Some Sodium Chloride Deposits from Patagonia, Argentina

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ABSTRACT

In Patagonia, in the vicinity of the Atlantic coast, there are deposits up to 447 million tons preserved at the bottom of two depressions: Gran Bajo del Gualicho (65°13′ and 40°23′ South) and Peninsula de Valdes low (64° and 42°40′ South). The first one is located 35 km from the San Antonio Oeste port. This low of 2,700 sq. km. has a centripetal drainage. The bottom is 78 m below sea level and has an area of 285 sq. km. The second, only 15 km from Golfo Nuevo, is 230 sq. km. and has two salt pans: the Salina Grande which is 40 m below sea level and 25 sq. km.and the Salina Chica, 12 m below sea level and 62 sq. km. These tectonically controlled depressions are under arid and temperate climatic conditions. The rainfall, ranging from 200 to 250 mm per year, occurs during autumn. The maximum temperature from 35° to 43°C produces an intense evaporation of the water accumulated in the previous seasons. In order to evaluate these salt pans, geologic surveys were carried out including a drilling program which consisted of 58 boreholes. These salt pans grade from few millimeters at the borders up to 5.7 m in the central area. In the salt bodies up to 4 cm thick layers are recognized which correspond to rainy seasons. These consist of an aggregate of small, poorly consolidated crystals, with an average grade of 96% NaCl. Under this layer, a permanent body is developed which constitutes the salt reserves and is composed by a sequence of salt and mud layers. The salt layers become thicker and harder with depth and have an average composition of 75% of NaCl.

400 million tons of NaCl recoverable reserves were measured in El Gualicho; 42 million tons in the Salina Grande and 5 million tons in Salina Chica. At the same time interesting tonnages of other salts were defined.

INTRODUCTION

The purpose of this paper is to describe the sodium chloride deposits near the Atlantic coast of the Argentine Patagonia. In the northern and central parts of the Patagonian coast there are two large depressions whose bottoms are below present sea level and which contain accumulations of salt.

The larger one of these depressions is located in the Province of Río Negro, and is called "El Gran Bajo del Gualicho." This salt deposit is located 35 km north of San Antonio Oeste, which has a natural port and where piers are being built at present.

The second depression is located in the province of Chubut near the central southern half of the Valdes Peninsula. It is known as Salina Grande–Salina Chica due to the fact that within this basin there are two separate salt deposits located at different ground levels. The Salina Grande is about 15 km in a straight line north of Golfo Nuevo, the best natural deep water port on the Patagonian coast. The nearest towns to the salt pans by road are Puerto Pirámides at 35 km and Puerto Madryn some 130 km away.

GENERAL GEOLOGY

Salina del Gualicho area. The lithology of the area consists of metamorphic rocks and dark greenish gray schists injected by quartz assigned to the Precambrian. These are followed by Jurassic volcanics over which discordantly are predominantly Tertiary marine, sandy, clayey, fossiliferous sediments covered by typical fluvioglacial pebbles, the "Rodados Patagónicos" of the Quaternary, and modern sandy sediments (Fig. 1).

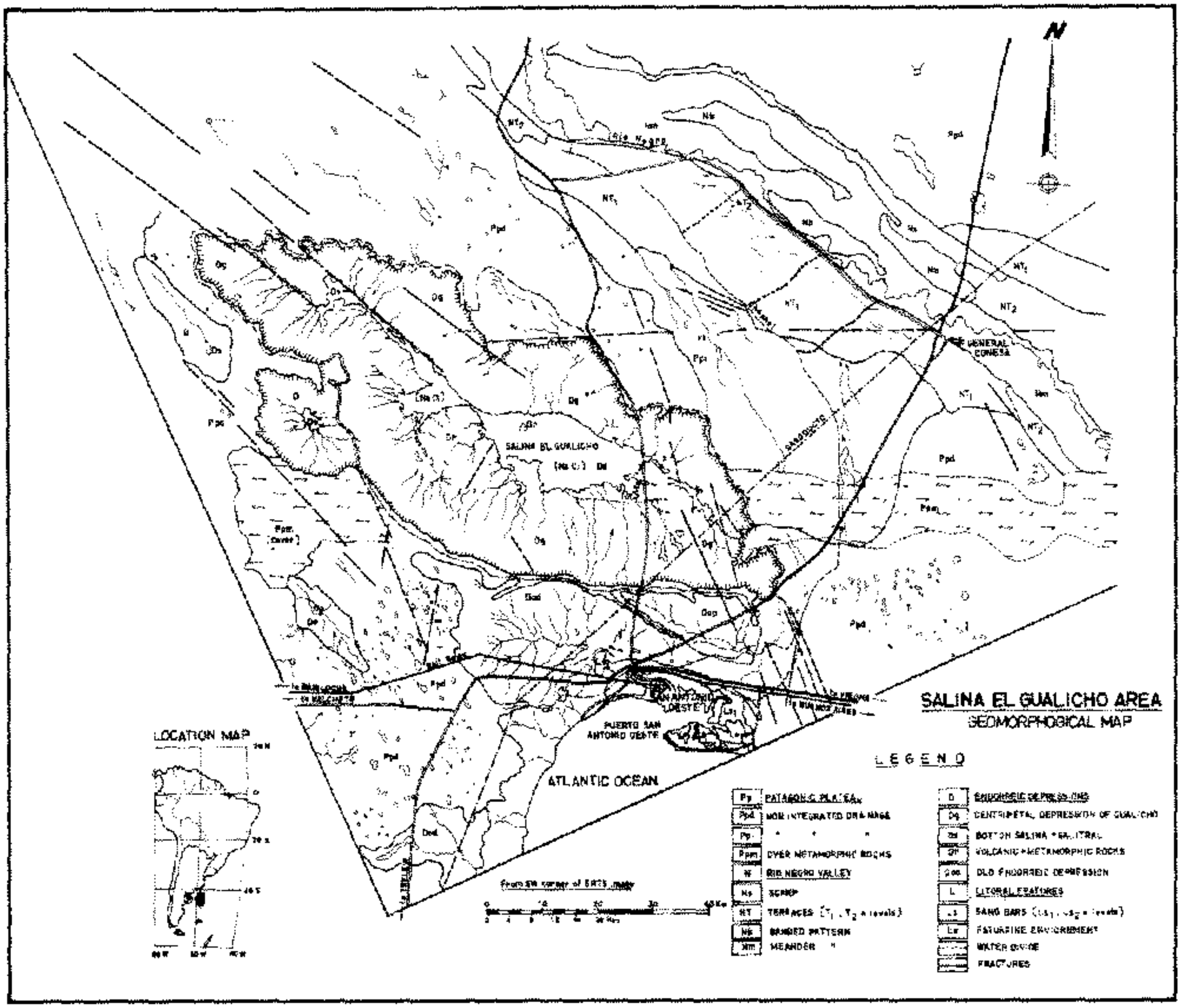

Figure 1. Geomorphological map of the Salina El Gualicho area, Argentina.

In the area four geomorphological units were recognized using ERTS images: (1) the Patagonian Plateau; (2) the Rio Negro Valley; (3) two endoreic depressions; and (4) a barrier beach. These are described below.

1. On the plateau, a peneplain with soft undulations, there is a non-integrated drainage and an integrated paleodrainage. The first is composed of multiple closed basins with a few short collectors. The second is located between the Gualicho depression and the valley of the Rio Negro. At present they consist of dry stream courses that run N and NW, disappearing at the edge of the second terrace level of the Rio Negro.
2. In the Rio Negro valley we distinguish the terraced levels and the present valley with a meander pattern which has the most fertile soils of the region.
3. The two more important depressions of the zone are the Gran Bajo del Gualicho, at present endoreic, and the San Antonio Oeste depression located immediately to the south and separated from it by a filiform outcrop of subhorizontal sediments of the upper Tertiary. It is an ex-endoreic basin which was invaded with seawater, due to a raise of the sea level, establishing an integrated drainage.

The Salina del Gualicho is located within the Gran Bajo del Gualicho. It consists of an irregular oblong basin adapted to the tectonic lines of weakness on a regionally dominant E-W trend. The basin is some 120 by 45 km, covering a surface of 2700 sq. km. The salina is about 78 m below present sea level, and on the border Precambrian metamorphites and Jurassic volcanices are shown.

The drainage of the depression is fed by surficial and ground water, the first of which are of short duration and dependent on rainfalls. The groundwater is almost permanent though the volume varies with the seasons. The water appears on the soft slopes of the depressions in the form of springs aligned according to the water table. This water flows on the surface over impermeable beds and is absorbed by the sandy permeable beds that surround the salina, reaching it from underneath. These waters are not fit for human use due to their salt content.

As far as the origin of these depressions is concerned, we may state that they are strongly influenced by the main fracture system of the region (E–W; NW–SE; NNW–SSE) that allowed differential subvertical movements of the basement blocks. Their later developments are due to climatic influences.

4. The Holocene barrier beach that edges the estuarine environment of San Antonio Oeste interrupted the preexistent drainage to the W and NE of that locality.

The Salinas Grande and Salina Chica area. In the Salina El Gualicho area, we find only Tertiary marine, sandy, clayey, highly fossiliferous sediments, covered by Quaternary, typical fluvio-glacial pebbles of substantially smaller size. Four geomorphological units are differenciated in the area, the Patagonian plateau, depressions, coast shape formation and sand drifts (Fig. 2).

1. The plateau is a peneplain that covers the main land, the land bridge and 2/3 of the peninsula itself. On the plateau we distinguish a scarce non-integrated drainage composed of small endoreic basins.

2. The Golfo Nuevo and Golfo San José are the more relevant depressions that actually are covered by the sea. Another depression of 230 sq. km., at present not invaded by the sea, contains two salt pans, the salinas Grande and Chica, which are at 40 and 12 meters below sea level respectively. The drainage of the Salina Grande and Gualicho are similar. The Salina Chica has approximately the same level of the water table and this water is not shown at its surface.

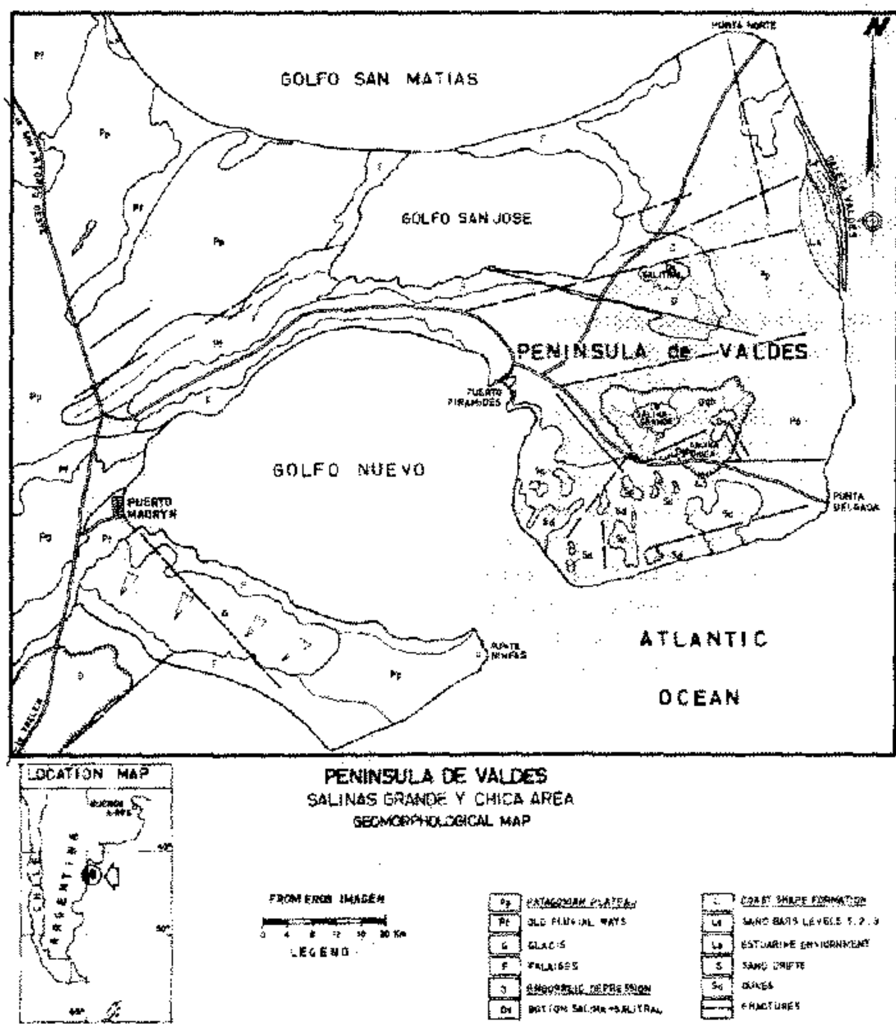

Figure 2. Geomorphological map of the Salinas Grande and Chica area, Peninsula de Valdes, Argentina.

The origin of the depressions is the same as of the Gran Bajo de Gualicho, that is, mainly due to subvertical movements of the basement blocks. Another geomorphological characteristic related to the depressions worth mentioning is located at the NW end, and known as El Salitral. This is a silled basin at the same level of the sea, separated from the water by a 20 meter high ridge. The same could happen to the Golfo San José if the sea level should drop by 20 meters from the present level. Then the gulf will be separated from the sea by the submarine swell located at the entrance.

3. The coastal shape is shown at the NE end of the peninsula, and is characterized by a psephitic ridge that builds an estuarine environment, known as Valdes inlet. On the west coast of this inlet there are three levels of sea ingressions differentiated. The highest ingression reached 45–50 meters and the lowest 8–10 meters above present sea level.
4. The sand drifts are localized at the south end of the peninsula. From west to east they start as dunes of different sizes and gradually they flatten into sand layers of up to 60 sq. km. The age of this geomorphological unit is Holocene.

CLIMATIC FEATURES

The region is distinguished by its arid climate, scarce rains, high evaporation and temperature, windy environment and a steppe type vegetation. On the Valdes peninsula the rainfall is somewhat higher than on the continental coast. The 18 year statistics (from 1944 to 1961) give a yearly mean of 262.5 mm with very marked variations. For example, in 1945 and 1947 rainfall reached only 93.5 and 126 mm, while in 1948 and 1957 there were 515 and 457 mm respectively (Fig. 3).

The warm months from November to May are relatively poor in rainfall. The mean values give no absolutely dry periods, especially during the summers, even though in that season there may be monthly periods without rains. The average number of rainy days is 5 to 8 days a month in winter and 2 to 3 days in summer. Evaporation reaches 1,700 to 2,000 mm which is 9 to 10 times higher than the volume of rainfall, giving an arid climate with the characteristic salt accumulations in the soil.

The daytime high temperatures of summer are bearable at 35° to 42°C. The lowest reach some 4°C. A variation of about 15°C between day and night temperatures for this season is normal. The coldest months are June, July, August and September when the absolute minimum temperatures range from 13°C and −5°C. During this season, frosts are frequent, while snowfalls are exceptional.

Winds predominantly from the western quadrant are notable in this region. In summer they blow from the NW and in winter from the SW. Windstorms lasting several days with gusts of up to 70 km/hour are not rare.

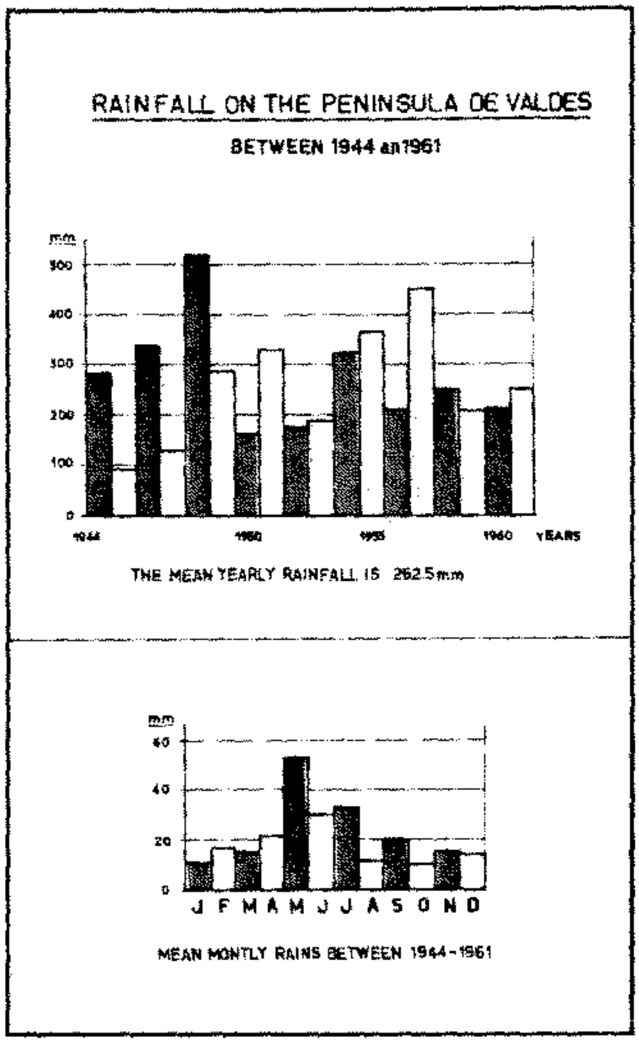

Figure 3. Rainfall on the Peninsula de Valdes.

NATURAL RESOURCES

As a consequence of the climatic features, water in the area is scarce. On the gentle slopes of the salines there are salty springs of diverse volume. On the banks of the Salina Grande at the Valdes peninsula there are only two springs usable for precarious human use, as they have about 1 gr/l dissolved salts, mainly sodium chloride.

There are three windmills located outside of the Valdes peninsula depression at about 5 km from the edge. Their water contains 0.8 gr/l of salts, but in most of the water wells the salt ranges at about 3 gr/l and there are some with as much as 50 and 80 gr/l. In the Salina del Gualicho area no water for human use could be found, so it had to be brought from San Antonio Oeste which is supplied by a channel from the Rio Negro.

Vegetation is shrubby, according to the climate and composed mostly of creosote bush, palo verde, prosopis, mesquite and several grasses. Wildlife is varied, especially on the Valdes peninsula. There are many hares, both the short eared Patagonian and the long eared European, ñandues, guanacos, armadillos, turtles, partridges, ducks, etc.

The economic profitability of the Valdes peninsula, though somewhat more humid than the continent, is low. Activity is limited mostly to sheep breeding, whose mean population is limited to one sheep every 2.5 Ha (equiv. 6 acres). For this type of development, a few men are enough to cover the labor needs, all of which is reflected in the notable depopulation of the area.

EXPLORATION OF THE SALT DEPOSITS

In order to know the size of the sodium chloride reserves in the depressions mentioned a geological study was carried out on topography, bore-holes, sampling and blocking out of reserves.

Figure 4. Sample channel with characteristic succession of salt and brine.

Topographic study defined the shape, borders and extensions of the formations, which means the central saline borders where the thickness of the salt is enough to bear the movement of heavy equipment in an eventual exploitation. It also defined the edges of the central salt body, the marginal muddy formations, the location of islands, springs and solid ground.

Fifty-eight pits were dug: 19 in the Salina del Gualicho, 24 in Salina Grande and 15 in Salina Chica. With the equipment available some bore-holes were driven, but due to the difficulty of reaching an acceptable core recovery, it turned out to be more practical to replace them by 1×1×5 m pits. To dig these pits simple tools were used, and at depths of more than three meters, pneumatic hammers were used. Pumps were also necessary to keep the level of the brine down which percolated towards the pits. The flow of brine in four of the Gualicho pits was greater than the pumping capacity due to which, these pits were not continued down to the base of the salt body, having already assured the size of the computable reserves.

Each pit was sampled by means of vertical channels. In Figure 4 we see a sample channel where the characteristic succession of sand and slime is evident. The slime lets out quantities of mud and brine that stains the lower salt beds giving them an apparent lesser thickness.

CHARACTERISTICS OF THE SALT BODIES

The bottom of the depressions are full of a greenish black watery slime and over this the salt bodies float. Consequently, below the salt bodies we will find slime, and seen from above, there is a ring with variable widths, surrounding and separating the salt flats from firm land at the edges of the depressions.

In this slime we collected samples by means of a piece of pipe 3 m long and 10 cm in diameter with a sample holder placed at the lower end. The typical profile (top to bottom) is as follows: 1–3 mm of white salt laying over a crust of soft slime and salts of also 1–3 mm. Immediately below, about 1 meter of greenish black watery slime, very ill smelling due to decomposing organic matter, and progressively denser at greater depths. It has thin interlaced beds of crystals of 1 to 2 mm of halite. Then there follows a bed of volcanic ash about 50 mm thick, followed by another bed about 2 meters thick of slime with skeletal and cubic crystals up to 4 cm on a side and also crystals of glauberite and gypsum either as loose crystals or as rossetes. The plasticity of this slime decreases gradually downward with an increase of sand sized sediments.

Some boreholes were made in the slime below the salt bodies in pits located in the central part of the Salina Grande. Three meters were bored in watery slime without reaching the plastic mud. Instead, in the central holes of the Salina Chica, the watery slime is only about 0.5 m thick

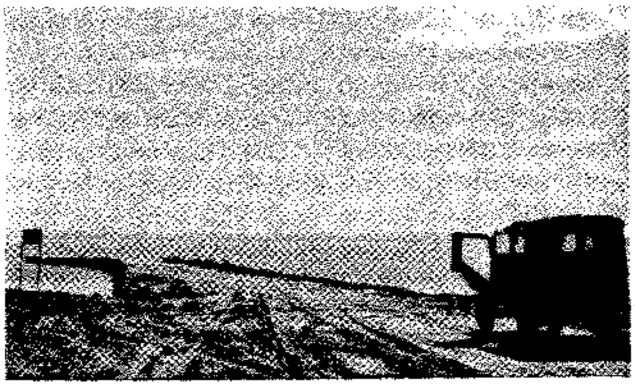

Figure 5. Embankment to reach the Salina El Gualicho.

and at 3 meter depths we reached predominantly sand sized sediments.

Access to the sodium chloride deposits, the slime that borders the salt body should be crossed by building embankments, (Fig. 5).

The salt pans in general conform to the shape of the depressions and usually tend to have an oval shape. The surface is horizontal. Levelings carried out at Salina Chica showed a slight slope towards the SW with a difference in altitude of about 25 cm. Salina Grande has a small elevation at the center of between 5 and 25 cm.

In profile, these salt bodies are only a few milimeters thick at the edges, but they increase gradually towards the center. For example, in an E–W profile through the center of the Salina Grande, we find that at 300 m from the edge the salt is 80 cm thick, at 1500 m it is 220 cm and at 3,000 m the thickness reaches 570 cm in the deepest pit dug in this salina. The profile is illustrated well in Figure 6 and is typical for the three salt bodies. This profile shows an upper layer, some 35 mm thick and below these the salt body or permanent bed which is the main salt reserve.

The formation of the upper or annual layer is directly related to the rainfall, which is to say when there is the greatest level of water covering the salina. The relation between the thickness of the annual bed of salt and the innundating water is about 1 to 10. The annual bed is characteristic because it is made up predominantly by high purity sodium chloride (Table I).

TABLE I

The Mean Measures for the Three Salinas

Hypothetical Components	Salina El Gualicho %	Salina Grande %	Salina Chica %
NaCl	96.82	96.0	95.0
$MgCl_2$	0.47	0.67	0.45
$CaCl_2$	—	0.16	0.34
Na_2SO_4	0.24	0.08	0.7
$CaSO_4$	1.20	1.55	2.14
Insoluble	1.15	1.38	2.10

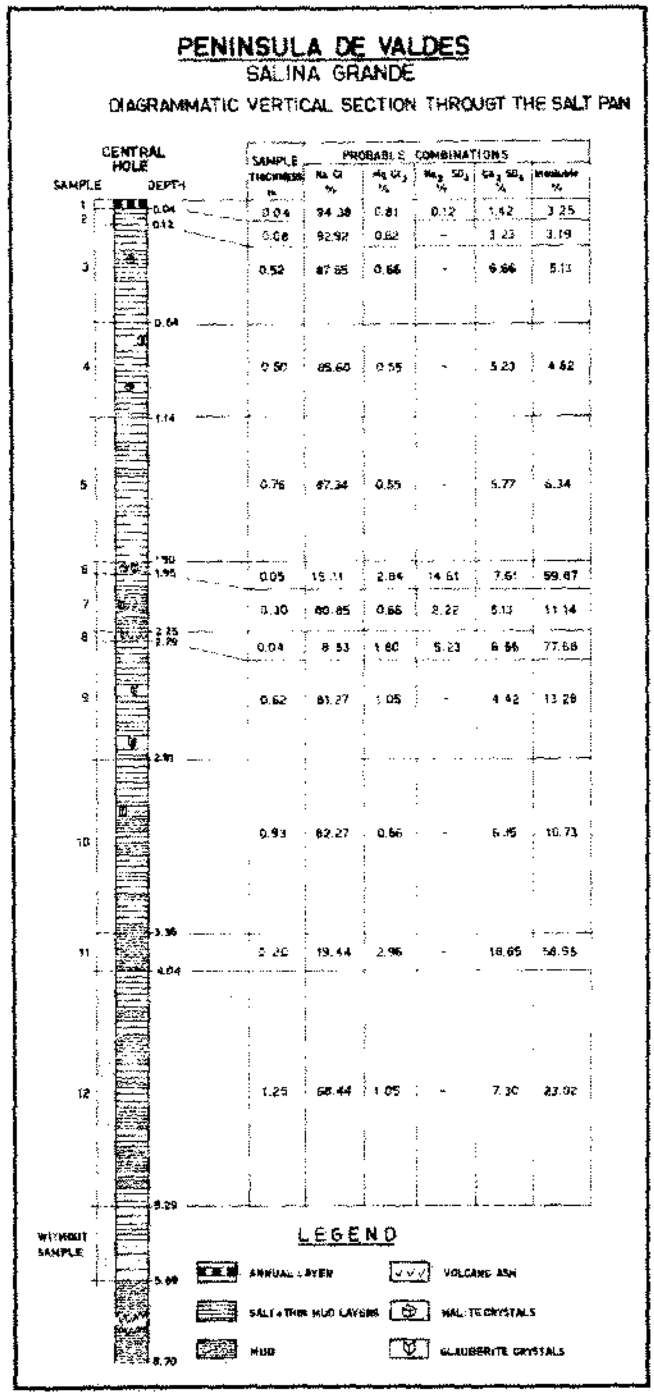

Figure 6. Diagrammatic vertical section through the salt pan at the Salina Grande, Peninsula de Valdes.

The temporary layer is composed of a superficial coat of about 10 mm made up by an association of small uniform crystals of halite, non cohesive and with many intermediate spaces, with a light rose color while wet but white once dry. This last layer crystallizes latest in the annual cycle over a thin dark layer made up of insolubles of aeolin origin. Below this there develops a second layer made up by an association of crystals of halite, somewhat more developed and coherent, of a milky white color. This last rests on 1 to 2 mm of black mud that overlays the permanent bed.

The permanent bed is formed by a succession of salt layers that alternate with thin layers of slime. These last are black or greenish black, some of them with a strong hydrosulfuric smell. Thickness varies from a few to 100 mm, exceptionally are they more than 150 mm thick.

Summing up the observations made on the three salt bodies, we may say that the thickness of the salt layers in the upper portions ranges between 40 and 50 mm, alternating with layers of 1 to 3 mm of slime. In the deep pits, such as shown in Figure 6, these layers are 50 to 400 mm thick alternating with layers of slime of 20 to 150 mm. At medium depth in this pit as well as at similar depths in the rest of the pits, the thickness of the layers of salt or slime varies gradually with between the values mentioned.

The hardness of the layers of salt is in direct relation to the degree of crystallization and this, to the age of the layers. Consequently, the hardness of the salt layers increases gradually with depth. In the upper layers, the halite crystals grow in their normal cubic habit, in the lower ones there is a gradual tendency for the halite to crystallize as prisms whose elongation is more pronounced at greater depths. For lack of lateral space to grow as cubes, the halite crystals grow vertically, aided by the plasticity of the under and overlaying slime. The lower layers of salt in the pit illustrated on Figure 6, present a massive crystallization where the cubic or prismatic habitus of halite are not identifiable macroscopically and the hardness is evidently greater. In most of the slime layers that alternate with the salt, cubic and skeletal crystals of halite develop, and only in some, idiomorphic crystals of glauberite predominate, (in Figure 6 there is one from 190 to 195 cm in depth).

Salina Chica presents a different situation. Immediately under the salt body there is a bed 20 to 900 mm thick, composed of watery slime occupying the spaces between large and small crystals of glauberite and gypsum strongly welded together; in lesser proportion there are some cubic crystals of halite. Here the content in sodium sulphate in some pits reaches more than 35% and in sodium carbonate to more than 15%.

In all three salt bodies we found conspicuous beds of volcanic ash about 50 mm thick and some lesser ones. The first, in the Salina del Gualicho about 250 cm deep, in Salina Grande at about 200 cm and in Salina Chica it shows up not very clearly below 70 cm. These ashes come from volcanic eruptions which occur even now in the Andean Cordillera.

Finally, we must mention the presence of islands, springs and brines in this salt bodies. The islands are small pieces of firm land which emerge above the horizontal surface of the salt bodies. In general they are small and don't merit much attention. In the Salina del Gualicho they are located in the western part and are composed of volcanics (ignimbrites). At Salina Grande there is only one, on the NW part which doesn't interfere with the blocking of reserves.

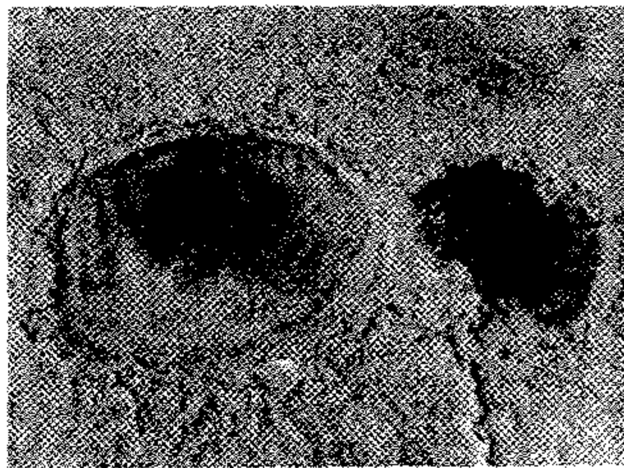

Figure 7. Springs of the Salina Grande. The larger one is 1 meter in diameter.

The springs are surficial openings of irregular conduits (Fig. 7), which lined by slime and well-developed halite crystals and are connected to the numerous layers of salt and slime that conform the salt bodies. Brine circulates through these conduits dissolving and weakening the bond between crystals and making the floor unstable for the harvesting machines. There are only a few at Salina del Gualicho and they are located mostly near the islands and in a few places of the eastern part which usually is flooded longest. On the Salina Grande they are also, scarce and restricted to the ESE edge. Due to its marginal position, this zone is not included as workable by heavy harvesters. In the Salina Chica the springs are abundant and scattered which makes the surface difficult to work.

In the computation of the mean estimated values (Table 2), all data of analysis and thickness of samples, including the intercalation of salty slimes and volcanic ashes were considered. As to the estimated mean for the Salina Chica, it does not include samples taken below the salt body with high values in sodium and calcium sulphates, also excluded from the estimation of reserves.

TABLE 2

Mean Estimated Values of Composition for the Permanent Layers of the Three Salt Bodies

Hypothetical Components	Salina El Gualicho %	Salina Grande %	Salina Chica %
NaCl	73.89	77.68	80.51
$MgCl_2$	0.52	0.86	0.63
$CaCl_2$	—	0.19	1.80
Na_2SO_4	2.95	0.99	2.26
$CaSO_4$	6.19	7.19	6.09
Insoluble	16.44	10.98	7.39

THE SURFACE OF THE SALT BODIES EXPLORED AND RESERVES

We will now give the total surfaces of the salt bodies and of the surfaces considered for the estimation of reserves. We will also give the surfaces which can bear machines and equipment in case of an eventual exploitation, except for the Salina Chica which is only practicable for medium weight equipment (Table 3).

The estimation of reserves for these salinas was done by applying the graphic block method. In the center of the straight lines which joined two exploration pits we drew perpendicular lines resulting in irregular polygons. Equidistant in the center of each polygon therefore, there is an exploration pit. For the estimation of the volume of reserves we multiplied the surface of each polygon by the thickness measured in its respective pit, separating for the estimation of tonnage, the upper layers of lower density from the deeper ones. The volumes estimated are in Table 4. The density for the upper and lower layers was determined by means of a series of data which were later averaged and resulted in a density of 1,7 kg/dm³ for the porous upper layers and of 1,9 kg/dm³ for the more compact lower layers. In the estimation of tonnage of the measured reserves we deduced 10% for the three salinas, as a security margin to cover imponderables; the resulting tonnages are in Table 4.

For the estimation of the mean grades of the salt bodies, we determined the mean grade for each one of the exploration pits with the values of the probable chemical combinations and the corresponding thickness of each one of the samples taken along each one of the sampling channels. Later, with the mean grades of the pits and the volumes corresponding to each one of the polygons we estimated the mean grades for each one of the salt deposits. These mean grades embrace each one of the salinas in total, that is to say the yearly salt bed, the permanent salt layers, the alternating layers of slimes and volcanic ashes, and are given in Table 5. With the mean grades resulting from the probable chemical combinations, the total measured reserves of salts may be discriminated as in Table 6.

The measured reserves of the Salina El Gualicho may be increased with deeper exploration pits that would allow measuring the whole thickness of the salt body. It would also be possible to add the salts contained in the western salt body which was not explored and which reach from the narrows to the NW of the main salt body and covers a surface of more than 60 km² (Table 6).

The salt that might be harvested yearly with mechanical equipment from these bodies estimating a high of 35 mm of clean salt would produce the tonnages shown in Table 7. The thickness of this surficial bed which will be regenerated yearly depends on rainfall as we briefly mentioned before. The quality of the salt to be harvested is as was mentioned for the annual layer.

TABLE 3

Surface Areas of the Salinas

Surface	Salina El Gualicho km²	Salina Grande km²	Salina Chica km²
Of salt bodies	157.5	25.6	6.2
For estimation of reserves	133	18.5	5.0
Workable with heavy machines	133	17	—
Not practicable	24.5	8.6	1.2
Islands	0.5	—	—

TABLE 4

Volume and Measured Reserves

Volume of Reserves	Salina El Gualicho m³	Salina Grande m³	Salina Chica m³
Upper layers	9,310,000	851,000	240,000
Lower levels	332,500,000	29,779,000	3,302,000
	tons	tons	tons
Measured reserves	582,820,000	52,224,300	6,013,600

TABLE 5

Mean Grades of Salts in Different Salinas

	Salina El Gualicho %	Salina Grande %	Salina Chica %
NaCl	74.57	80.25	82.5
$MgCl_2$	0.51	0.83	0.62
$CaCl_2$	—	0.19	1.72
Na_2SO_4	2.86	0.97	2.17
$CaSO_4$	6.04	6.99	5.88
Insoluble	16.02	10.65	7.09

TABLE 6

Mean Grades and Total Measured Reserves

	Salina El Gualicho tn	Salina Grande tn	Salina Chica tn
NaCl	434,610,000	41,891,000	4,961,200
$MgCl_2$	2,970,000	433,300	37,200
$CaCl_2$	—	99,100	103,400
Na_2SO_4	16,670,000	506,300	130,500
$CaSO_4$	35,200,000	3,648,800	353,600
Insoluble	93,360,000	5,559,300	426,300

TABLE 7

Harvestable Salt

	Salina El Gualicho tons	Salina Grande tons	Salina Chica tons
Salt to be extracted on the surface	7,900,000	1,104,000	298,000

At present, on the Salina El Gualicho, some 20,000 tons are harvested yearly, though there is a project for extracting 360,000 tons a year to supply a future soda ash plant.

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