan to re-organize the Chilean saltpeter industry. In the beginning, the ownership of the company was shared between the government (CORFO, 37.5%) and private capital (Compañía Salitrera Anglo Lautaro S.A., 62.5%). In 1971, the company became completely state-owned. In 1983, CORFO started the privatization of the company, which was completed in 1988. In 1989, CORFO sold its share to Foote, which was controlled by Cyprus Minerals Co.

Between 1988 and 1993, the company carried out a modernization process of their production plants. Heap leaching and a fertilizer mixing plant were introduced. Potassium nitrate, iodine derivatives, and specialty blends of fertilizers were added. Between 1994 and 1998, the company developed the Salar de Atacama project where lithium carbonate, potassium chloride, potassium sulphate, and boric acid were produced.

Figure 99. Salar de Atacama.

Figure 100. Lithium plant near Antofagasta [Photo by Nadia Habashi, 1994].

TARAPACÁ REGION

Iquiqui (Figures 101, 102) is the capital of Tarapacá Region was a former Peruvian province, which was annexed by Chile in 1883 at the close of the War of the Pacific. It is the home of Arturo Prat University. In December 1907, the city of Iquique was marred by a massacre when the Chilean Army, under the command of General Roberto Silva-Renard, opened fire on thousands of saltpeter miners, and their wives and children, who assembled inside the Santa María School. The workers had marched into town to protest their working conditions and wages. Somewhere between 500 and 2,000 people were killed.

Figure 101. View of Iquique in Tarapacá Region.

Figure 102. A cross section through Iquique region.

Universidad Arturo Prat

The Arturo Prat University in Iquique, named after the Chilean Admiral who won the battle in the War of the Pacific (Figure 103), organized in August 2001 the 7th Mining Meeting of Tarapaca jointly with the 2nd Mining Meeting of South America. Chair person of the Organizing Committee was Professor Ximena Veloso.

Figure 103. Arturo Prat (1848-1879).

A metallurgy conference was held in Iquique in 2001 (Figures 104, 105).

Figure 105. With old friends. From left: Jose Hevia [Universidad Catolica del Norte, Fathi Habashi, Guillermo Coloma [Antofagasta], Iquique 2001.

Figure 104. Invited speakers at the Iquique conference 2001 with Professor Ximena Veloso Chair person of the Organizing Committee.

ARICA REGION

Arica (Figure 106) is the capital of Arica and Parinacota Region is the home to the University of Tarapacá. In 2007, the region was subdivided to create the Arica and Parinacota region and the present day Tarapacá Region to the south. The archeological remains of the Inca were visited in 1994 (Figures 107, 108).

Figure 106. View of Arica and the Morro [the Castle] on top.

Figure 107. Archaeological route of Inca in Arica. From left: Jaime Villanueve, Ernesto Ponce (Host), Fathi Habashi, Guillermo Focacci (Archaeologist) [Photo by Nadia Habashi, 1994].

Figure 108. With Rector of the University of Tarapacá Luis Tapia (center) [Photo by Nadia Habashi, 1994].

BIOBIO REGION

Concepción is the capital of Biobio Region, was founded by Pedro de Valdivia in 1550 north of the Bío-Bío River is the second-largest city in the country and the seat of the University of Concepción. It was the headquarters of the military forces engaged against the Mapuche Indians.

University of Concepción

The University of Concepción was founded in 1919 and its Department of Metallurgy was established in 1961 by Alexander Sutulov (1925-1991) (Figure 109) who was born in the former Yugoslavia and moved to Chile in 1955. The Univeristy was visited in 1994 (Figures 110, 111).

Figure 109. Alexander Sutulov (1925-1991).

Figure 110. With Faculty members at the University of Concepcion. Extreme right Mario Sanchez [Photo by Nadia Habashi, April 2005].

Figure 110. Mural at the University of Concepcion [Photo by Mario Sanchez, April 2005].

HYDROCOPPER CONFERENCES

HydroCopper is annual conference devoted to the hydrometallurgy of copper since 2003 organized by the Mineral Engineering Department of the University of Chile in collaboration with Gecamin Ltda. (Figures 112, 113).

Figure 112. Receiving a certificate at the Third International Copper Hydrometallurgy Workshop known as HydroCopper 2005 that was held in Santiago November 23-25, 2005. The citation reads, " In recognition of five decades of contributions to the knowledge in science, technology, and history of extractive metallurgy".

Figure 113. Banquette at HydroCopper 2009. From right: Esteban Domic, ?, xxx, Luis Sobral from CETEM in Rio de Janeiro, Joge Menacho Conference Chairman. Sitting: Mrs. Darvishi-Alamdari, graduate student from Laval University in Quebec City.

MOLYBDENUM AND RHENIUM

In 1939, molybdenum concentrate was obtained as a by-product of flotation at El Teniente mine. Later, it was recovered from copper concentrates at the Chuquicamata, El Salvador, and Andina operations. In 1994, Disputada started production of molybdenum concentrate and today produces about 2,000 tons/year. In 2000, Los Pelambres mine began production and currently produces 6,933 tons/year. In 2002, Chilean molybdenum concentrate production was about 30,000 tons; 68% was obtained from Codelco's operations.

About 50% of world rhenium production comes from Chile. The largest producer of molybdenum concentrates in Chile is Corporacion Nacional del Cobre (Codelco). Codelco roasts a portion of their concentrate production to make technical grade molybdenum oxide, exports a portion of their concentrate directly to various overseas customers, and sends the balance to Molibdenos y Metales (Molymet) for processing. Only the portion sent to Molymet is known to be processed for rhenium recovery. Molymet also receives concentrates from two other mines in Chile and at least one in Peru. Rhenium concentration in the South American molybdenum concentrates ranges from about 250 to 400 ppm. Rhenium production at Molymet is about 12.6 t/yr. Molymex's production of molybdenite concentrates is closely tied to production from the La Caridad Mine in Sonora, Mexico.

Molibdenos y Metales was formed in 1975 Molymet acquired Molymex in 1994 in the area of Sonora, Mexico. In 2000 Molymet Corporation was formed in Baltimore, USA: in 2001 CM Chemiemetall GMBH was bought in Bitterfeld, Germany. They acquired Sadaci in Ghent in Belgium in 2003 and at the end of 2005 they formed Molymet Services in the UK. Since January 2010 Molynor plant began operations at Mejillones, located at Chile's second region. During May this year Molymet through ChinaMoly makes a 50% Joint Venture with the company Luoyang High-Tech from China. Figure 114 shows a flowsheet for rhenium recovery.

Molymet uses molybdenum concentrate roasting to recover the by-product rhenium. It produces technical molybdenum oxide, molybdenum oxide briquettes, ferromolybdenum, high-purity molybdenum chemicals, and all the rhenium products such as ammonium perrhenate, perrhenic acid, rhenium powder, and rhenium pellet.

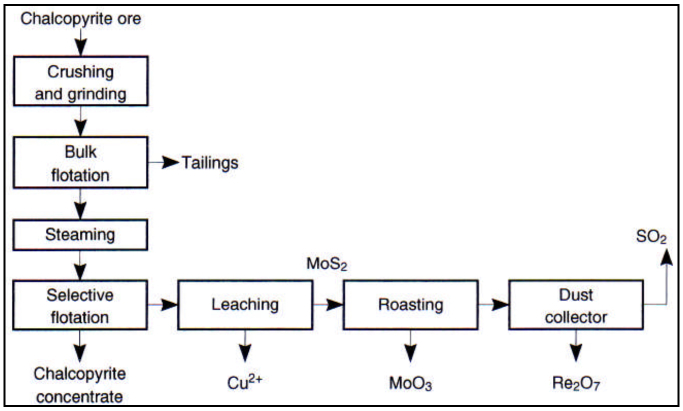


Figure 114. Recovery of molybdenum and rhenium.

EASTER ISLAND

On Easter Sunday, April 5, 1722, a Dutch sea captain named Jacob Roggeveen landed his ship on an island known as *Te Pito o Te Henua*, meaning "The Center of the World" (Figures 115 - 117). He renamed it Easter Island. Located 3500 km off the coast of Chile, it is about 100 km in size with three extinct volcanoes. At first, Polynesian travelers from the Marquesas, or Society Islands, populated the island. As the population increased, the food chain broke resulting in famines. Those who survived were left to the mercies of slave traders from other lands. Since the island consists of volcanic rock, the early inhabitants quarried the material into giant statues, some as tall as 5 m and weighing about 14 tonnes (Figures 118 -120). The villagers used the trees to transport these giant rocks all over the island. Most of the surviving statues are lined up all along the shoreline facing out to sea. The statue cult symbolized male dominance and power throughout the societal structure of the inhabitants.

Figure 115. Location of Easter Island.

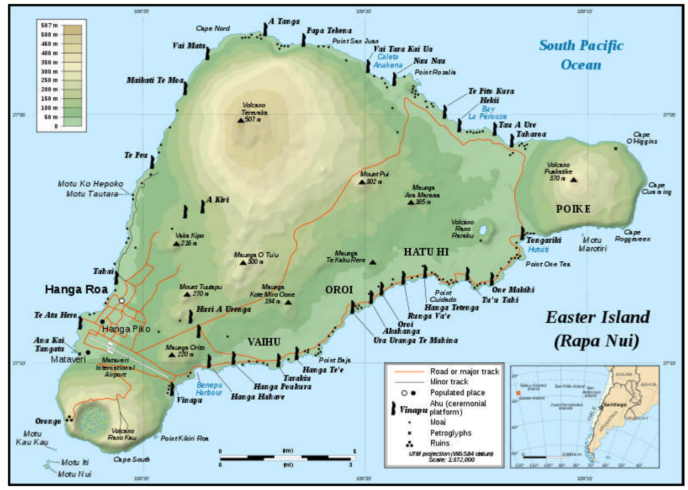


Figure 116. Map of Easter Island.

Figure 117. Easter Island [Photo by Nadia Habashi, 2001].

Figure 118. Statues carved by Stone Age people in Easter Island.

Figure 119. Easter Island [Photo by Nadia Habashi, 2001].

Figure 120. Easter Island monuments.

EPILOGUE

Copper and gold have been recovered by natives before the arrival of Spanish conquerors. Later, during the Colonial period (1545-1810), gold and silver were also recovered by the Spanish using mercury. Towards the end of the eighteenth century, foreign engineers from Europe began arriving to introduce new technologies. In modern times Chile became the top producer and exporter of copper and the largest producer of rhenium recovered from molybdenite. Chile is also one of the world's significant producers and exporters of industrial minerals such as potassium and sodium nitrate, iodine, lithium salts, and borate

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- Chile, August 8-26, 2001
- Chile, April 7-21, 2005
- Chile, Santiago, November 22-28, 2005
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APPENDIX

Summary of trips to Chile

	Date	Purpose of visit & places visited	Host
1	December 9-17, 1992	[1] Department of Chemical & Metallurgical Engineering, Catholic University in Antofagasta [2] Help organize the National Metallurgy Conference known as CONAMET to be held in 1994 [3] Ruins of Silver Refinery, Antofagasta [4] Escondida process [5] Empressa Minera de Mantos Blancos [6] Compania Minera Carolina de Michilla	Dr. Raul Ibarra
2	July 31 - August 21, 1993	[1] Lecture tour [2] Chuquicamata [3] Archaeological Museum at San Pedro de Atacama [4] Salar de Atacama [5] University of Atacama at Copiapó [6] Nitrate recovery plant at Maria Elena [7] Department of Metallurgy, University of Santiago [8] Research Center for Mining & Metallurgy (CIMM) in Santiago [9] El Teniente [10] Technical University Federico Santa Maria in Valpariso	Dr. Raul Ibarra Dr. German Cáceras
3	August 2-17, 1994	[1] Viña del Mar [2] Plenary lecture at Congreso Nacional de Metalurgia [3] Universidad Tecnica Federico Santa Maria in Valpariso [4] Research Group on Prehispanic Metallurgy at the Universidad de Trapacá in Arica [5] Chuquicamata [6] Sociedad Chilena de Litio, Antofagasta [7] Sociedad Quimica Maria Elena in Antofagasta	Dr. Jorge Pontt Dr. Rougette Araneda
4	August 8-26, 2001	[1] Easter Island [2] University Arturo Prat in Iquique [3] Lecture at Chilean Mining Society, Santiago [4] Seminar at University of Concepcion [5] Seminar at University of La Serana	Ing. Armando Valenzuela Dr. Mario Sanchez
5	April 7-21, 2005	[1] Short course on leaching of copper minerals at the University of Atacama [2] Copper industry in Copiapó	Prof. German Cáceras
6	November 22-28, 2005	Keynote Address at HydroCopper 2005, Santiago	Dr. Jesus Casas
7	May 9-17, 2009	[1] Short course on hydrometallurgy at HydroCopper 2009, Antofagasta [2] Keynote lecture at HydroCopper 2009	Dr. Jesus Casas