CHISA

CHISA 2000

CHISA 2000, 14th International Congress of Chemical and Process Engineering, Praha, Czech Republic.

APLICATION OF ION INTERACTION MODEL DEVELOPED BY PITZER TO NATURAL SALINES WATERS: PREDICTION OF THE ACTIVITY COEFFICIENT AND RELATED PROPERTIES

I. Garcés M.

E-mail: igarces@uantof.cl
Depto. de Ingeniería Química. Universidad de Antofagasta
Avda. Angamos 601, Antofagasta, Chile

Keywords: activity coefficients, Thermodinamic of electrolites, Geochemistry of natural brines, Pitzer`s ecuations

ABSTRACT

The ion interaction model developed by Pitzer (1973), has been applied to the natural brine of Surire Salar`s. The physico-chemical processes, including the solubility or deposition of various salts, can to be determined by the ionic composition of the solutions. The solubilities of minerals in brines and activitiy coefficients can be calculated from thermodinamic considerations. But this is difficult largely because the solubilities of many salts become highly dependent on the solution composition when the concentrations of other solutes increase.

The Surire salar`s is a saline system which maintains characteristics typical of the andean deposits, of the Na-Cl-SO_4 type with near-neutral brines. Most ions display distinct trends with increasing salinity. The mineralogic composition of this salar is mainly composed of ulexite and sodium sulphate, both with significant reserves y halite and gypsum subordinate. The principle geochemical process controlling lake chemistry is evaporative concentration, other process are operating but lesser extent mineral precipitation and dissolution, organic reducction.

The salt basin has a plane surface, formed by soluble saline material which were originated from precipitation of salts from brines concentrated by evaporation, including principally borates, sulfates, chlorides and subordinate carbonates. At the extreme southeast of the salar occur geyser-type springs of elevated temperature. There are no permanent water flows draining over the surface, but during summer the Surire River may reach the salar from the south.

The samples were obtained from exploration in salar of Surire. Temperature, pH, density were determined in the field. The cations and anions were determined by standart protocol. The solid samples and sediment were analized too. The anionic relation found for the brines was $Cl^{-}>SO^{-2}_{4}>HCO^{-}_{3}>BO_3^{-3}>NO_{3.}$ and for the cationic relation $Na^{+}>K^{+}>Mg^{+2}>Ca^{+2}>Li^{+}>Sr^{+}>As^{+3}>Rb^{+}$.

The results of the calculations of ionic activity coefficients for major ions are presented. The ionic strengh varies between 0.008 molar and 5.03 molar. The conduct of ion activity coefficients in function of the concentration can be divided into two patterns. The first group contains the ion activity coefficients of Na^{+}, Mg^{+2}, Ca^{+2} and Cl^{-}, which pass through a minimun after an initial drop. The second group contains the ion activity coefficients of SO_4^{-2} and HCO_3^{-} characterized by present a progressive conduct to decrease with the concentration.

INTRODUCTION

Chile is actuality the world's most important producer of natural salt, p.e. $NaNO_3$, KNO_3, $LiCO_3$, NaCl, I_2 (the Chilean exports of industrial minerals contribute with US$ 302 million, while the mining exports total is of US$ 8406,4 millions). The industrial mineral are obtained from deposits of saline solutions located in this region. If demand of other type of salt continues to increase as it has been in the last decade, new others mining operations will be initiated and more saline deposits will be exploted. Economical interest, mainly for the obtention of boron, iodine, lithium and nitrates from the brines it has generated descriptive studies of some salar *Risacher and Fritz* (*1991*), and *Risacher* (*1992*) at the Bolivian Altiplano Andino and *Alpers and Whittemore* (*1990*), *Risacher and Alonso* (*1996*), *Garcés* (*1996, 2000)* in the Chilean Altiplano.

The Northeast Chilean Altiplano is a volcanic area wich contains numerous undrained basins occupied by playas and saline lakes, named salars. It is a wide closed basins extends over 10.000 km^2, located between Cordillera de la Costa and Cordillera de los Andes. The Cordillera de los Andes is mostly volcanic in origin. Many factors related to tectonics, vulcanism and climatic condition among others, favouring conditions for the deposition of salts.

There are many studies of properties physics-chemistries of natural waters of commercial interest. It is been interrelated with the salinity of the system Krumgalz and Millero (1982), Steinhorn et al. (1979), Steinhorn and Assaf (1980) or processes of precipitation, Ben-Yaakov and Saas (1977) thermodynamics studies.

An understanding of nature and variability of this lake water composition and salinity is essential to ensure optimum manegement from its resources. Therefore, the chemical and mineralogical characterization of these salar become of first relevance. In this context, the objectives of the work are

i) to present a brief description geochemical characteristics of saline deposits.

iii) to examine physical chemistry characteristics of natural evaporites and some aspects related with application of Pitzer model to natural waters.

SURIRE SALAR\`S

The Surire salar\`s is located northeast of Chile at 18º 53\`S and 69º 03\`W at an altitude of 4300 m with a 140 km$^2$ closed basin. The most caracteristic of Surire\`s salar is in the central part because emerges the volcan Oquecollo to a height of 70 m on the surface cutting the saline cover.

The salar receives water from two form, meteoric and groundwater, creating a very shallow body of brine in the southcentral area. The region is semiarid with an average annual rainfall of about 230 mm. During the rain season the salar may be brine covered to a depth of 20 cm, but during the dry season the brine water table in the dry season cements the upper crust pores. There are number of saline thermal springs located on all southeast border of salar. Almost all the time the river is dry up during the dry season. This suggest that it is fed mainly by atmospheric precipitation. Each year rain water partially recharges ground water system wich in turn discharge in topographic depressions. Such waters don\`t undergo deep circulation, wich would put them in contact with ancient evaporites. They owe their composition almost exclusive to the weathering of the volcanic rocks and the re-solution of ancient buried evaporites.

The mean annual air temperature is estimated between 10-15º C. Air temperature ranges from –15º C in winter to 20º C in summer. Daily variations may reach 35º C. The potencial evaporation is high 2500 mm/y.

TEORICAL ASPECT

The physico-chemical processes, including the solubility or deposition of various salts, are known to be determined by the ionic composition of the solutions. The solubilities of minerals in brines can be calculated from thermodinamic considerations, provided the equilibrium constants are known and activitiy coefficients can be obtained. The prediction of salt solubilities is difficult largely because the solubilities of many salts become highly dependent on the solution composition when the concentrations of other solutes increase.

The solubility equilibrium of a minerals can to be represented as:

$$\mathrm{Xa\ Yb\ nH_2O} \rightleftarrows \mathrm{a\ X^{b+} + b\ Y^{a-} + n\ H_20} \qquad (1)$$

A thermodynamic solubility product (Ksp, $XaYb \cdot nH_2O$) of the mineral, if the activity of the solid phase is considered to be equal to 1 is defined as:

$$\mathrm{Ksp,}_{\mathrm{XaYbn\ H2O}} = a\,^{a}{}_{X}\ .\ a^{b}{}_{Y}\ \ a\,^{n}{}_{H2O} = (m_{x,\,sat}\ .\ \gamma_X)^a\,(m_{Y,sat}\ .\ \gamma_Y)^b\ .\ a^{n}{}_{H2O} \qquad (2)$$

Where m $_{x,sat}$ and m $_{Y,sat}$. are molal concentrations of cation and anion, respectively, in the liquid phase saturated with respect to the solid phase. In the specific case of the gypsum, the ec.1 is:

$$Ca_2SO_4\,2H_2O \rightleftarrows Ca^{+2} + SO_4^{-2} + 2\,H_20 \qquad (3)$$

The thermodynamic solubility product ($Kps,Ca_2SO_4{\cdot}2H_2O$) of the gypsum in funtion of the activity is:

$$Kps = (a_{Ca++} \cdot a_{SO4^{--}} \cdot a^2_{H2O}) / a_{CaSO4\,2H2O} \qquad (4)$$

The activity of the solid phase (mineral) is defined , $a_{CaSO4{\cdot}2H2O}$, to be equal to 1, where the equation 4 give:

$$Kps = (m_{Ca++} \, . \, \gamma_{Ca++}) \, (m_{SO4--} \, \gamma_{SO4--}) \, . \, a^2_{H2O}$$

This equation can be rewritten in the form:

$$Kps = Kps^*. \, \gamma_{Ca++} \, . \, \gamma_{SO4--} \, . \, a^2_{H2O} \qquad (5)$$

Where Kps* is the stoichiometric solubility product, $Kps^* = (m_{Ca++} * m_{SO4--})$
The estimation of the index of saturation (I.S.) of a particular brine with respect to a certain mineral is very important in the studies of the geochemical evolution of the brine. In general, the index of saturation of a brine with respect to a mineral of the formula $XaYb.\ nH_2O$ is defined by

$$I.S. = Log\,(P.A.I.) / Kps|_{eq} \qquad (6)$$

where the numerator of the equation is the product of the real ionic concentrations in a particular systems, respect ionic concentrations in the equilibrium liquid phase saturated with respect to the solid phase.
As noted Krumgalz (1996), the chemical compositions of most natural brines, such as seawater derived brines, waters associated with continental evaporates, formation brines of mixed origin as well as various geochemical brines, deep sea hydrothermal vents, etc., can be described by various combinations of the following major ions: Na^+, K^+, Mg^{+2}, Ca^{+2}, Cl^-, SO_4^{-2}, HCO_3^- and CO_3^{-2}.
The estimation of conventional single-ion activity coefficients and water activity can be made using the PITZER approach, Harvie et al. (1984), showed the agreement of the Pitzer model with the available experimental solubilities data for a complex system in the prediction of mineral solubilities in natural waters the Na-K-Ca-Mg-Cl-SO_4-OH-HCO_3-CO_3-CO_2-H_2O system to high ionic strengths at 25ºC. The ion-interaction approach models the thermodynamic properties of electrolyte solutions based on a set of theoretically and empirically derived equations that account for the study of saline waters, incluyed for brine solutions in a variety of geologic environments points for the treatment to a wider range of temperature and pressure conditions.
For the calculations of the index of saturation, the activities and activity coefficients were utilized from the code PHRQPITZ (Plummer et al., 1988). The following system of equations is utilized for calculation of the ionic activity coefficients:

$$\begin{aligned} \ln \gamma_M = {} & z_M^2 F + \sum_a m_a(2B_M + 2C_{Ma}) + \sum_c m_c(2\phi_{Mc} + \sum_a m_a \psi_{Mca}) + \\ & + \sum_a \sum_{<a'} m_a m_{a'} \psi_{a'aM} \, | z_M | \sum_c \sum_a m_c m_a C_{ca} + 2\sum m_n \lambda_{nM} \end{aligned} \qquad (7)$$

$$\begin{aligned} \ln \gamma_x = {} & z_M^2 F + \sum_c m_c(ZB_{cx} + ZC_{cx}) + \sum_a m_a(2\phi_{xa} + \sum_c m_c \psi_{xac}) + \\ & + \sum_c \sum_{<c'} m_c m_{c'} \psi_{c'cx} + | z_x | \sum_c \sum_a m_c m_a C_{ca} + 2\sum m_n \lambda_{nX} \end{aligned} \qquad (8)$$

where m_C and m_A are the molality of the cation or anion of charge z respectivily. M, c, c` are refer at cation and X, a, a` anion. B'_s y Φ'_s are the mensurable combinations of the second virials coefficients and C'_s y ψ'_s are the mensurable combinations of the third virials coefficients. The B and C terms can be evaluated empirically from data on binary systems, while ϕ and ψ terms arise only for mixed solutions and can best be determined from common ion mixtures. The quantity F includes the Debye-Hückel term.

METHODS

Waters samples of the salar were collected in 1 liter poliethylene bottles. The localizations of the samples were make with GPS. Temperature, pH, specific gravity, conductivity salinity and refractive index were determined in the field. The pHmeter and conductance was periodically calibrated using buffer solutions. Water samples were filtrated and analized at the laboratory. Cation were determined by Atomic Absorption Spectrophotometry (K, Na, Ca, Mg, Li and As) with Perkin Elmer 2380, using the standard protocol. The clorures by Mohr method, SO_4 by gravimetric method with BaCl and volumetric analysis (Cl, B_2O_3, CO_3, HCO_3). The precision of the analytic results is gave by porcentual ionic balance they are in ± 2.0 %. Some samples were analyzed for NO_3, PO_4. Data quality was analyzed by a ionic balance, Table 1. Mineral inspection of the solid samples and sediment were analized with computerized Siemens Atomic Absorption Difractometer, model D5000. The PHRQPITZ (Plummer et al., 1988) geochemical code has been used for calculation ionic activities and saturations indexes, in order to evaluate the mineral sequences controlling the geochemical evolution of brines. This code is the most appropiate for the treatment of solutions highly concentrated and it has been discussed in several publications (Krumgalz, B. 1996, Gueddari et al., 1983; Monnin and Schott, 1984; Spencer, Moller and Weare, 1989; López et al., 1999; Garcés 2000).

RESULTS AND DISCUSSION

The Table Nº1 constain the chemical composition of the brines. Salinity ranges is very variable, the lower values 0.15 g/l (SU-120) until values of magnitude greater than 262 g/l (SU-154). The highest salinity and concentrations of Na^+, Mg^{2+}, K^+, $C1^-$ and $S0_4^{2-}$ are northcentral sector, very nearby of the Oquecollo volcan.

The evolution of the water can be represented on the Eugster-Hardie diagram (1978), Figure Nº1, it shows the viariability of ionic composition, in funtion with its location. The ion dominances are $Na^+ > S0_4^{2-} > Cl^-$ and relation minor $K^+ > HC0_3^{\ +} > Ca^{2+} > Mg^{2-} > C0_3^{2-}$, an other words the clasification of the waters are near-neutral and it is Na-Cl-SO_4 type.

Both meteoric and hydrothermal alteration of volcanic rocks lead to Na-HCO_3 inflow waters of similar composition. Evaporite leaching leads to Na-Cl inflow waters of higher salinity. Atmospheric precipitation contributes only a small amount of Ca and SO_4.

With regard to boron this element is not preferentially enriched in the hidrothermal springs (samples SU-132 al SU-139). The meteoric and hidrothermal spring water lead to the same contents of B relative to salinity in spring water. Apparently this waters don`t undergo deep circulation and their contact with hydrothermal water must be minimal, therefore the source of boron is the leaching either meteoric or hydrothermal of volcanic rocks.

The variations in the ionic strength (Table Nº2) is 0.004 m at 5.03 m. The description of ionic compositions and their temporal changes in closed natural water bodies is very important for the explanation of formation mechanism and enrichment development of these brines. The waters show a considerable range in ionic composition and concentration. The water entering a closed basin under an arid climate will undergo evaporative concentration leading to the precipitation of a sequence of minerals, each removing ion selectively from the solution and thus altering its composition. The chemistry of the final brine is fundamentally dependent on the initial composition of inflow water and over the sequence and quantity of minerals which precipitate in the successive stages of the evolution of the water.

The evolution of the physicochemical conditions was calculated with the PHRQPITZ code it permits to calculate the ionic activity coefficients (γ_i), Table Nº2, and the degree of saturation of the waters. The Table Nº3 shows all the samples are oversaturated with calcite. The next steps is to regard of alkalinity. If (alk) > 2 (Ca^{++}) in initial inflow water, then it increase regularly during evaporation as long as only calcite precipitates. On the words, the ion activity product $\mathbf{a\ Ca^{++} \cdot a\ CO_3^{-2}}$ in the solution must remain contant as the concentration of the water increases. If one of the solutes increases, then the other one must decrease. La figure Nº2 of the left side, show the distribution of all inflow water should become carbonate rich brines. However their evolution the water represented on the Eugster- Hardie diagram (figure Nº1), show water Na-Cl-SO_4 type with pH below 8. This observation suggest that carbonate rich salar should be common. The usual explication to this anomaly is the precipitation of Mg-silicates (Hardie and Eugster, 1970). The figure Nº2 of the right side, illustrates the distribution of the points of all inflow water. This point are waters that should become alkaline but that actually are neutral brines. Therefore the fundamental ratio if (alk) > 2 ((Ca^{++}) + 2 (Mg^{++})) is not dependent on the nature of the weak-acid anion associated to Ca and Mg during evaporative concentration. One explanation for the data is the existence of excess sulfate source. In this model, additional sulfur is brought in the waters of the aquifer where it is oxidized into sulfate and removed as sulfate minerals. If all alkali cation are removed as sulfate the amount of oxidized sulfate would be the difference between the total loss of alkali cations and apparent loss of sulfate. In observation of the area very near it exists native sulphur. This is transported by the winds. This processes gives a reduction meaningful of the alkalinity.

The Figure Nº3 show that, the concentration dependences of ionic activity coefficients can be divided into two patterns. The first group contains the activity cofficients of Na^+, Ca^{++}, Mg^{++}, Li^+, Cl^-, which pass through a minimun after an initial drop, but the speed of the change is not equal in all. The most variability is experimented by Li, Mg and Ca ion. The γ_{Mg++} and γ_{Ca++}, whose values are positives if the concentration of the solution is I >1.2m. It is more gradual in case of the γ_{Cl-} and γ_{Na+} ; for the Cl^- is positive if I > 1.0m and for γ_{Na+} if I ≥ 1.0m . Then in both cases the ionic activity coefficients increase drastically with increasing ionic strengh. The second group contains the ion activity coefficients of K^+, SO_4^{-2} and HCO_3^- characterized by present a decrease with the concentration. The decrease was observed for the γ_{SO4}^{--}, with value falls quickly if I < 1m. The curve of the activity coefficients in function of the ionic strengh, they have a similar conduct for γ_K+. While that for γ_{HCO3}^- shows a great variability when ionic strengh is increased and the water reach a value of 0.375.

However, if you regard the data of Tabla Nº3 clearly we observe that the saturation index for the calcite is tending toward the equilibrium state or oversaturated. The chemical evolution shows a depletion of Ca^{++} and SO_4^{-2} due to calcite and gypsum precipitation. Some of the solutions are subsaturates with gypsum tending toward the equilibrium state, while another are clearly saturated concerning the gypsum and magnesite. The degrees of saturation for carbonate minerals are only rough estimates. As have pointed out Krumgaltz (1996) the degrees of saturation for carbonate minerals are very sensitive to the selection of ion interaction parameters of ionic combinations between CO_3^{-2} and other ions . Even though were found to be highly oversaturated with respect to many calcium and magnesium carbonates and sulfates. The phenomenon of the oversaturation of natural waters with respect to magnesium, calcium, mineral is governed by kinetic factors.

REFERENCES

Ben-Yaakov, S.& Saas, E. (1977): "Independent be valued [of the pH] Dead [of] Is [brine]." Limnol. Oceanogr., 22, 1076-1078

Eugster, H. P. and Hardie, L.A. (1978): Saline lakes. *In*: A. Lerman (Editor), Lakes, Chemistry, Geology, Physics. Springer, Berlin, 237-293pp.

Garcés, I. (1996): "Caracterization geoquímica and mineralógica del salar de Llamará (Chile): Na-Cl- System (SO_4)." Rev. Innovation, Chile

Garcés, I. (2000): Geochemistry of Huasco Salar`s, Chile. Origin of solutes and brine evolution. ***In:*** R.M. Geertman (Ed.) Akzo Nobel Central Research, 8th World Salt Symposium, vol.II, Elsevier Science, The Hague, Netherlands.

Gueddary, M., Monnin, C., Perret, D., Fritz, B. and Tardy, Y (1983): geochemistry of the brines Chott El Jerid in Southern Tunisia: Application of Pitzer`s equations. Chem. Geol. 39, 165-178.

Harvie, C.E., Moller, N. and Weare, J. (1984): The prediction of mineral solubilities in natural waters: the Na-K-Ca-Mg-Cl-SO_4-OH-HCO_3-CO_3-H2O system to high ionic strengths at 25ºC. Geochim. Cosmochim. Acta, 48, 723-751.

Krumgalz, B. and Millero, F. (1982): Physical chemistry study of the Dea Sea waters. I Activity coefficients of mayor ions in Dea sea Water. Mar. Chem. 11, 209-222.

Krumgalz, B. (1996): Some aspects of physical chemistry of natural hypersaline waters. Recent Res. Devel. *In* Solution Chem., 1, 9-28.

López, P. Auque, L., Garcés, I. y Chong, G. (1999): Características geoquímicas y pautas de evolución de las salmueras superficiales del Salar de Llamará, Chile. Rev. Geológica de Chile, 26, (1)89-108

Monnin, C. and Schott, J. (1984): Determination of the solubility products of sodium carbonate minerals and an application to trona deposition in Lake Magadi (Kenya). Geochim. Cosmochim. Acta, 48, 571-581.

Pitzer, K.S. (1973): Thermodynamics of electrolytes. I. Theoretical basis and general equations. Jour. Phys. Chem., 77: 268-277.

Plummer, L.N.; Parkhurst, D.L.; Flemming, G.W. y Dunkle, S.A. (1988): PHRQPITZ. A computer program incorporating Pitzer's Equations for calculation of geochemical reactions in brines. U.S. Geological Survey, Water Resources Invest., 88-4153 Reston, Virginia, 310p.

Risacher, F. y Fritz, B. (1991a): Geochemistry of Bolivian salars, Lipez, southern Altiplano: Origin of solutes and brine evolution. *Geochim. Cosmochim. Acta*, **55**: 687-705.

Risacher, F. y Fritz, B. (1991b): Quaternary geochemical evolution of the salars of Uyuni and Coipasa, Central Altiplano, Bolivia. *Chem. Geol.*, **90**: 211-231.

Risacher, F. (1992): Geochimie des lacs salés et croûtes de sel de lÀltiplano Bolivien. Sci. Géol. Bull., **45**: 135-214.

Risacher, F. y Alonso . (1996): Geoquímica del Salar de Atacama, parte 2: Evolución de las aguas. Rev. Geológica de Chile, **2** (2), 123-134.

Spencer, R.; Moller, N. and Weare, J. (1989): The prediction of mineral solubilities in natural waters: A chemical equuilibrium model for the Na-K-Ca-Mg-Cl-SO4-H2O system at temperatures below 25ºC. Geochim. Cosmochim. Acta, 54, 575-590.

Steinhorn, I., Assaf, G., Gat, J., Nishry, A., Nissenbaum, A., Stiller, M., Beyth, M., Neev, D., Garber, r., Friedman, G. & Steinhorn, I. y Assaf, (1980):"The physical structure of the Dead Sea water column, 1975-1977". In: A. Nissenbaum (Editor), Hypersaline Brines and Evaporitic Environments. Elsevier, Amsterdam, 145-152.

.

.

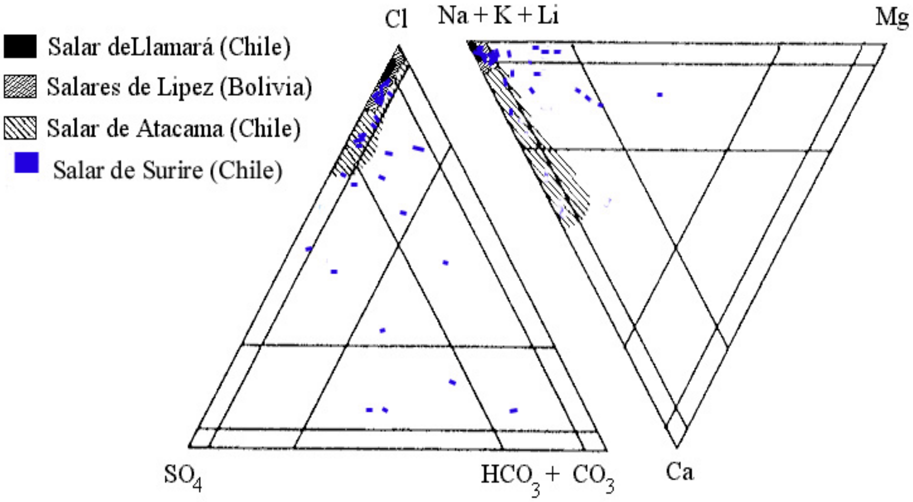

FIGURE Nº1: Clasification of system using the fields defined by Euster and Hardie (1978) for the chemical composition of inflow waters in Surire.

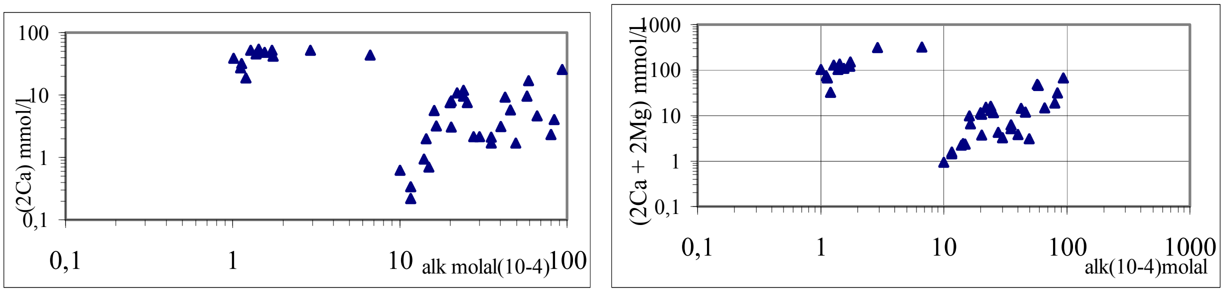

FIGURE Nº2: Plot of calcium and calcium plus magnesium vs. alkaline in moles. This representation schematic compositional trend characteristic of carbonate precipitation

TABLE Nº1: Chemical composition in mg/l , pH, temperature, densities and localization of Surire waters

MUESTRA	POSICIÓN S W	Tº	DENS.	PH	B	HCO_3	SO_4	CL	MG	CA	NA	K	LI
SU-120	18º51,38 69º08,55	1.5	0.999	7.94	*	*	78	9	15	7	15	5	0.1
SU-121	18º51,86 69º08,03	13	0.998	7.67	n.d.	71	78	22	15	9	37	7	0.1
SU-122	18º51,86 69º08,03	6	0.999		11	91	202	262	20	14	223	34	1

SU-125	18º53,05 69º03,28	22	0.998	7.0	11	168	161	21	26	43	47	13	0.1
SU-126	18º52,71 69º02,90	21	0.997	7.23	9	214	187	44	38	42	68	14	0.2
SU-128	18º52,24 69º02,04	8.5	1.001	8.69	23	214	383	988	55	34	672	118	4
SU-131	18º53,17 69º08,55	10	1.001	8.35	19	488	854	434	200	47	407	74	1
SU-132	18º54,93 68º59,99	50	0.996	6.47	43	153	1033	1709	48	151	1233	242	7
SU-133	18º54,93 69º00,02	33	1.000	7.84	43	122	1062	1711	47	151	1245	243	7
SU-134	18º54,93 69º00,05	23	1.001	8.05	43	122	1060	1733	48	151	1261	242	7
SU-137	18º54,93 68º59,77	70	0.989	6.21	57	122	708	2025	32	160	1279	249	8
SU-139	18º54,96 68º59,60	84	0.986	6.82	70	122	243	2508	8	62	1510	224	11
SU-144	18º54,24 68º58,41	42	0.997	7.22	59	244	210	1764	8	63	1125	140	8
SU-145	18º52,18 68º58,44	42	0.996	6.92	46	244	123	1595	17	34	1023	108	6
SU-147	18º51,65 68º58,28	16	1.002	6.89	38	183	136	2056	14	43	1302	128	7
SU-152	18º49,01 68º59,67	11	1.041	8.92	314	671	8677	25083	588	550	17378	2175	79
SU-153	18º48,99 68º59,66	11	1.029	9.04	151	686	6684	17017	434	638	12101	1350	51
SU-154	18º48,26 69º04,26	8	1.184	7.5	1627	1784	13583	144028	3363	875	82225	13500	472
SU-155	18º48,23 69º04,50	7.5	1.174	7.55	1519	1647	13019	137380	3163	1050	78571	12900	446
SU-156	18º47,717 69º05,30	6	1.008	9.66	89	259	2375	3720	63	184	2896	532	17
SU-157	18º47,94 69º04,95	4	1.037	8.93	259	564	8483	19755	498	513	14152	2025	59
SU-158	18º47,74 69º00,64	2	1.007	9.7	46	351	3322	2553	478	194	2081	244	7
SU-160	18º48,53 69º02,37	11	1.020	8.75	173	320	3931	12940	352	342	8516	1175	45
SU-161	18º48,03 69º03,63	9	1.050	8.59	411	610	9088	31376	775	775	20105	3038	104

TABLE Nº2: Ionic ActivitiesCoefficients of mayor ions in Surire water and Ionic Strengths molar.

MUESTRA	Γ Ca	Γ Mg	Γ Na	Γ K	Γ Li	Γ Cl	Γ SO_4	Γ HCO_3	Γ MgOH	F.IONIC
SU120	0.733	0,738	0,932	0,931	0,933	0,934	0,734	0,933	0,931	0,0043
SU121	0.709	0,715	0,926	0,925	0,926	0,927	0,713	0,926	0,925	0,0053
SU122	0.564	0,574	0,882	0,879	0,885	0,883	0,578	0,877	0,892	0,0164
SU125	0.627	0,633	0,899	0,898	0,900	0,905	0,615	0,905	0,897	0,0105
SU126	0.601	0,605	0,889	0,887	0,890	0,896	0,585	0,894	0,886	0,0132
SU128	0.434	0,443	0,825	0,819	0,832	0,828	0,424	0,816	0,861	0,0462
SU131	0.391	0,402	0,809	0,803	0,816	0,825	0,388	0,810	0,816	0,0565
SU132	0.339	0,357	0,785	0,775	0,799	0,787	0,333	0,773	0,836	0,0895
SU133	0.335	0,353	0,784	0,774	0,799	0,786	0,332	0,772	0,835	0,0897
SU134	0.334	0,353	0,783	0,774	0,798	0,786	0,331	0,771	0,835	0,0903
SU137	0.357	0,371	0,786	0,776	0,801	0,790	0,333	0,777	0,854	0,0879
SU139	0.386	0,393	0,790	0,781	0,806	0,792	0,345	0,773	0,885	0,0832
SU144	0.422	0,425	0,808	0,800	0,819	0,811	0,386	0,797	0,878	0,0623
SU145	0.445	0,445	0,816	0,809	0,826	0,819	0,406	0,804	0,882	0,0546

SU147	0.416	0,419	0,803	0,795	0,815	0,806	0,375	0,789	0,884	0,0672
SU152	0.169	0,204	0,616	0,562	0,752	0,633	0,080	0,533	0,842	1,0415
SU153	0.174	0,203	0,634	0,592	0,731	0,651	0,104	0,574	0,834	0,7430
SU154	0.597	0,957	0,727	0,449	1,781	0,846	0,0203	0,375	0,516	5,0320
SU155	0.538	0,848	0,725	0,462	1,667	0,812	0,0206	0,387	0,538	4,7940
SU156	0.249	0,271	0,734	0,717	0,762	0,728	0,239	0,698	0,816	0,1896
SU157	0.166	0,197	0,627	0,579	0,736	0,639	0,093	0,550	0,822	0,8718
SU158	0.231	0,257	0,724	0,707	0,749	0,739	0,232	0,707	0,762	0,2015
SU160	0.207	0,232	0,665	0,630	0,739	0,673	0,134	0,611	0,879	0,5047
SU161	0.182	0,221	0,624	0,556	0,772	0,635	0,0705	0,532	0,862	1,1980

TABLE Nº3: Saturation Index of minerals of Surire brines at differet ionic strenghts

MUESTRA	FUERZA IÓNICA	ACTIV. AGUA	IS CALCITA	IS YESO	IS MAGNESITA	IS ANHIDRITA	IS HALITA	IS MIRABILITA
SU-120	0,004	0,9999	-1,225	-2,492	-1,535	-2,733	-8,35	-7,247
SU-121	0,005	0,9999	-1,374	-2,367	-1,773	-2,617	-7,58	-6,513
SU-122	0,016	0,9996	-1,815	-2,011	-2,232	-2,274	-5,78	-4,238
SU-125	0,011	0,9998	-1,069	-1,533	-1,924	-1,777	-7,52	-6,073
SU-126	0,013	0,9998	0,786	-1,513	-1,481	-1,751	-7,04	-5,664
SU-128	0,046	0,9988	0,485	-1,613	0,162	-1,882	-4,79	-3,977
SU-131	0,057	0,9991	0,471	-1,173	0,444	-1,403	-5,34	-3,661
SU-132	0,09	0,9979	-1,459	-0,7	-2,606	-0,929	-4,29	-2,705
SU-133	0,09	0,9979	0,15	-0,712	-1,258	-0,96	-4,31	-2,854
SU-134	0,09	0,9979	0,054	-0,716	-1,044	-0,964	-4,29	-2,846
SU-137	0,088	0,9977	-1,762	-0,811	-3,115	-1,04	-4,2	-2,828
SU-139	0,083	0,9974	-1,46	-1,652	-2,951	-1,905	-4,04	-3,34
SU-144	0,062	0,9981	-0,746	-1,624	-2,278	-1,866	-4,3	-3,497
SU-145	0,055	0,9983	-1,285	-2,078	-2,225	-2,321	-4,38	-3,779
SU-147	0,067	0,9979	-1,312	-2,016	-2,377	-2,277	-4,2	-3,798
SU-152	1,042	0,9736	1,615	-0,164	1,073	-0,379	-2,18	-0,466
SU-153	0,743	0,9818	1,827	-0,086	1,074	-0,308	-2,48	-0,724
SU-154	5,032	0,829	1,395	-0,021	1,723	-0,128	-0,51	-0,358
SU-155	4,794	0,841	1,534	0,113	1,651	-0,005	-0,57	-0,333
SU-156	0,19	0,9995	1,641	0,584	0,639	-0,844	-3,675	-2,145
SU-157	0,872	0,9787	1,57	-0,16	1,025	-0,397	-2,373	-0,719
SU-158	0,202	0,9966	1,649	-0,447	1,457	-0,688	-3,967	-2,093
SU-160	0,505	0,9871	1,119	-0,395	0,529	-0,623	-2,72	-1,089
SU-161	1,198	0,9691	1,86	-0,052	1,407	-0,295	-2,037	-0,813

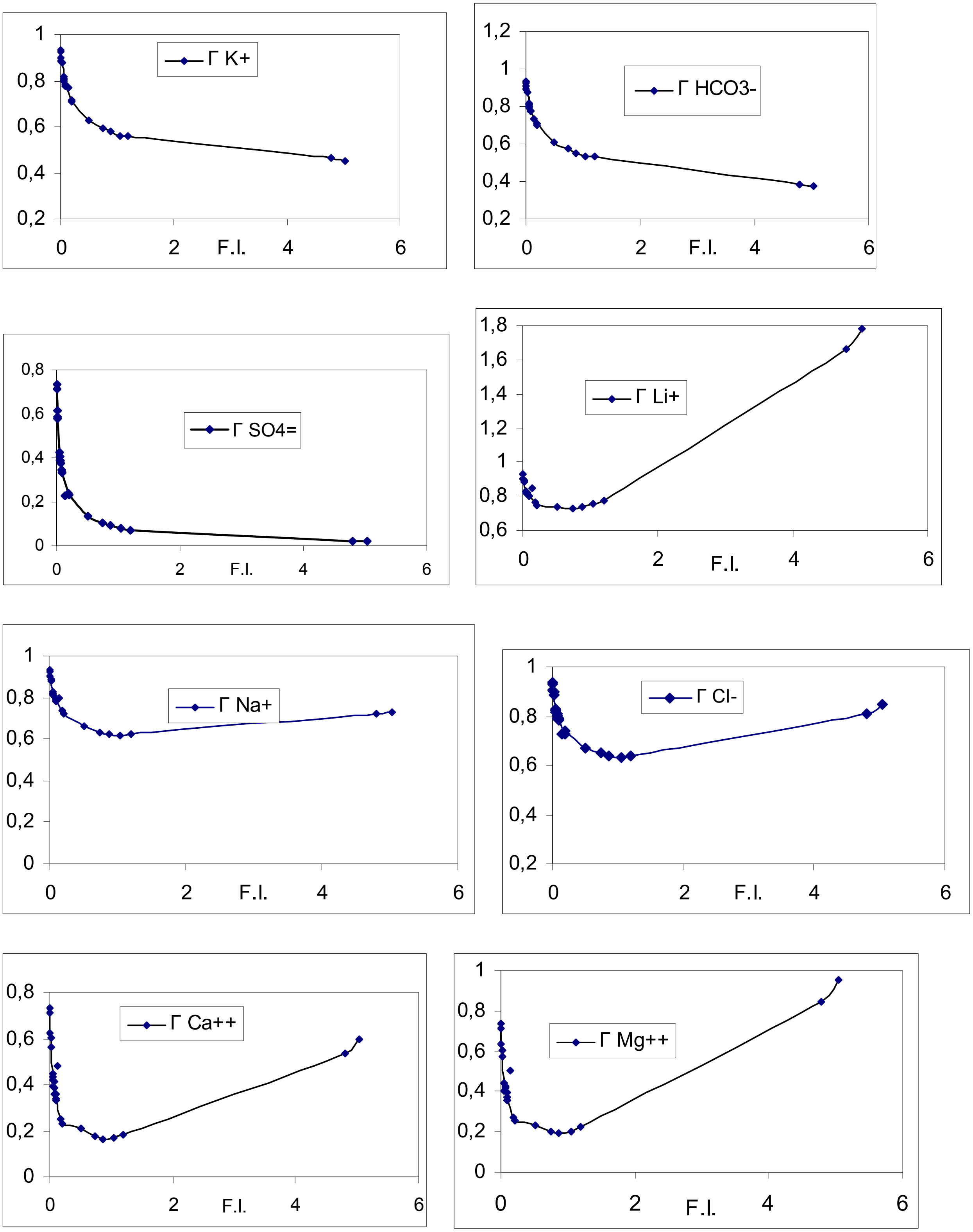

FIGURE Nº3: Ionic Activities Coefficients for mayor ions in such highly saline natural water (Surire salar).