MINERALOGY AND GEOCHEMISTRY OF THE SALAR GRANDE SALT ROCK (I Región de Tarapacá, Chile). GENETIC IMPLICATIONS

Javier GARCIA-VEIGAS[(1)], Guillermo CHONG[(2)] and Juan José PUEYO[(3)]

[(1)] Serveis Científico-Tècnics. Universitat de Barcelona. Zona Universitaria de Pedralbes. 08028 Barcelona.
[(2)] Departamento de Geología. Universidad Católica del Norte. Avda.Angamos, 6810. Casilla 1280. Antofagasta.
[(3)] Facultat de Geología. Universitat de Barcelona. Zona Universitaria de Pedralbes. 08028 Barcelona.

KEYWORDS: salar, halite rock, halite textures, minor elements, interstitial brines, paleohydrology.

INTRODUCTION

The Salar Grande (Fig. 1), located about 80 km at the South of Iquique (70°00' W, between 20°45' and 21°45' S latitude), is the only significant intermontane evaporitic basin in the Coastal Range of Chile. It is some 45 km long (in N-S direction) and 5 km wide. The altitude of the salar surface ranges from 640 to 750 m.a.s.l.

The salar basin is located in a tectonic depression controlled by one branch of the Atacama Fault System. This fault controls the Salar Grande basin on the SE, W, and NW edges. The fault generates several blocks (in the northern part of the salar) displaying level differences of several hundreds of meters. The Atacama Fault cuts the salar obliquely, producing a sharp scarp. E-W faults control the eastern edge, generating creeks perpendicular to the salar shoreline.

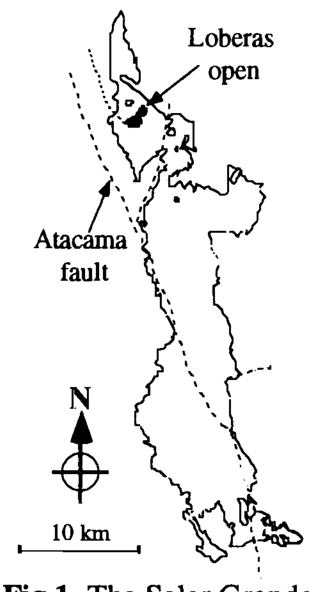


Fig.1. The Salar Grande

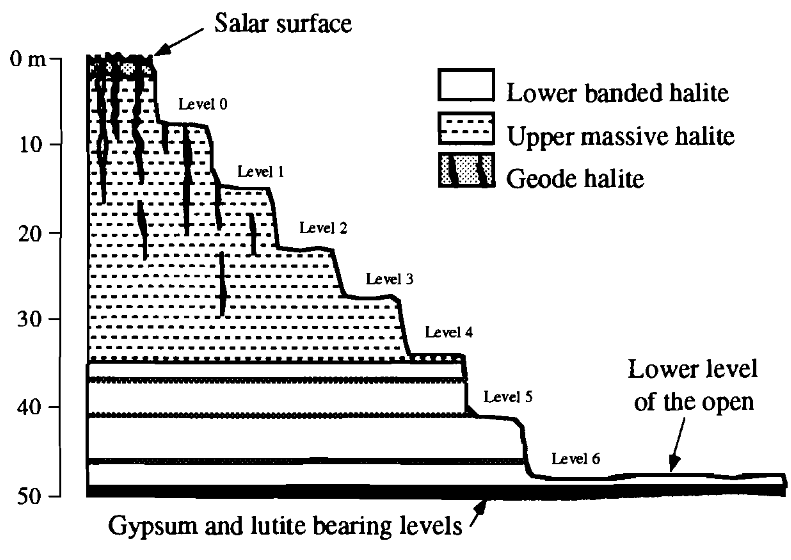
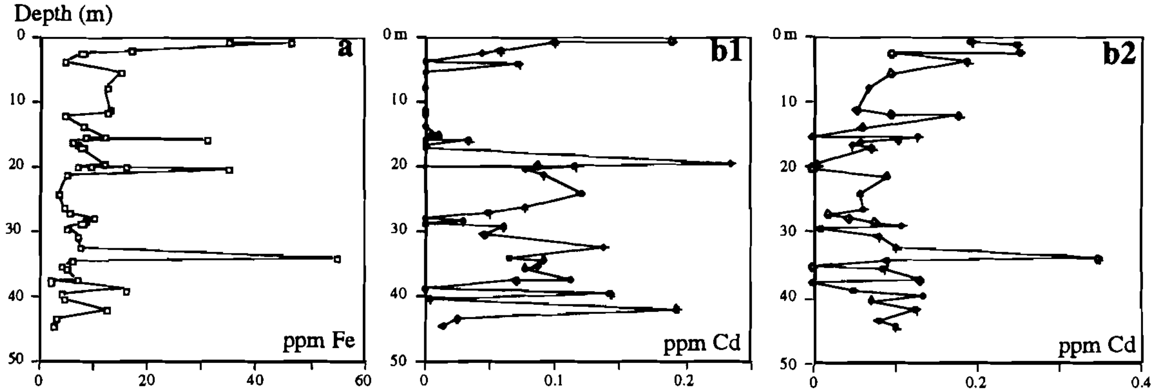


Fig. 2. Mina Loberas. North end of Salar Grande.

The Salar Grande, still not covered by younger sediments, is an ancient salar (Chong, 1984) that has lost its brines and whose sedimentary infill is composed of very pure halite, with very scarce amounts of sulphates, and no clear evidence of bull-eye facies distribution, as expected in a salt lake. The salar surface shows thick saline crusts with polygonal cracks. The effects of deflation, dissolution, and capillar processes (produced by the effect of local fog *-camanchaca-*) are evident. Large blocks, probably related to substrate fractures, are visible in aerial and satellite images.

BASIN INFILL CHARACTERISTICS, MINERALOGY, AND PETROLOGY

Several open pits (mainly in the northern part) and four boreholes (made towards the center and the southern part) are the only available sources of information about the substrate composition of the salar. These sources reveal that their sedimentary infill is composed of a massive halite body, reaching about 100 m in thickness. Their composition is homogeneous, without significant detrital (or other) sediments. The extremely scarce interlayers (cm- to mm- thick) are black and brown altered volcanic ashes.



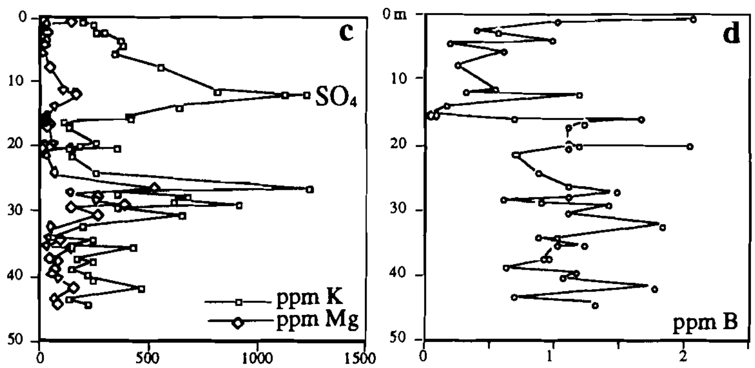


Fig. 3. Metal concentration profiles. **a** and **b2** have been obtained by extraction with N HCl, and **b1**, **c** and **d** using distilled water. In **c**, SO_4 corresponds to an increase in sulphates (thenardite, polyhalite).

The salt body outcropping in the open pits of Salinas Punta de Lobos (northern part of the salar) (Cabrera *et al.*, 1995) is about 45 m thick. Beneath it, fine clastic sediments of volcanic origin, bearing gypsum and halite cement, are present. In its lower 10m the salt body displays a thinly banded structure (*lower banded halite*, LBH). The bands or cycles (1 to 2 cm thick) are formed by chevron-like halite crystals, cm- to mm- in size. Cycles are separated by dissolution surfaces that smooth or truncate the chevron apex. Very few sulphate minerals (mainly glauberite, thenardite and polyhalite, µm-sized) and clays are present along these dissolution surfaces as well as interstitially between the halite crystals. Towards the upper part, the halite crystal aggregates evolve to coarse (reaching several cm in size), disoriented, and masive (*upper massive halite*, UMH), becoming more brownish due to the presence of interstitial terrigenous material. Euhedral thenardite crystals (cm in size) are common on levels 2 and 3 (Fig. 2). Thenardite crystals act as a diagenetic cement, replacing halite and displaying poikylitic growths and solid inclusions of glauberite, clay, and micrite. Polyhalite is the most abundant sulphate, always related with grain boundaries and dissolution surfaces. The transition between lower and upper halite units is made through a several-meter-thick interval displaying alternances of both lithofacies. Moreover, synsedimentary halite, another generation of very coarse grained (until 50 cm in size), masive, extremely pure halite, is present as pockets (reaching tens of meters in diameter). Large halite crystals infill the pockets following a geode-like arrangement. Some levels, bearing isolated thenardite crystals (until 5 cm in size) are present in the UMH. The entire salt body is affected by cracks. The lateral edges of the salt body are affected by dissolution and encrustment; the salt rock is in direct contact with the substrate rocks. No concentric mineral pattern is evident. Nevertheless, anhydrite levels (some meters thick) displaying selenite gypsum pseudomorphs (reaching some decimeters in size) are present on the SE and S margins. At the SE end of the salar there is an anhydrite level located at the top of the salt body which continues eastwards towards the Salar de Llamara. There is no physical continuity (only in sulphate lithofacies) between these two salars.

GEOCHEMICAL DATA OF ROCK SALT

Minor and trace elements

Twenty-six elements (Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Ni, P, Pb, S, Se, Si, Sr, Ti, V and Zn) have been determined in 50 salt rock samples scattered along a vertical section (Fig.2; Mina Loberas section) of the salt body. PCA performed on this analytical dataset reveales three well defined correlation factors. The first factor (involving Al, Fe, Mn, P, Si and Ti; Fig. 3a) is related to the particulate silicate fraction (eolian dust, volcanic ash, terrigenous material) always mixed in minor amounts with rock salt. The second factor (involving As, Cd, Co, Cr, Cu, Ni, Pb, Se, V and Zn; Fig. 3b) is strongly related to sulphide ore (leachate) inputs entering the salar through the hydrologic system. The third factor (involving B, Ca, K, Li, Mg and Sr) is mainly related to minor amounts of accessory saline minerals (glauberite, thenardite, polyhalite; Fig. 3c) and to the interstitial brines (Fig. 3d) present as fluid inclusions in the halite.

Fluid inclusion composition

The LBH displays a number of primary (synsedimentary) fluid inclusions in its chevron-like halite crystals whereas the UMH only shows grain boundary fluid inclusions. Cryo-SEM-EDS analysis (Ayora *et al.*, 1994a) were performed on the primary fluid inclusions of the banded halite of the LBH and on a sample of a banded halite alternance located in level 4 (Table 1).

Sample-m	Na	Mg	SO_4	Cl	K	Sat. Ind.
181-27,00m	5.65	0.39	0.90	5.48	0.63	-0.0279
188-27,90m	5.71	0.40	0.89	5.41	0.62	-0.0469
263-35,80m	5.66	0.37	0.82	5.56	0.58	-0.0282
287-37,70m	5.62	0.33	0.83	5.60	0.59	-0.0523
317-41,10m	5.18	0.49	0.97	5.15	0.70	-0.0301
340-44,50m	5.21	0.50	0.76	5.83	0.77	-0.0488

Table 1. Average contents of solutes (mol/kg H_2O) in fluid inclusions.

The brine chemical composition is very homogeneous. This implies that during the sedimentation of the Salar Grande halite, the parental brines reached a steady-state without significant changes in their solute content.

Brines are of the $Cl-SO_4-Na-K$ type, very rich in SO_4 and depleted in Mg y Ca. The high concentration of SO_4 is explained by the kind of imputs entering the basin (recycled volcanic S) and by the extremely low Ca content in the brine. More Ca give rise to an increase of sulphate mineral (gypsum, anhydrite or glauberite) precipitation. When Ca is lacking, dissolved SO_4 increases by evaporation trending to saturation in thenardite. Nevertheless, halite saturation was reached before, lowering the Na concentration of the brines. K is also very abundant in the Salar Grande brines, being similar to that measured in halite samples from marine potash salts (Ayora *et al.* 1994b).

Sample	Halite	Sylvite	Thenardite	Glauberite	Anhydrite
181	-0.07	-0.68	-0.11	-0.16	-0.64
188	-0.07	-0.69	-0.10	-0.18	-0.67
263	-0.07	-0.70	-0.13	-0.19	-0.67
287	-0.07	-0.70	-0.13	-0.18	-0.64
317	-0.16	-0.67	-0.18	-0.27	-0.68
340	-0.06	-0.54	-0.22	-0.26	-0.64

Table 2. Mineral saturation index of brines.

The mineral saturation index data (Table 2) implies that parental brines trapped in the Salar Grande halite are in equilibrium with halite and thenardite. Sylvite subsaturation is due to the high Na concentration that had led previously to halite precipitation. Assuming a Ca concentration of 0.001 mol/kg H_2O (under the detection limit of the *cryo-SEM-EDS* analytical method used), brines are close to saturation in glauberite and clearly subsaturated with respect to anhydrite.

SEDIMENTOLOGICAL AND PALEOENVIRONMENTAL IMPLICATIONS

Halite lithofacies infilling the salar (LBH and UMH) implies the following paleohydrological evolution: (1) Early environments with cm-deep free brines showing banded halite with piramidal (*chevron*) texture. Dissolution surfaces indicate the ephemeral character of brines and the alternance of dessication and inundation stages. (2) A change to environments where brines are mostly in pore position, generating displacive halite (and thenardite) facies. This fact reveals a hydrological evolution where the amount of brine becomes gradually smaller. Halite is the only sedimentary product of precipitation. Thenardite, glauberite and polyhalite are early diagenetic precipitates developed in dissolution pockets and grain boundaries.

The type and distribution of facies, and the salar geometry, suggests that the salar underwent fracturation, brine losses, and surface erosion, the latter implying partial or total elimination of marginal and surficial facies. Nevertheless, the marginal facies preserved in S and SE edges are poorly developed. This, and the extreme purity of the halite body, implies evolved parental brines. Pore brines trapped as fluid inclusions show high potassium and sulphate contents, being saturated as regards halite and thenardite (and nearly saturated concerning glauberite). Ca-depletion was generated by precipitation of calcium sulphates. The waters coming from the Puna, moved towards the Central Depression which in turn acted as an endorreic system, making the Salar Grande basin the final container for the most evolved (Ca-depleted) brines. The Salar Grande basin was originally connected with the Central Depression at its SE edge. Their disconnection is probably related to recent movements of the Atacama Fault System. The absence of significant terrigenous levels indicates a dominant underground recharge.

The content and distribution of minor elements through the salt body reflects the inputs entering the salt lake: 1) Terrigenous inputs growing towards the upper part (Fig. 3a) indicating a progressive increase of interstitial processes; 2) Trapped brine content (as fluid inclusions in halite) higher in the lower part of the series (LBH, Fig. 3d), and sulphate minerals higher towards the upper part of the salt body (Fig. 3c) reflecting the halite facies distribution; 3) Trace metals present in rock salt in two forms: one, extractable with distilled water (Fig. 3b1), probably related to fluid inclusions, and another extractable with N HCl, binded to terrigenous inputs.

Acknowledgments. We are indebted to the Minera Punta de Lobos Company (Chile), for helping us with sampling and general field work. We also wish to thank Frances Luttikhuizen for her help with the English draft of this paper. Analytical work (ICP and *crio*-SEM-EDS determinations) were performed in the Scientific-Technical Surveys division of Barcelona University. This research was carried out thanks to the EC contract n: CI1*-CT94-0069 (DG 12 HSMU).

REFERENCES

Ayora, C.; García Veigas, J. and Pueyo, J.J. 1994a. X-ray microanalysis of fluid inclusions and its importance to the geochemical modeling of evaporite basins. *Geochimica et Cosmochimica Acta*, 58, 43-55.

Ayora, C.; García Veigas, J. and Pueyo, J.J. 1994b. The chemical and hydrological evolution of an ancient potash-forming evaporite basin as constrained by mineral sequence, fluid inclusion composition, and numerical simulation. *Geochimica et Cosmochimica Acta*, 58, 3379-3394.

Cabrera, Ll.; Chong, G.; Jensen, A.; Pueyo, J.J.; Sáez, A. and Wilke, H.G. 1995. *Cenozoic and Quaternary lacustrine systems in northern Chile (Central Andes, Arc and Fore-Arc zones).* Recent and Ancient Lacustrine Systems in Convergent Margins. GLOPALS-IAS Meeting (Antofagasta 12-18th November 1995). Excursion Guidebook. 77 p.

Chong, G. 1984. Die Salare in Nordchile. Geologie, struktur und geochemie. *Geotek. Forsch.*, 67, 146p.