Government of Chile
Ministry of Mines

09/30/2014

Translated Copy from Spanish to English

LITHIUM POTENTIAL IN SALARS OF THE NORTH OF CHILE

Gobierno de Chile

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TO 01

WHY THE LITHIUM?

- Relatively small but dynamic market US $ 2.2 km 2012.
- It is expected to increase due to the increase in the consumption of lithium batteries, and of glasses, ceramics and fluxes, mainly.
- Production of lithium compounds increased from 97,000 t LCE in 2005 to 178,000 Mt LCE in 2012 (LCE = Li content x 5.3).
- World demand in 2020 is estimated> 230,000 t SCL, compared to 130,000 Mt SCL in 2012.
- Chilean deposits in brine with low operating costs and significant comparative advantages, due to high concentration (1.8-2.5 gr / l Li; 20-22 gr / l K) and high evaporation rate.
- Its reserves of up to 7.5 Mt are equivalent to 20% of the world total.
- The annual national production of lithium compounds in 2012 reached 40% of world production.

SALARS OF NORTH OF CHILE

- The main saline deposits in northern Chile correspond to **fields of nitrates and salt**, which, together, are located in the four northern regions of the country, between 18º and 27ºS, and comprise an area of about 250,000 km two , from 1,000 m asl in the W, to almost 5,000 m asl in the E.

- The salt flats correspond to **continental salt deposits** located in endorheic basins, generated due to high evaporation rates and low precipitation rates. Are composed of **salt crust,**

  brine Y **clastic fraction,** whose extensions and depth can vary very widely. They contain **carbonates, sulfates, chlorides and borates,** in different concentrations, both in the salt crust and in the brine.

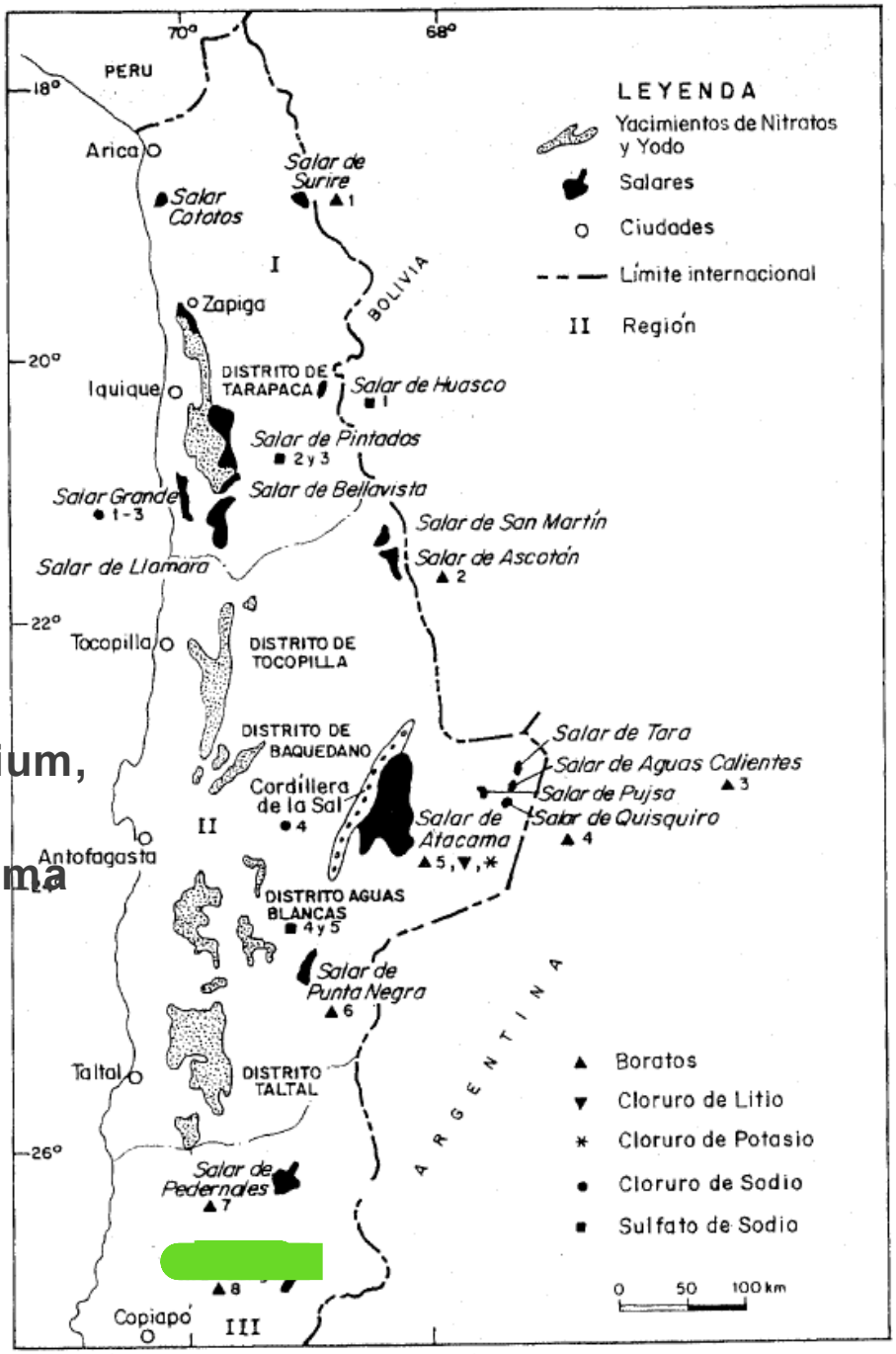
- The approximately 60 known salt flats in the north of the country are distributed in the regions of Arica and Parinacota, Tarapacá, Antofagasta and Atacama. According to their location WEare classified into **salt flats of the Cordillera de la Costa, the Central Depression, Preandinos and Andeans,** and together they mainly contain **lithium, potassium, boron and sodium salts.**

DISTRIBUTION OF SALARS OF THE NORTH OF CHILE

The salt flats of main interest for **lithium** are the **Pre-Andean and Andean salt flats,** that they also have **potassium and boron salts.**

Of them, the most important and only one currently in operation to produce **lithium, potassium and boron compounds,** since the 80's of the 20th century, it is the **Atacama salt flat,** Pre-Andean salt flat located in the Region of

Antofagasta.



DETERMINING FACTORS IN THE GENESIS OF SALARIES

- **GEOLOGICAL FACTORS**

  > Cenozoic volcanic activity (generates basins and contributes chemical components).

  >The leaching of Cenozoic volcanic rocks that surround these basins (contributes chemical components).

Pre-Andean salt flat: ignimbrite leaching

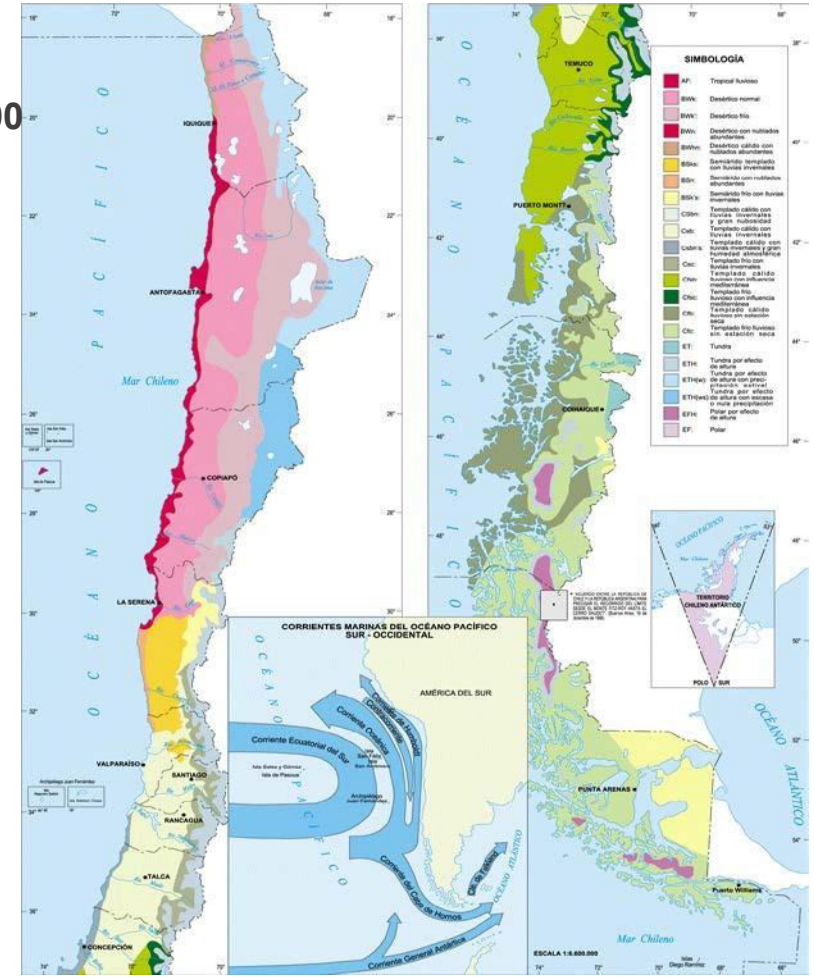
Andean salt flat: volcanic activity

DETERMINING FACTORS IN THE GENESIS OF SALARIES

- **CLIMATIC FACTORS**

  >Solar evaporation rates of approximately **3,200 mm / year**
  and an average rate of water fall of only 15 mm / year, in the desert, western sector.

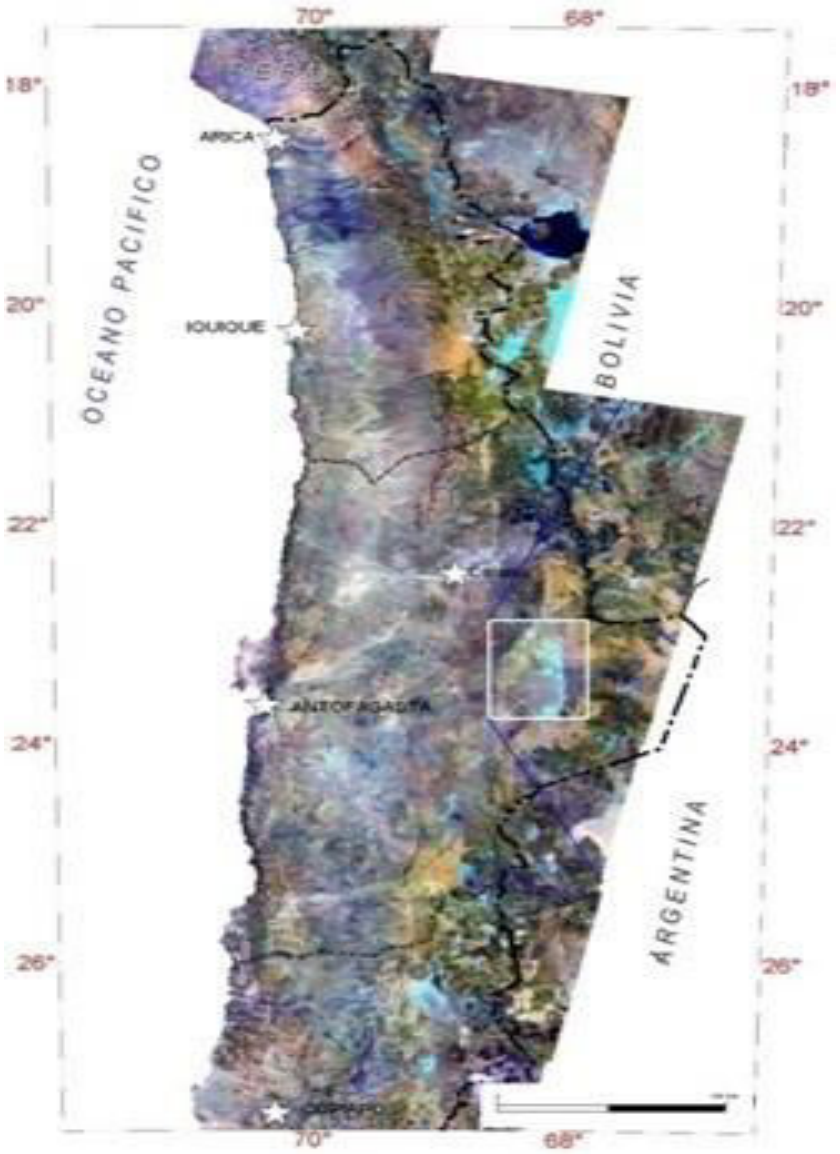
  > Rainfall during the hemispheric winter and during the "Altiplanic Winter", in the eastern sector. Average annual evaporation in the Atacama salt flat:
  2,000 mm / year;



DETERMINING FACTORS IN THE GENESIS OF SALARIES

- **STRUCTURAL FACTORS**

  >NS and WE bearing regional fault systems, which have facilitated the formation of major geomorphological entities: Cordillera de la Costa, Intermediate Depression, Precordillera, Pre-Andean Basins, Altiplano and Andean Cordillera, and local endorheic basins.



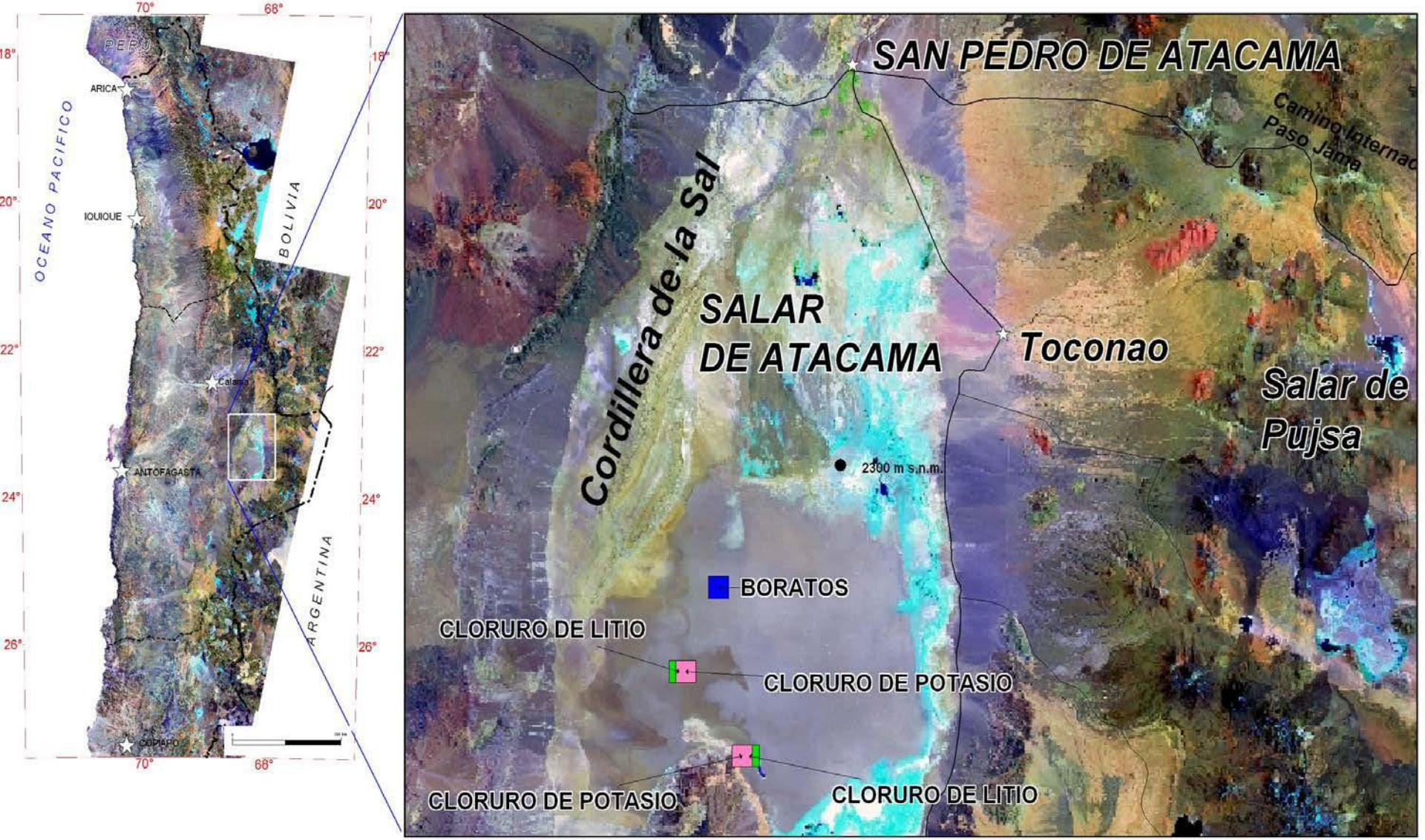
PRE-ANDEAN SALTS

- Located in tectonically controlled pre-Andean basins, generally aligned in a NS direction, to the east of the Precordillera and about 2,500 to 3,000 m asl: Atacama, Punta Negra, Pedernales and Maricunga

- They correspond to the oldest active salt flats, with well-developed saline crusts that present concentric zonation of carbonates, sulfates and chlorides, and with brines with a high concentration of dissolved solids, supersaturated in sodium chloride.

- Virtually all surface and subsurface water recharge, highly concentrated, comes from the Andean Cordillera.

- They are dynamic systems, in which the ore of interest is brine, which migrates and varies in volume, concentration and distribution in the saline body, making it difficult to determine its physical and chemical properties.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SAN PEDRO DE ATACAMA
Camino Internac
Paso Jama
Cordillera de la Sal
SALAR
DE ATACAMA
Toconao
Salar de
Pujsa
2300 m s.n.m.
BORATOS
CLORURO DE LITIO
CLORURO DE POTASIO
CLORURO DE POTASIO
CLORURO DE LITIO

SALARIES AND ANDEAN LAKES

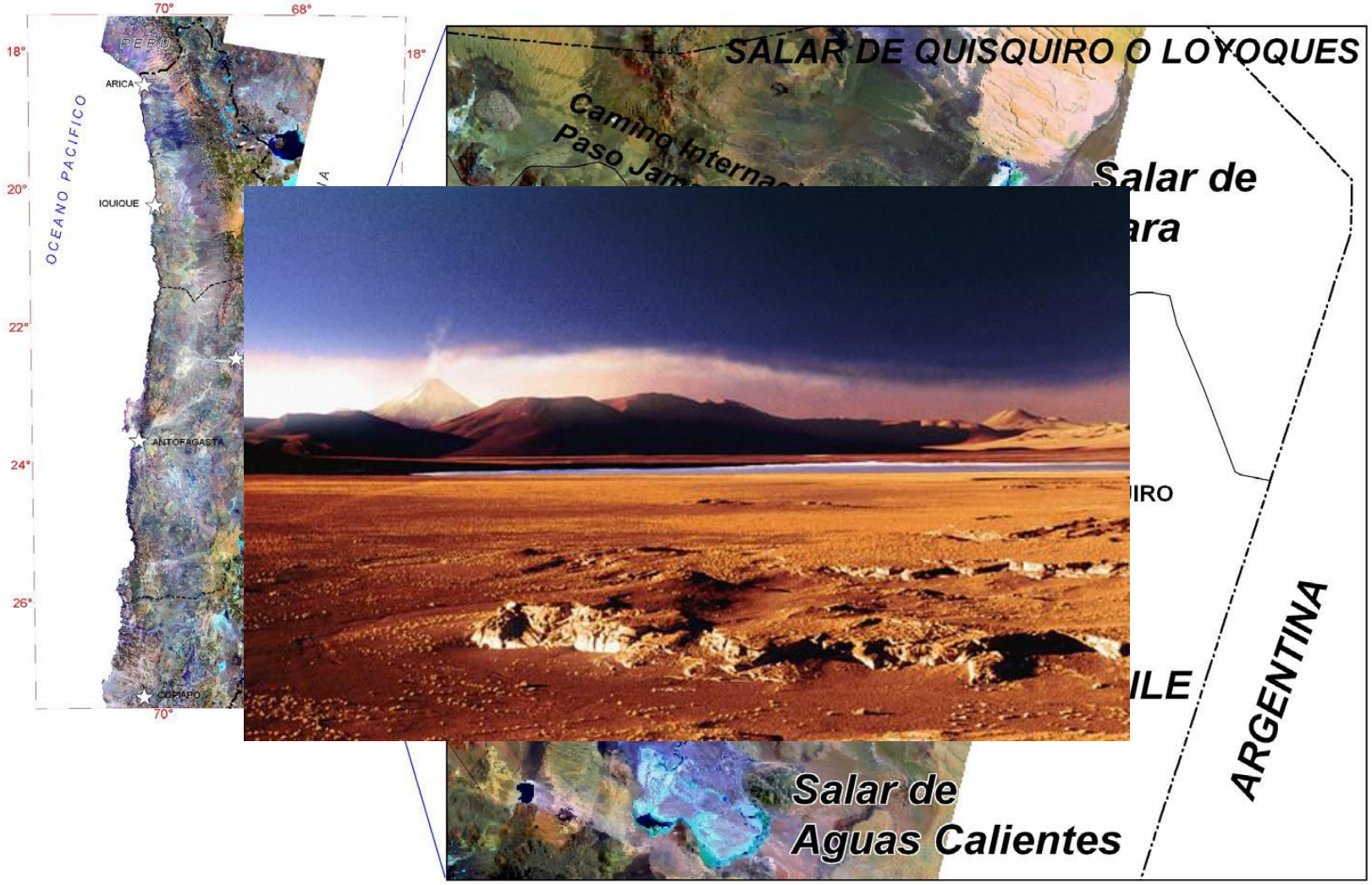
- Located in the Altiplano, more than 4,000 m above sea level, mainly in basins controlled by volcanism.

- The brines are subsaturated in sodium chloride and contain Na^+, Ca^{2+}, Mg^{2+} and K^+ as the main cations.

- They correspond to the youngest saline deposits and are spatially and genetically related to the Plio-Quaternary volcanism and affected by rainfall.

- They are characterized by containing significant concentrations of boron salts in the solid phase, such as Surire, Ascotán and Aguas Calientes, and lithium and potassium salts in the brine, such as La Isla, Loyoques and Pujsa.

- They are very dynamic and very fragile systems, due to their location and geological, climatic and environmental characteristics.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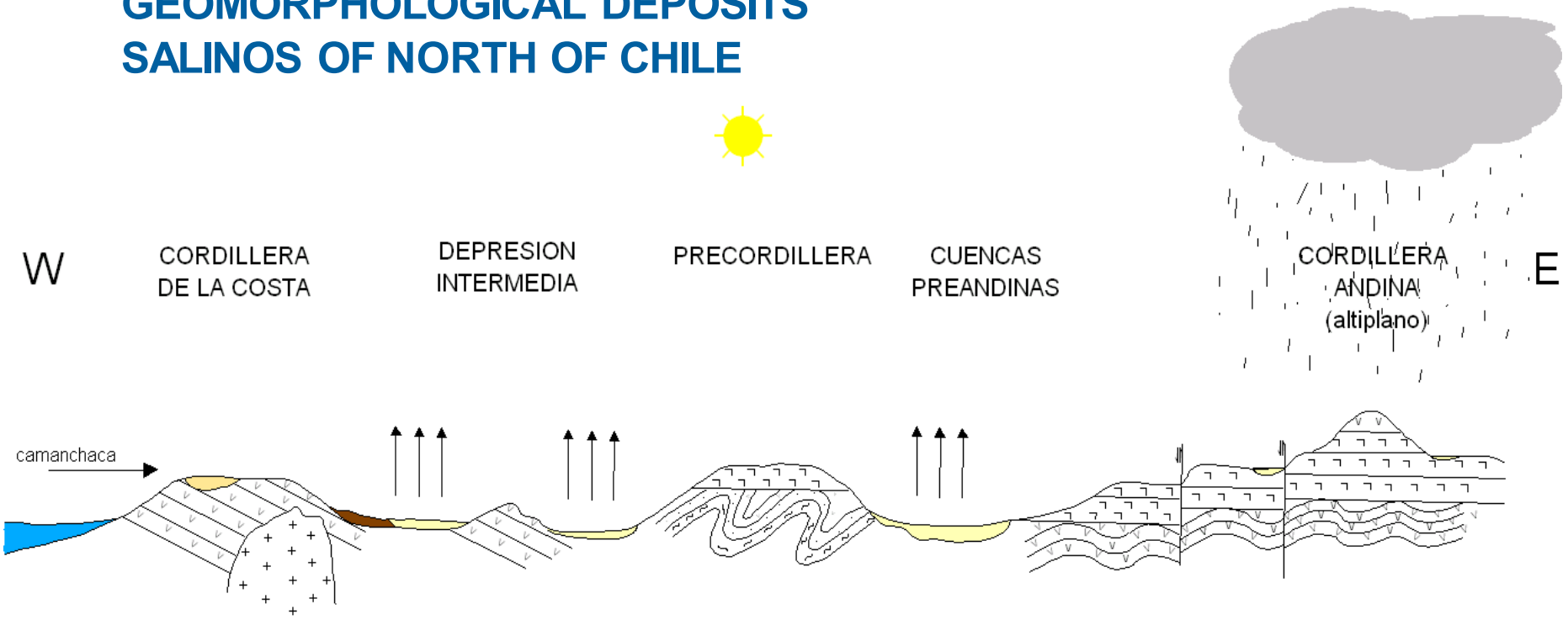
Salar de
Aguas Calientes

SCHEMATIC PROFILE GEOMORPHOLOGICAL DEPOSITS SALINOS OF NORTH OF CHILE



Salares de la Cordillera de la Costa	Depositos de Nitratos	Salares de la Depresión Intermedia	Salares Preandinos	Salares y Lagunas Andinas
Salar Grande -NaCl	Nitratos -Na y K -Yodo -Na2SO4	Salar de Bellavista -Na2SO4 -NaCl	Salar de Atacama -Boratos -Cloruro de Li y K	Salar de Surire -Boratos

THE MAIN RESOURCES IN SALARIES PRE-ANDEANS AND ANDEANS

LITHIUM

- The occurrence of **lithium** it is mainly associated with pegmatites (30%) and brines (70%).

- Pegmatitic deposits contain lithium minerals, such as **spodumene, petalite** Y **lepidolite.** The US, Australia, Canada and Zimbabwe are the main countries with these deposits.

- In brine deposits, lithium occurs as **Lithium chloride.** Chile, Argentina, Bolivia and the US have these lithium deposits.

- The **lithium** and the **lithium carbonate** are used in:
  >manufacture of glass and ceramics, ceramic glazes, special concretes, lubricants and synthetic greases,
  > pharmaceutical industry and medical applications,
  > aluminum manufacturing process,
  > manufacture of batteries for electric cars.

POTASSIUM

- The **potassium** it is found in silicate minerals of igneous, metamorphic and sedimentary rocks, and in brines.

- Rock reservoirs account for most of the world's potassium resources, such as those in the US and Canada, and contain the minerals **Silvita, Carnalita** Y **kainite.**

- In surface and subsurface brines, potassium is a major component, and is found as **potassium chloride.**

- The **potassium chloride** and the **potassium sulfate** are used in:

  >fertilizers for crops demanding in potassium and / or in soils deficient in the element

  > preparation of other potassium compounds

  > some drilling fluids, and dietary salts for human consumption.

BORON

- There are about 15 minerals of **boron,** of which four are of greater commercial interest: **borax, kernite, colemanite** Y **ulexite.**

- According to their composition, borates can be classified, mainly, into **sodium, sodium-calcium** Y **Calciums.**

- Borate deposits occur in sedimentary sequences ontinentalc, mainly of Tertiary Superior, which contain borax and colemanite (USA, Turkey and Argentina), and in the crust and brine of salt flats of the Upper Tertiary-Quaternary, which contain ulexite (**Chile and Argentina**).

- The **boric acid** and the **treated ulexite** are used in:
  >chemical industry and manufacture of common glass, borosilicate glasses, and ceramic glazes,
  > manufacture of fire retardants for wood and building elements,
  > plantation of alfalfa, apple, olive, peanut, beet sugar, marigold, forest plantations and vines.

THE POTENTIAL OF LITHIUM IN SALARES DEL NORTH OF CHILE

According to existing knowledge, the known lithium potential in the salt flats of northern Chile is circumscribed to the pre-Andean salt flats and Andean, and can be described as follows:

1.- SALT ROOMS WITH KNOWN RESERVES AND RESOURCES

1.a.- Salar de Atacama:

- The only one in operation due to lithium and potassium compounds, in addition to boron (1.8-2.5 gr / l Li; 20-22 gr / l K).
- Studied since the late ´60 by the former IIG and CORFO.
- Mining Concessions belong to CORFO, since lithium is a substance not concessional according to the 1983 Mining Code
- CORFO transfers them through a lease, currently to the companies SQM Salar (180,100 t Li, until 12/31/2030) and Rockwood Lithium (ex SCL) (200,000 t Li, undefined).
- These companies produce, together, carbonate, chloride and hydroxide lithium, and potassium chloride and sulfate.
- The available information indicates a reserve of 6.3 Mt Li (SQM).

BRINE PRODUCTION PROCESS
(Salar de Atacama)

Sal

Molienda, Flotación
Conversión, Secado
Compactado

FERTILIZANTE
* Cloruro de Potasio
* Sulfato de Potasio

Solución
Concentrada

Refinación
Conversión
Secado

* Carbonato de Litio
* Ácido Bórico

Salmuera

Bombeo de Pozo

Reinyección Salmuera Concentrada

Costra Salina

Salmueras

1.b.- Salares de Maricunga and Pedernales

- They are not in operation due to lithium or potassium; yes they have been exploited by boron.

- Studied by CODELCO to determine its resources and reserves.

- Mining Concessions belong to CODELCO, they represent 18% of the surface area in Maricunga and 100% in Pedernales

Estimates made by independent authors indicate

280,000 t and 240,000 t Li, respectively.

- The information on resources and reserves is not available as it is reserved.

2.- SALT ROOMS WITH ESTIMATED POTENTIAL

2.a.- Project 7 Salares Tallison Lithium

- Private project with no information available

2.b.- Andean Salt Flats of the Antofagasta and Atacama Regions

- SERNAGEOMIN study to know potential in lithium

STUDY OF THE LITHIUM POTENTIAL IN SALARS OF NORTH CHILE

R. Troncoso, O. Ercilla, R. Carrasco and W. Vivallo

SERNAGEOMIN (2013)

Study requested by the Undersecretariat of Mining, whose objective is to validate the existing information on selected salt flats in the field, and provide background information regarding its potential as a source of lithium.

BACKGROUND

The following three studies have been the basis and starting point for the development of this work:

•**"Possibilities of lithium and potassium in saline deposits of Region II, Chile" (CORFO, 1978).** Preliminary survey of most of the salt flats in the Antofagasta Region, in which the possibility of the presence of lithium and potassium, among other elements, is evaluated through field and laboratory studies.

• **"Geochemistry of waters in closed basins: I, II and III Regions, Chile" (Risacher *et al.*, 1999).** Information for each of the salt flats and lagoons of the four northern regions of the country to date, with an appreciable amount of water analysis from the springs that feed these places and a basic study of the geochemical evolution of the waters in each salt flat. .

•**" Bibliographic report on the Norte Grande salt flats, Chile ”(Ercilla *et al.*, 2012).** Compilation of available information about the selected salt flats, referring to fundamental aspects of geology and the laboratory analyzes carried out to date.

METHODOLOGY

Stage 1: Compilation of information and selection of salt flats to study.

to) **Equivalent lithium content (mg / l)**

b) Extension of the salt area (km two)

c) Lithium / potassium ratio (Li / K)

Based on a study by SERNAGEOMIN (Gajardo and Carrasco, 2010) referring to 15 salt flats excluding Atacama, due to known potential.

Prioritization of pre-Andean and Andean salt flats as potential sources of lithium:

- ***Group I:*** **Maricunga, Pedernales, La Isla, Quisquiro**

  Li: 423-1080; area: 80-335 km two; Li / K: 0.08-0.18

- ***Group II:*** **Punta Negra, Aguas Calientes Center, Pajonales, Aguilar, Tara, Parinas, Pujsa**

  Li: 220-620; area: 18-250 km two; Li / K: 0.04-0.30

- ***Group III:*** **Aguas Calientes North, Talar, Aguas Calientes South South**

  Li: 205-290; area: 15-27 km two; Li / K: 0.03-0.24

METHODOLOGY

Stage 2: Validation of the available information, obtaining new geological information and obtaining samples of the waters and brines, and specific samples of the saline crust.

Field campaigns: April 03-15 and May 06-17, 2013; April 15-28, 2014.

Stage 3: Laboratory analysis of water samples and scab specimens.

•The mineralogy of the salt crust specimens was determined by means of RX diffraction and its chemical composition (ICP-MS); in total 56 elements were determined.

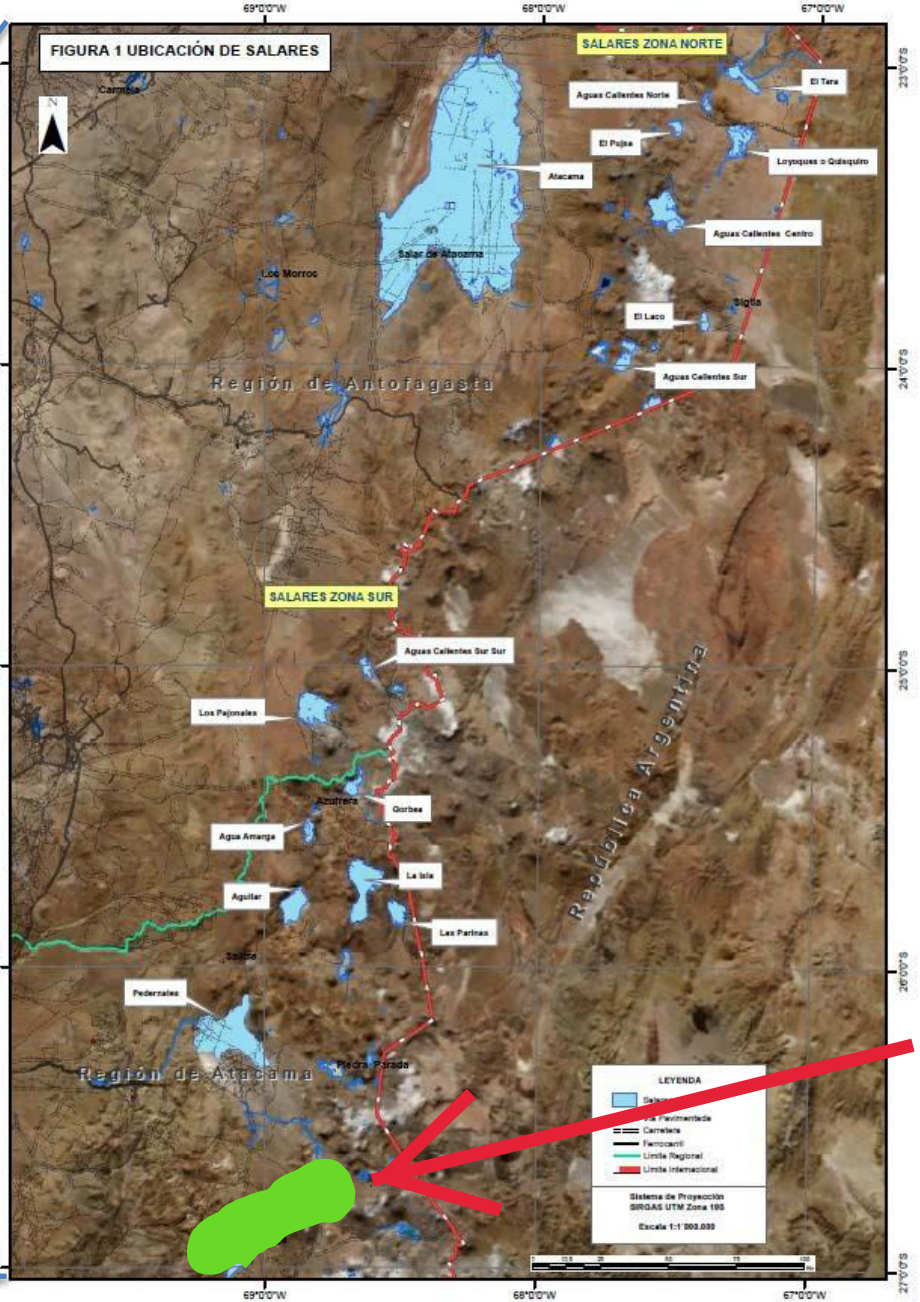
•The water samples were analyzed for major and trace elements (ICP-MS), and with emphasis on Li and K.

SALARIES STUDIED

SALARES NORTH ZONE

- Atacama
- Tare
- Aguas Calientes North or 1
- Pujsa
- Loyoques or Quisquiro
- Aguas Calientes Downtown or 2
- She co
- Aguas Calientes South or 3

LOCATION MAP SALARIES STUDIED



Salar Maricunga

TARE

Characteristics

- Li (mg / l): 3-440
- Crust area (Km_{two}): 48
- Li / K ratio: 0.07-0.81
- Li / Mg ratio: 0.16-0.97

LOYOQUES or QUISQUIRO

Characteristics

- Li (mg / l): 6-425
- Crust area (Km two): 80
- Li / K ratio: 0.17-3.32
- Li / Mg ratio: 0.13-0.18

AGUAS CALIENTES CENTRO or 2

Characteristics

- Li (mg / l): 5-45
- Crust area (Km two): 134
- Li / K ratio: 0.02-0.05
- Li / Mg ratio: 0.01-0.03

AGUAS CALIENTES SUR or 3

Characteristics

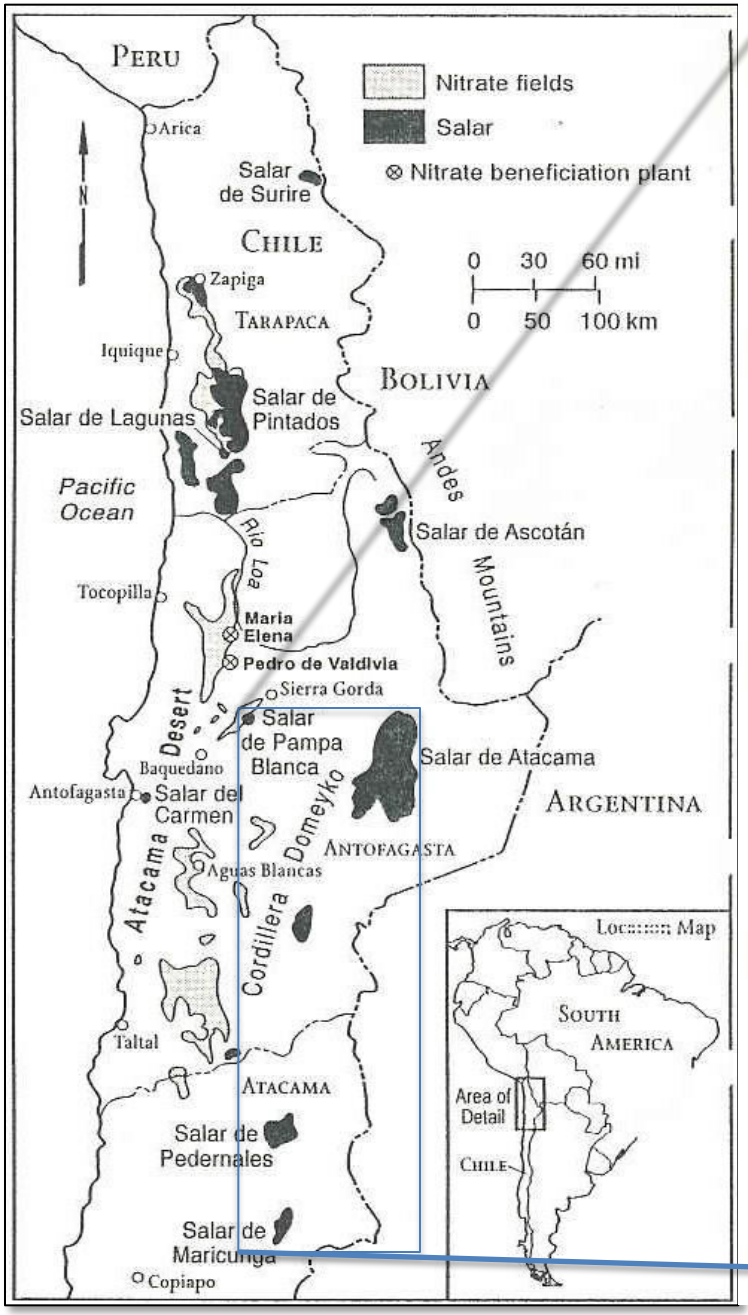
- Li (mg / l): 0.5-17.5
- Crust area (Km^{two}): 46
- Li / K ratio: 0.01-0.06
- Li / Mg ratio: 0.01-0.03

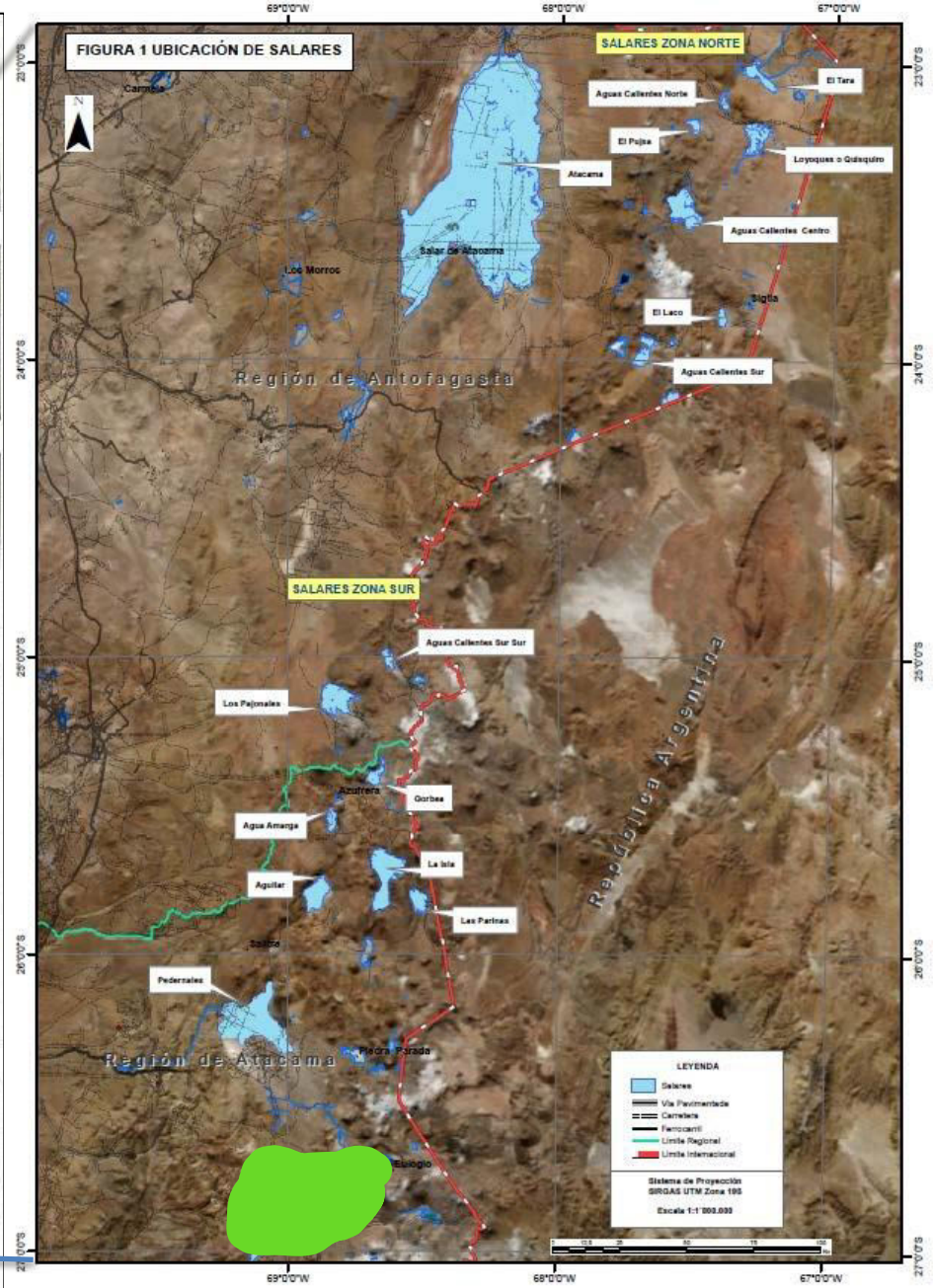
SALARIES STUDIED

SALARES SOUTH ZONE

- Aguas Calientes South South or 4
- Pajonales
- Gorbea
- Bitter water
- The island
- Aguilar
- Parinas
- Big
- Flints
- **Maricunga**

LOCATION MAP SALARS STUDIED





THE ISLAND

Characteristics

- Li (mg / l): 13-1,150
- Crust area (Km_{two}): 152
- Li / K ratio: 0.01-0.31
- Li / Mg ratio: 0.14-0.22

GORBEA

Characteristics

- Li (mg / l): 5-500
- Crust area (Km $_{two}$): 27
- Li / K ratio: 0.06-0.20
- Li / Mg ratio: 0.01

BITTER WATER

Characteristics

- Li (mg / l): 13.7-60.5
- Crust area (Km^{2}): 2. 3
- Li / K ratio: 0.03-0.08
- Li / Mg ratio: 0.01-0.05

AGUAS CALIENTES SOUTH SOUTH or 4

Characteristics

- Li (mg / l): 0.1-8.5
- Crust area (Km two): 19.5
- Li / K ratio: 0.03-0.04
- Li / Mg ratio: 0.01-0.09

SALARIES STUDIED

SALARES NORTH ZONE								
to Salt	Li (mg / L)		K (mg / L)		Li / K		Li / Mg	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Atacama	> 1,000	-	> 10,000	-	-	-	-	-
Tare	3	440	6	700	0.07	0.81	0.16	0.97
Aguas Calientes North	25	130	6.5	1,020	0.13	0.5	0.1	0.5
Pujsa	1	400	16	3,400	0.04	0.12	0.04	0.26
Loyoques or Quisquiro	6	425	22	1,650	0.17	3.32	0.13	0.18
Aguas Calientes Downtown	5	Four. Five	150	1,025	0.02	0.05	0.01	0.03
She co	two	32.5	95	1,850	0.02	0.03	0.01	0.06
Aguas Calientes South	0.5	17.5	45.5	900	0.01	0.06	0.01	0.03
SALARES SOUTH ZONE								
to Salt	Li (mg / L)		K (mg / L)		Li / K		Li / Mg	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Aguas Calientes South South	0.1	8.5	3	1,050	0.03	0.04	0.01	0.09
Pajonales	4.5	57.5	285	2,825	0.02	0.03	0.01	0.03
Gorbea	5	500	25	5,000	0.06	0.2	0.01	0.01
Bitter water	13.7	60.5	185	2,035	0.03	0.08	0.01	0.05
The island	13	1,150	42	108,000	0.01	0.31	0.14	0.22
Aguilar	350	375	2,600	2,600	0.14	0.14	0.05	0.06
Parinas	7	400	41	6,000	0.07	0.19	0.1	0.11
Big	4	123	176	2,770	0.0004	0.02	-	-
Flints	130	423	-	-	0.07	0.08	-	-
Maricunga	1	1,050	-	-	0.14	0.18	-	-

MINING CONCESSIONS

		Owner Concessions State	Resources	Potential	Surface of to Salt (ha)	EXPLORATION CONCESSIONS				OPERATING CONCESSIONS			
						Total P.M	P.M State. Code Miner from 1983	PM Code Miner of 1983	State PM (Code Miner of 1983) v/s Surface of the Salar	Total PM	P.M State. Code Miner, 1932	P.M State. Code Miner of 1932	State PM (Mining Code from 1932) v/s Surface of to Salt
					ha	ha	ha	%	%	ha	ha	%	%
SALARES NORTH ZONE	Atacama	Private, CORFO	Li; K	high	300,000	271,391	0	0%	0%	451,115	163,840	36.3%	54.6%
	Tare	Private	Li; B	half	4,800	6,400	0	0%	0%	0	0	0%	0%
	Hot Waters North	Private	Li; K	under	1,500	2,000	0	0%	0%	400	0	0%	0%
	Pujsa	Private	Li; K; B	under	1,800	0	0	0%	0%	800	0	0%	0%
	Loyoques or Quisquiro	Private	Li; K	half	8,000	0	0	0%	0%	9,246	0	0%	0%
	Hot Waters Center	Private	Li; K	high	13,400	1,100	0	0%	0%	13,700	0	0%	0%
	She co	Private	Li	under	1,620	600	0	0%	0%	9,453	0	0%	0%
	Hot Waters South	Private	Li	under	4,600	21,499	0	0%	0%	0	0	0%	0%
	Subtotal				335,720	302,990	0	0.0%	0.0%	484,714	163,840	33.8%	48.8%
SALARES SOUTH ZONE	Hot Waters South South	Private	Li	under	2,000	3,000	0	0%	0%	2,800	0	0%	0%
	Pajonales	Private	Li; K; B	high	10,400	8,500	0	0%	0%	11,795	0	0%	0%
	Gorbea	Private	Li; K; B	under	2,700	8,700	0	0%	0%	4,353	0	0%	0%
	Bitter water	Private	Li; K; B	under	2,300	11,200	0	0%	0%	3,100	0	0%	0%
	The island	Private	Li; K	high	15,200	20,199	0	0%	0%	16,499	0	0%	0%
	Aguilar	Private, ENAMI	Li; K	half	7,100	11,300	0	0%	0%	8,765	300	3%	4%
	Parinas	Private	Li; K	half	4,000	4,100	0	0%	0%	5,400	0	0%	0%
	Big	Private	Li; K	under	2,900	8,900	0	0%	0%	4,150	0	0%	0%
	Flints	Private, CODELCO	Li; K	high	33,800	27,799	3,200	12%	9%	82,207	56,281	68%	167% *
	Maricunga	Private, CODELCO	Li; K	high	14,500	16,499	0	0%	0%	24,584	2,682	eleven%	18%
	Subtotal				94,900	120,197	3,200	2.7%	3.4%	163,653	59,263	36.2%	62.4%
	Totals				430,620 423,18	7	3,200	0.8%	0.7%	648,367	223,103	34.4%	51.8%

* There is overlap in mining exploitation concessions; PM = mining property; ha = hectares

CONCLUSIONS

Concentrations in Brines

- The highest concentrations of lithium were detected in the salt flats of the South Zone, confirming its high potential as a source of this element. Eg Salar de La Isla: concentrations over 1,000 mg / l of lithium in brines.

- In brines from the Tara, Loyoques and Pujsa salt flats, in the Northern Zone, lithium concentrations were detected with values of up to 440 mg / l.

- In general, high concentrations of lithium in water correspond to those of boron, potassium and magnesium, in a non-linear and variable relationship between the different salt flats.

Concentrations in Salt Crust

- Numerous samples of the saline crust of the Northern Zone indicate lithium contents over 200 ppm, the Aguas Calientes Norte salt flat, and even over 1,000 ppm, the Tara salt flat.

- In the South Zone, high concentrations of lithium (> 200 ppm) are recognized in the saline crusts of the Gorbea, Parinas and Isla salt flats, indicating that in salt flats with a lithium-rich saline crust, their brines are also.

CONCLUSIONS

Mining Concessions

- The entire surface area covered by the studied salt flats has mining exploitation and / or exploration concessions from private and state companies.

- The State of Chile, through CORFO, ENAMI and CODELCO-CHILE, maintains mining concessions in the areas of the Atacama, Aguilar, Pedernales and Maricunga salt flats.

- All of the exploration concessions in force as of 2013 (423,187 ha) are regulated by the 1983 Mining Code, and of it, only 0.8% is in the hands of the State (3,200 ha) (CODELCO-CHILE in the Salar de Pedernales).

- The exploitation concessions in force to date, reach 34.4% (223,103 ha), and have been granted according to the Mining Code of 1932; all are in the hands of state agencies.

- CORFO controls 36.3% of the mining property and covers 54.6% of the surface of the Salar de Atacama, while ENAMI owns 3% of the exploitation concessions in the Salar de Aguilar, and CODELCO-CHILE maintains the 100% and 18% of the exploitation concessions in the Pedernales and Maricunga salt flats, respectively.

- If only the total area of the salt flats included in this study is considered, the State exploitation concessions cover 51.8% of this.

CONCLUSIONS

Reserves and Potential

- The Atacama salt flat contains the largest lithium reserves in the country; Recent estimates made by the Chilean Chemical and Mining Society (SQM) indicate 6.3 million tons of lithium, based on the confirmation of the presence of brines at 200 m depth.

- For its part, the United States Geological Survey indicates for Chile reserves of 7.5 million tons of lithium, mostly concentrated in the Salar de Atacama.

- According to the relationship between:

  > the lithium concentration (mg / l) in brines,

  > the lithium / potassium ratio,

  > the surface of the salt flat (km two),

  the salt flats that present potential half Y high for lithium they are:

  > North Zone: Tara and Loyoques; Atacama and Aguas Calientes Centro, respectively.

  > South Zone: Aguilar and Parinas; Pajonales, La Isla, Pedernales and Maricunga, respectively.

- To know the resources and reserves, and to complete the determination of the potential as a source of lithium in these salt flats, it is necessary to know the depth of the brines.

GENERAL CONCLUSIONS

- Chile has significant potential in lithium and potassium resources, mainly in its pre-Andean salt flats, with reserves of up to 7.5 Mt Li.

- These salt flats have important comparative advantages for their exploitation, especially due to both the concentration of saline compounds of interest in their brines, and the high evaporation rates.

- So far, only the Atacama salt flat has supported the production of lithium and potassium compounds, but the Maricunga and Pedernales salt flats also contain resources of interest in terms of concentration and volume.

- Regarding the Andean salt flats, their real potential in lithium is not yet known, although the studies carried out so far by SERNAGEOMIN allow them to be assigned degrees of potential, based on factors and criteria that are decisive to define such condition.

- Consequently, it is necessary to carry out studies to determine the resources and reserves of lithium and potassium contained in these salt flats, as well as the real comparative advantages for their exploitation by resources saline, considering, especially, factors geological, climatic and environmental.

Thanks

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