Preliminary Hydrochemical Characterization of the Lagoons of "Los Flamencos" National Reserve (Salar de Atacama, Chile)

/ JORGE MARTÍNEZ SOLER (1), PATRICIA ACERO SALAZAR (1), JOAQUÍN SALAS NAVARRO (2), LUIS FRANCISCO AUQUÉ SANZ (1)*

(1) Earth Sciences Department, University of Zaragoza, c/Pedro Cerbuna 12, 50009 Zaragoza (Spain)
(2) Centro de Estudios Avanzados en Zonas Aridas, Campus Andres Bello, Colina El Pino, La Serena (Chile)

INTRODUCTION

The Salar de Atacama is a closed evaporite basin located in the Pre-Andean Depression in the NE of Chile (Fig. 1A). Although the Salar de Atacama is placed in the most arid region of the world, a system of wetlands and lagoons is developed along its E margin, inhabited by a wide variety of wildlife. In order to preserve the environmental value of this delicate system, the processes and factors controlling its hydrochemical evolution must be identified and evaluated. With this purpose, hydrochemical data from some of the main lagoons of the area have been interpreted in this work with the assistance of geochemical modeling.

GEOLOGICAL SETTING

The study has been focused on the Soncor system as the main ecosystem placed within the "Los Flamencos" National Reserve. This system mainly consists of two main lagoons - Chaxa and Barros Negros - linked and fed by the Burro Muerto channel (Fig. 1B). Apart from this channel, the lagoons (and the channel itself) are thought to receive some contribution of surface and groundwaters mainly from their E-SE margin (Salas *et al*., 2010). The Soncor system is placed between the deposits of alluvial fans coming from the Andean Cordillera and the evaporitic crusts of the Salar core (Fig. 1C). The mineralogy in the study area mainly consists of sulphates, carbonates and aluminosilicates, with scarce amounts of disperse halite and possibly other chloride phases.

METHODOLOGY

The hydrochemical data have been provided by the DGA (Dirección General de Aguas de Chile) from the environmental monitoring programs developed by mining companies. To help interpret these data, solubility calculations and reaction-path modeling has been carried out using the PHREEQC code (Parkhurst and Appelo, 2013). Given the concentrated character of the studied waters, the geochemical calculations have been done using the Pitzer ion interaction approach with a modified version of the pitzer.dat thermodynamic database distributed with the PHREEQC code.

RESULTS AND DISCUSSION

The waters from the lagoons of the Soncor system are Na-Cl type, slightly alkaline (pH generally between 7 and 8) and very concentrated, with contents of Total Dissolved Solids (TDS) varying from 70 to 370 g/L. Average Cl and Na values are around 70 and 35 g/L, respectively, although larger contents for these and the rest of major ions are generally reached during the summer seasons. Most waters are undersaturated with respect to halite and mirabilite, equilibrated with respect to gypsum and oversaturated with respect to calcite and dolomite. Calculated partial CO_2 pressures are well above the atmospheric value, with average values close to $10^{-2.5}$ atm.

As shown in Fig. 2A, Cl and Na contents are closely correlated in the Soncor waters and the average stoichiometric Na/Cl ratio is around 0.8. Since the whole system presents this feature, the observed stoichiometry seems to be inherited from the recharging groundwaters, for which similar ratios have already been reported (Salas et al., 2010). Although the most apparent origin for this Na-Cl correlation would be the dissolution of halite, this mineral is scarcely present in the sediments and evaporitic crusts towards the E-SE of the system, from where most of the

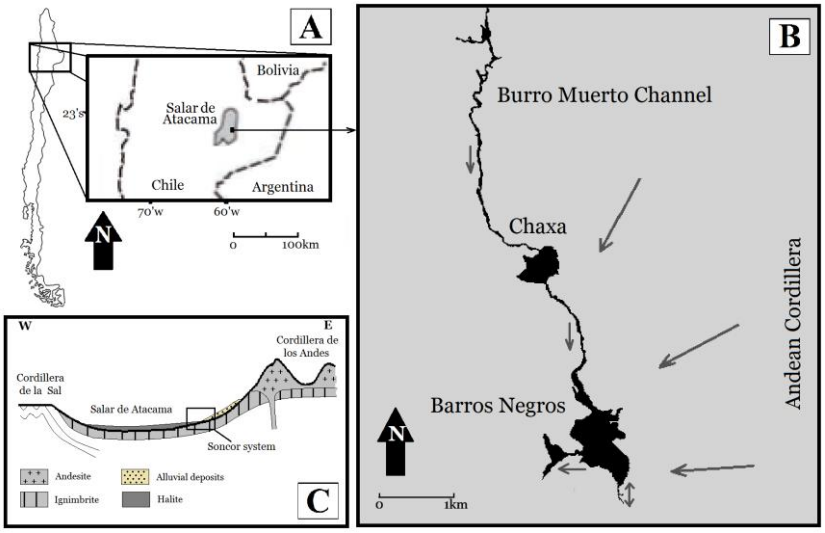

fig 1. *A. Sketch of Chile and localization of Salar de Atacama and Soncor System, modified from* Salas *et al*, 2010. *B Sketch of the Soncor system, with the main water bodies and deduced flow directions (arrows). C. Cross section from Cordillera de la Sal to Cordillera de los Andes, showing andesitic materials in Cordillera de los Andes, detritic materials and the filling of the Atacama Basin.*

palabras clave: Sistema Soncor, agua subterránea, evaporación, modelización geoquímica

key words: Soncor System, groundwater, evaporation, geochemical modelling

* corresponding author: **patriace@unizar.es**

recharging waters are thought to come. A possible explanation for the observed correlation would be the progressive solute concentration by evaporation.

As displayed in Fig. 2B, Cl concentrations and their temporal evolution in Burro Muerto channel and Chaxa lagoon are generally very similar and the same pattern is followed by the rest of major ions (not shown). This is consistent with the fact that the main inputs to Chaxa lagoon are via Burro Muerto channel. In contrast, the dissolved contents of major elements in Barros Negros lagoon are clearly higher and describe much stronger seasonal variations, with the highest contents during the summer season (December-March). A possible explanation for this behavior, which is also observed in the Barros Negros channel and the Chaxa lagoon (although much weaker), would be the concentration by evaporation.

In order to test the feasibility of this hypothesis, reaction-path evaporation simulations have been carried out for the Chaxa and Burro Muerto lagoons. These simulations have been done taking as initial water compositions the ones corresponding to the samples with the lowest dissolved contents (from the winter season) and evaporating them until Cl contents reach similar values to the measured ones in the samples with the peaking contents (at summer season). At that point, the simulated concentrations of the rest of elements have been compared with their corresponding measured values in the summer samples after evaporation. During the simulations, which were developed for the data from 2010, 2011 and 2012, the precipitation at oversaturation of gypsum, halite, calcite, sepiolite and mirabilite was allowed.

The results obtained in these simulations indicate that evaporation proportions between 6 and 33% for Chaxa and between 40 and 89% for Barros Negros are needed to justify their measured Cl contents during the summer season just by evaporation. For Chaxa, such proportions could be consistent with the field observations. On the contrary, the evaporation proportions obtained for Barros Negros would imply, in some cases, the almost complete desiccation of the lagoon, which has never been observed nor reported in earlier works.

Moreover, although the evaporation simulations produce similar contents of some of the dissolved elements to the measured values, other concentrations cannot be fully accounted for (Figs. 2C and D, for Barros Negros and Chaxa, respectively). This is especially evident for the sulphate contents, which are two to three times lower in the simulations than in the measured values. Thus, additional input for this element is required. Two main sulphate sources could contribute to explain the high measured sulphate values: 1) input of sulphate-rich groundwater from the E margin of the Salar, as suggested by Salas *et al.* (2010) mainly for Barros Negros, and/or 2) dissolution of other hypothetical mineral phases not taken into account in the evaporation simulations. In order to test the validity of these two (alternative or complementary) hypotheses, further studies and modeling exercises should be carried out in the future.

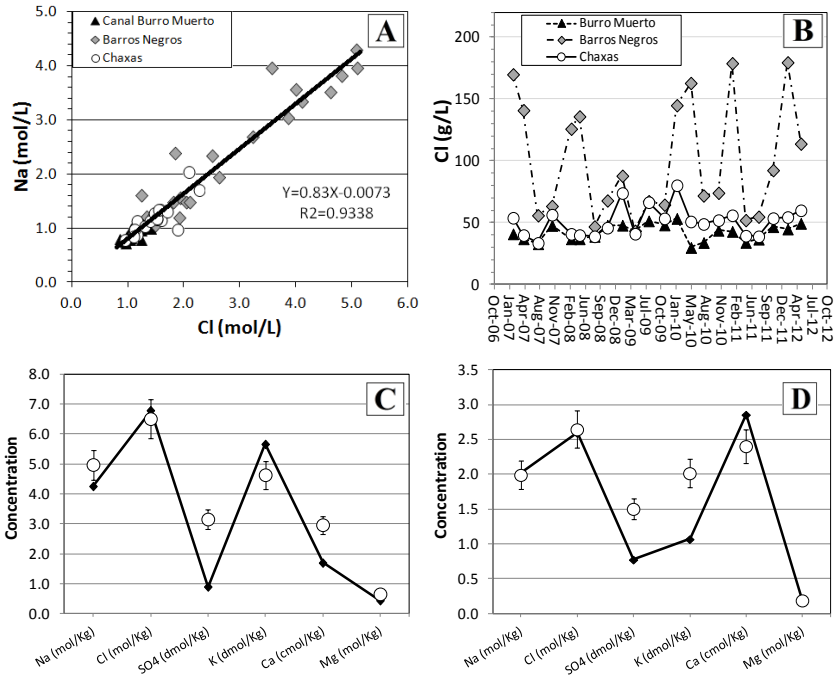

fig 2. *A) Evolution of Cl contents in the main water bodies of the Soncor system, from October 2006 to October 2012. B) Na-Cl molar correlations in the same waters. C and D) Comparison between measured (white dots) and simulated (geochemical model of evaporation; black line) contents for the major ions, both in the Barros Negros (C) and in the Chaxa lagoon (D). Bars in white dots represent a 10% uncertainty.*

CONCLUSIONS

The preliminary characterization of the hydrochemistry of some of the water bodies of the Soncor system has allowed identifying their evolution patterns, the differences in their seasonal behavior and some of their possible geochemical controls. Moreover, the results obtained in evaporation simulations suggest that the evaporative processes, although probably very important in the Soncor system, do not fully justify the elemental concentration peaks observed in the Chaxa and Barros Negros lagoons during the summer season. Some alternative processes (dissolution of additional mineral phases, input of concentrated groundwaters) have been hypothesized, which will have to be examined further in future studies.

ACKNOWLEDGEMENTS

This study is being carried out in the framework of the ProEcoServ project (www.proecoserv.cl), funded by the UNEP (United Nations Environment Programme). We would like to express our gratitude to DGA, for providing the hydrochemical data and the access to complementary information.

REFERENCES

Parkhurst, D.L., and Appelo, C.A.J. (2013): Description of input and examples for PHREEQC version 3—A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations: U.S. Geological Survey Techniques and Methods, book 6, chap. A43, 497 p.

Salas, J. Guimerà, J. Cornellà, O. Aravena, R. Guzmán, E. Tore, C. von Igel, W. and Moreno, R. (2010): Hidrogeología del sistema lagunar del margen este del Salar de Atacama (Chile). Boletín Geológico y Minero, 121 (4): 357-372.