THE SODIUM SULPHATE AND ULEXITE DEPOSITS: SALAR OF SURIRE, CHILE

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The Surire salar`s is a saline system which maintains characteristics typical of the Andean deposits. Solutes carried by springs and rivers into the salars originate mostly from the alteration of the volcanic rocks and the re-solution of ancient buried evaporites. Both weathering and hydrothermal alteration lead to inflow waters of similar composition containing Na-HCO_3. Evaporite leaching leads to the inflow waters of higher salinity containing NaCl. Atmospheric precipitation contributes only a small amount of Ca and SO_4.
The system to present neutral brines of the Na-Cl-SO_4 type. Most ions display distinct trends with increasing salinity. This salar is mainly composed of ulexite and sodium sulphate, both with significant reserves in the halite and gypsum subordinate. The economic importance of this salar lies in its borates content of and eventually sodium sulfate content.

1. BASIC CONSIDERATIONS

The salar is located between 18°55' S and 69°05' W, at an altitude of 4300 m in a closed basin of 150 km^2. It is a geologically young evaporite body, associated with the present volcanism. The Surire Salt Basin has characteristics typical of the altiplano, defined as high steppe (1), very low relative humidity, cold and dry, predominant northeast wind, precipitation between December and March, with a median annual temperature between 5° and 18°C.
The salt basin has a plane surface, formed by soluble saline material which originated from precipitation of salts from brines concentrated by evaporation, including principally borates, sulfates, chlorides, and subordinate carbonates. The cover may present a centimeter thick microrelief and may be either dry or brine-saturated. The structures observable are polygonal plaques derived from dessication. Crystals of $NaSO_4$ are formed on the shores of the brine within the salar.
Its geologic location reflects special characteristics, since it is located in a basin among volcanoes, and can even be considered a caldera, which also has a new volcano breaking up the saline bodies located near the center. Additionally, important thermal springs are found on the eastern side. The combination of these factors produces the confluence of several very distinct inputs to the basin, such as the normal input of subterranean and superficial waters, which arrive at the closed basin, and on the other hand, geothermal waters which produce hot springs.
The upper 60 m of the salt surface are characterized by the formation of evaporites and organic sediments, plus fine-grained sedimentary rocks where pyrite is present (2). The inferior part is made up of saline and organic sediments rich in organic material. The upper unit includes the present covering of the salt basin, whose thickness varies from several centimeters up to 8 m (2) including borates, chlorides, sulfates, and carbonates. The superficial crust observed are polygonal plaques derived from drying and later saline filling of their borders owing to mobilization of salt because of water saturation, or due to drying.

2. METHODOLOGY

During 3 years, a total of 60 brine samples were obtained from exploration in salar. Temperature, pH, density were determined in the field. Water samples were filtrated and analyzed at the laboratory. Cations were determined by Atomic Absorption Spectrophotometry (K, Na, Ca, Mg, Li and As). Anions were determined by gravimetric (SO_4) and volumetric analysis (Cl, B_2O_3, CO_3, HCO_3). Data quality was analyzed with an ionic balance, where the error in the balance is less than ±1.5%. The solid samples were analyzed with Siemens Atomic Absorption Diffractometer. The PHRQPITZ code (3), is utilized for determine the thermodynamic equilibrium by means of the mineral saturation index

3. DISCUSSION AND RESULTS

The recharge to the salar is effected in several ways, one of which includes rain and snow precipitation, natural thermal sources and recharge from springs at the eastern side, with probable bolivian resupply from subterranean sources, besides springs, rivers and underground waters. Pluvial imports are significant in the summertime. The precipitation collects in a system of drainages, and superficial flows in small watercourses, which infiltrate rock fractures or clastic sedimentary materials, forming small aquifers.
In the south central sector there is a large alluvial cone through which circulates water from the Surire River. In the southeast sector there are a number of important hot springs.

The principal source of the geothermal system (above 80°C), is located within the salt basin. The origin of the heating may be of a magmatic nature. Waters from the thermal springs contain sodium chloride and are acid. There are numerous inflows from the springs in the SE sector, where temperatures vary from 20° to 40°C. These groundwater flows are probably of magmatic origin or of Bolivian sector. These waters contain sodium chlorides and sulfates.

In the north-central sector the waters are alkaline (pH>8) and contain B, As, Sr, NO_3 in higher concentrations than other sectors.

The SW zone has some deep pools, containing salt-saturated brines. The freatic level is 1.2 m depth with variation from the surface to the center.

The chemical composition of the waters are generally sodium chlorides with an ionic strength of less than 2.1 M. Based on values from chemical analyses, the north central sector shows anomalous K concentrations, which reach values of 13.5 g/l. The NE is more concentrated in Na, Cl, As, B, Li, K, Sr (66 ppm). A comparison between the characteristic water reported (4) of Bolivian evaporite (Cl<2 mM) and the Surire salar`s shows a striking similarity. The brines of higher density, contain high amount of Li and B. The anionic relation found for the brines was $Cl>SO_4>HCO_3$ and slightly alkaline. The cationic relation is Na>K>Ca>Mg>Li. The ratio K/Mg and Na/Cl remain constant. The ratio $SO_4/Cl<1$.

The use of the geochemical model code PHRQPITZ (3) allowed us evaluating the solutions saturation degree up front for the saline minerals in the system of interest.

Calcite presents is slightly oversaturated except in the case of a sample with lower ionic strength where it was slightly undersaturated. Aragonite showed similar behavior. In the case of gypsum, some solutions were undersaturated, with the rest showing a clear tendency to equilibrium for this mineral. The anhydrite phase showed a slight tendency toward an equilibrium state, without reaching it. The remaining minerals are undersaturated.

The inputs from water are lost by dispersion among the superficial salt plates, producing a shallow freatic level with discontinuous water recharge based on the season of the year. The salt bed is recharged during summer by means of the rains, which partially submerge the deposits. Discharge is effected principally by evaporation. This produces a hydraulic gradient that generates a continuous flow towards the center of the salt basin. This is the phenomenon that produces the accumulation of waters having the soda-carbonate characteristic, and those from springs with sodium chloride with pH values being slightly alkaline.

Table N°1: Chemical composition of the brines of Surire salar`s (g/l).

Samples	Ca	Mg	Na	K	Li	Cl	SO_4	HCO_3	B	pH	T(°C)	Dens
PM-1	970	725	4659	4659	153	50166	18419	915	n.d.	8.22	10	1.079
PM-4	1055	844	3920	3920	145	34212	12920	976	n.d.	8.35	15.2	1.060
PM-17	116	76	145	145	0.23	1259	547	268	n.d.	7.14	12.1	1.001
SU-126	42	38	68	14	0.2	44	187	214	9	7.23	21	0.997
SU-128	34	55	672	118	4	988	383	214	23	8.69	8.5	1.001
SU-147	43	14	1302	128	7	2056	136	183	38	6.89	16	1.002
SU-153	638	434	12101	1350	51	17017	6684	686	151	9.04	11	1.029
SU-154	875	3363	82225	13500	472	144028	13583	1784	1627	7.5	8	1.184
SU-155	1050	3163	78571	12900	446	137380	13019	1647	1519	7.55	7.5	1.174
SU-157	513	498	14152	2025	59	19755	8483	564	259	8.93	4	1.037
SU-160	342	352	8516	1175	45	12940	3931	320	173	8.75	11	1.020

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