SALTPAN SURFACE VARIATIONS ANALYSIS WITH RADARSAT-2 DATA.

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ABSTRACT

The aim of this paper is to give the general outlines of a SOAR project named “Saltpan surface variations analysis with RADARSAT-2 data”. The main goal of this project is to study the potential of polarimetric RADARSAT-2 data for landscape and environmental analysis of quaternary salt bodies located in the southern part of Buenos Aires province, Argentina. Most of these deposits are traditionally exploited to mining “salt” for industrial and domestic use. However, their exploitation is conditioned by a number of factors related to environmental and weather conditions as well as on hydrologic regimes. The geomorphologic, hydrological and environmental settings of recognized salt pan deposits of this area are presented, as well as the general properties of their evaporite minerals, resulting from field and laboratory studies. Also, the methodological approach proposed to take advantage of RADARSAT-2 data is discussed.

1. INTRODUCTION

In Argentina, salt bodies are widespread all around the country [1], from the north to the south, and most of them are of economic interest, as a source of natural “salt” [2]. The most important salt bodies are located in Salta and Jujuy provinces (north region), Córdoba and San Luis provinces (center-north), Buenos Aires and La Pampa (center-south). Within these salt bodies we can distinguish: saltpan deposits (basins with commercially exploitable sodium chloride), sulphate deposits (sulphate-rich basins) and salt-peter deposits (basins where clastic material is dominant over salts).

In the southern part of the Buenos Aires province (Fig. 1), some morphological depressions, sometimes with negative altitude referred to the near sea level, have been developed. During the last 10 My, the semi-arid conditions of this area have facilitated the concentration of evaporite minerals with temporary saltpan deposits. These salt deposits are in continuous change due to the influence of different environmental agents (superficial waters, deep aquifers, winds, temperature, wetness, etc.) conditioning saltpan evolution and exploitation by harvest methods. Evaporitic deposits are the most important economic Holocene mineral resource of this area. Because of their environment dependence and delicate stability, saltpan equilibrium and benefit is usually affected by climatic exceptional circumstances.

The main objective of this project is to study the potential of polarimetric RADARSAT-2 data for landscape and environmental analysis of salt bodies located at the southern region of Buenos Aires province. It is expected that this images will contribute to analyze the dynamics and evolution of these salt bodies, and to find an adequate model for their genesis. From the methodological point of view, we will look forward to establish a methodology to routine mapping and monitoring this kind of deposits, typical for semi-arid areas, taking into account environmental conditions and consequences. Polarimetric RADARSAT-2 data could offer new criteria for discrimination and mapping the different textural and compositional variations inside these salt bodies, which condition harvest possibilities.

2. GENERAL SETTING

The study region is located near the southern coast of Buenos Aires province, from 62º to 64º W and from 38º to 41º S (Fig. 1a). The relief is flat to slightly undulated, with some marked morphological depressions, frequently aligned in the NW-SE direction. These basins could contain one or more actual saline bodies and saline lakes. This particular area constitutes a transition zone between the Pampas region, at the North, and the Patagonian region, at the South.

The general climate is semi-arid but weather conditions change gradually from the north to the south. Pluvial precipitations are about 350 mm/year at the south but could reach 450 mm/year at the north. The wettest period is from August to October (almost springtime), followed by autumn season (from April to June). The temperatures are quite moderate, with a cool season (winter: 7ºC), a hot season (summer: 27ºC), and two transitional seasons (springtime and autumn). The
Evapotranspiration levels reach precipitation levels during almost the whole year, except in summer season where these levels increase so much that they overcome long precipitation levels and determinate a water deficit that facilitate the concentration of evaporite minerals.

In this area, there are two main groups of saline basins 200 km apart in the N-S direction (Fig. 1b). This research will be focused in these two areas. North area is located near Médanos (Villarino district) north of Río Colorado, related to Bahía Blanca Estuary while South area is located north of Río Negro, near Carmen de Patagones (Patagones district).

2.1. North Area

North area main feature is a regional tectonic NW-SE depression, 6 to 10 km wide, controlled by faults (Fig. 2). This lowland starts at Lihué Calel Hills, in La Pampa province, at the west, and through Laguna Chasicó, Salinas Chicas and Salitral de La Vidriera, extends towards the East in the Canal Principal of Bahía Blanca Estuary.

Outcropping geological units recognised in this area correspond to the Late Mioocene-Holocene period [3]. Oldest unit is F. Arroyo Chasicó, composed by clay-sandy silt of continental origin (fluvial and aeolic) from the Late Miocene. Above this unit appears F. Los Salitrales, integrated by lacustrine sediments and whose upper part is interdigitated with F. Río Negro, composed by bluish-gray sands of fluvial origin, with crossed stratification. Both units are of Late Miocene-Pliocene age. In this area it is found also a sandy-gravel level, with calcareous cement from Pleistocene age, the Grava Arenosa Salinas Chicas, of fluvial origin, which represents very northern relicts of the Rodados Patagónicos. Finally, very widespread in the area, is F. Estancia La Aurora of Holocene age. It is composed by sand mantles and sand dunes integrated by median and fine sand with a few proportions of silt and clay.

2.2. South Area

This area is characterized by the alternation of hills and close depressions, most of them alienated and elongated in NW-SE direction, such as those that lodge Salitral del Algarrobo, Salina de Piedra, Salitral del Barrancoso and Salitral Grande. The others have more circular shapes: Salina del Inglés and Salina del Eje. Eastern depressions have an active communication with the near sea by tidal channels during the high tidal periods (Fig. 3).

Outcropping geological units in this area correspond to the Pliocene-Holocene period. Oldest recognised unit is F. Río Negro, of Pliocene age, which is visible at the saline ravines and is composed by bluish-gray sands of fluvial origin, with clay intercalations and calcareous cement in the upper levels. Above this unit it appears a fluvial gravel level of the Rodados Patagónicos, some times re-worked by marine action. In higher areas, several terrace levels composed of reworked gravels, corresponding to ancient tidal plans are found [4]. Over these gravel units, it is found an aeolic level composed by silty fine sand sediments correlated with F. Estancia La Aurora from the Holocene. This geological sequence ends with marine salty sediments with mollusc and brachiopod shells, from modern sea ingressions.

Figure 1. Geographic situation of the study area and general location of interest groups of saltpan deposits.
Figure 2. LANDSAT-TM image showing North group of interest saltine deposits of the study area.

Figure 3. LANDSAT-TM image showing South group of interest saltine deposits of the study area.
3. SALTPAN GENERAL MORPHOLOGY

Saltpan deposits could be described as evaporite minerals concentrations of variable size and shape, usually located within morphological depressions. Most of the saltpans of the area are described in [5] and [6]. They are composed by salt flats and mud flats surrounded by sand flats, ravines and aeolian deposits. Their mineralogical composition is dominated by halite, with intercalations of gypsum, clastic materials and organic matter and, in some cases, glauberite. Within these salt deposits, different kinds of surfaces could be differentiated, depending on their origin (continental or marine) and evolution stage. They vary in the proportion and texture of evaporite minerals, the clastic materials contribution, the concentration and density of brine, the thickness of evaporite layers, etc.

Saltpan mean body is surrounded, generally, by a flat zone of sediments, which could be colonized by sparse halophyte vegetation (Fig. 4). In this flat zone two different areas could be recognized: a) an external area: “distal flat” or “sand flat”, composed by sand-silty sediments, that could occasionally be covered by a very subtle layer of salts, and b) an internal area: “proximal flat” or “mud flat”, composed by clay-silty sediments. These sediments, of dark colorations, rich in organic matter, extend towards the interior of the saline body itself, below the layer of salts or as thin interleaves between the evaporite levels.

In saltpan central area an evaporitic layer of variable depth is located. Its more superficial part constitutes the “temporary reserve” of salt, precipitated recently. This layer is subjected to successive dissolutions and annual re-precipitations, and do not surpass 5 cm of thickness. Directly below the temporary salt layer, mediating sometimes a clastic sediment level, it appears a more compacted salt horizon that constitutes the “permanent reserve” of salt, not subject to annual dissolution processes. Its upper levels are composed principally by halite, going trough deeper levels, gradually richer in mud and hydrated sulphates (gypsum and glauberite). The depths of these deposits could vary from 5 to 10 m. The 4 or 5 superior meters are richer in salts (more than 50%).

On top of these salt levels, they are found the superficial waters, constituted by almost permanent saturated brine with a variable depth that in general does not surpass 30 cm. According to the flooding and desiccation periods succession of these basins, is even observed an oscillation in the water level, which leads to long periods of total drying of the lagoon. As a consequence of this seasonal and climatic dependency, it is possible to have years with more than one salt harvest and years with none.

Distinctive features of mean salt bodies of the study area are well described in [7] and [8] for northern area saltpans (Salinas Chicas, Sulfatera Choique, Salitral La Vidriera and Laguna Chasicó), and in [9] and [10] for the southern ones (Salina del Inglés, Salina de Piedra o Caglier, Salina del Eje, Salina La Espuma, Salitral del Algarrobo, Salitral del Barrancoso and Salitral Grande).

Figure 4. General morphology and composition of saltpan deposits.
4. SALT-PAN EVOLUTION

In saltpan deposits they could be recognized different stages of evolution that modifies surface characteristics of the salt body and the size of the exploitable deposit: a) flooding of the basin, b) evaporative concentration and c) desiccation and diagenesis. They constitute the main evolution stages of a typical saline life cycle [11].

a) Flooding of the basin: except in summer, saltpan may be covered by several tens of cm of water, mainly derived from the upwelling of the surroundings aquifers and also from contribution of rainfall and tributaries. The salt body is permanently impregnated by brines which are a few cm below its surface. As soon as the levels of the aquifers rise -as in winter- flooding occurs needlessly of an inflow of floodwaters from tributaries. Flooding leads to a partial dissolution of superficial salt and to the formation of saturated and undersaturated brines. Textures such as cavities and channels, crystals rounding and porosity, testify the temporary conditions of subsaturation. In this stage, organisms reach their maximum development and vermiform channels and other animal remains and traces may be seen in the salt body close to the surface. During this stage, the maximum accumulation of clastic material occurs.

b) Evaporative concentration: this stage is reached when the combined effect of wind and heating leads to the prevalence of evaporation over fluid supply and supersaturation conditions takes place. The salt body grows, with an initial formation of laminae (rafts) and tabular hoppers of halite at the brine-air interface, cemented by fine-grained halite. They form the annual layer of salt, 2 to 8 cm thick, depending on the season. In this stage, according to their solubility, a separation of the saline phases occurs, with an initial precipitation of sulphates and successive layers with more than 96% of halite. During the dry season winds continuously shifts the clastic material fallen on the saline surface.

c) Desiccation and diagenesis: desiccation in the dry season affects only the most superficial part of the salt deposit, as brines permanently impregnate the entire thickness of the salt body. Salt crystallize from brines, with an overall increase in volume which leads to pressure gradients. Within the first 30-60 cm, early diagenesis phenomena include cavity filling by halite, syntaxial growth of cornet and chevron structures, and genesis of large euhedral displacive halite and gualberite crystals within the muddy levels. At deeper levels brine aquifers under pressure flowing in between salt layers; they are a powerful agent for diagenetic processes leading to solution-recrystallization, textural modifications and salt layers compaction. Sporadic uplifting and polygonal rupture of the superficial salt crust may be seen. Along the fracture lines, spongy, fine-grained white halite often crystallizes.

Typical features of these stages are illustrated in Fig. 5 with several images of salt the bodies of the study area.

Figure 5. Typical views of characteristic saltpan surfaces at different stages: a) general view of saltpan surrounded by a flat zone with sediments, b) mud flat area with gypsum crystals, c) sand flat area with halite crystals d) salt lake in winter (basin flooding stage), e) saltpan in summer (evaporative concentration stage), f) polygonal ruptures with spongy halite crystallization (desiccation and diagenesis stage).
5. TECHNICAL PROPOSAL

There is not an extended bibliography available neither about radar images use nor about the use of satellite images in general, in the study of saline deposits. We can mention the researches of [12] and [13] as a general reference, and the very exhaustive work of [14] with multispectral and hyperspectral data of White Sands (New Mexico). As an example of the potential use of radar images in this kind of environment, we can point out the work of [15], which tests the use of AIRSAR, AVIRIS and TIMS data to obtain information about surface roughness, mineralogy and moisture content of salt flats and alluvial fans of Death Valley, California.

5.1. Objectives and Methodology

Within this context, polarimetric RADARSAT-2 data is proposed to be used in this investigation, together with multispectral ASTER data. The main methodological bases for this research are image processing and field control, supported by laboratory studies, oriented to:

a) Test polarimetric images discrimination and mapping potential applied to saltpan surfaces by analyzing the relationships between radar response and ground characteristics using field criteria of surface roughness, moisture content, mineralogical composition, etc.

b) Look for the optimal choice of polarimetric data in terms of polarization, incidence angle and resolution for the study of different saltpan surfaces (salt flats, sand flats, and mud flats) and salt deposits (halite deposits, sulphate-rich basins and saltpeter deposits).

c) Explore the integration of radar polarimetric data with optical multispectral data to better exploit their synergism in the study of this kind of deposits and their surroundings, at different observational scales.

d) Establish a methodology to routinely map saltpan surface characteristics and extension and to monitor the evolution and cyclic changes of salt bodies.

Two groups of images will be used -winter images and summer images- to analyze and monitoring the evolution and seasonal changes of salt bodies and their dependence on the environmental and hydrological conditions. For each seasonal group of images, the research will be carried out at three different scales: regional, local and detailed. At the regional scale the research aims at the analysis of geological setting and the relationships with the regional drainage network and the near sea of the geomorphologic depressions containing several salt bodies. The local scale is selected in order to study closely spaced salt bodies located within the same basin. The emphasis is put on their general morphology and that of their surroundings (aeolian deposits, ravines, cliffs, etc.) as well as on their hydrological conditions. At the detailed scale the study will be oriented to the internal characteristics and compositional and textural variations of individual salt bodies.

5.2. Images Acquisition Plan

The research will be focused initially on the south area to take advantage of the heterogeneity of the salt bodies. For both south and north areas it is planned to acquire summer and winter images. The following images will be acquired for this research:

a) Summer images:
   1. South area:
      - Two Standard Images both SDP modes (HH+HV and VV+VH) covering the whole area of interest, including saltpan, saltpeter deposits and coastal areas.
      - A Fine Quad Polarization FQP (HH+HV+VV+VH) covering the most important saltpan of the area and its surroundings, centred in a selected saltpan.
   2. North area:
      - A Multi Look Fine Image in SSP mode to be selected based on the results obtained from the south area study.

b) Winter images:
   1. South area:
      - Two Standard Images both SDP modes (HH+HV and VV+VH) covering the whole area of interest, including saltpan, saltpeter deposits and coastal areas.
      - A Fine Quad Polarization FQP (HH+HV+VV+VH) covering the most important saltpan of the area and its surroundings, centred in a selected saltpan.
   2. North area:
      - A Multi Look Fine Image in SSP mode to be selected based on the results obtained from the south area study.

6. DISCUSSION

We think that the study of salt bodies could benefit from the availability of RADARSAT-2 full polarimetric data, because of it sensitivity to small-scale morphological surface characteristics, scattering mechanisms and scattered types differentiation. Also the different polarization options could help to isolate the effects of surface roughness and soil moisture and to separate wetland from not wetland areas. Discrimination of salt surfaces according their small-scale surface roughness characteristics could benefit from the fine resolution and cross polarization of data. The revisit period could be an advantage because it gives the possibility of routine mapping and monitoring the dynamic of the evaporite deposits of the study area. Working with radar data on this kind of mineral deposits could provide methods and techniques for mapping salt surfaces of different nature and characteristics, understanding their distribution within the salt bodies and monitoring their evolution.
The characteristics of the salt pan and salt flats surfaces (roughness of the salt deposits, amount of silt, etc.) are indicatives of their formation particularities and also they condition the possibilities and methods of salt harvest. Within this perspective, the results of this project could offer a new tool to control salt bodies’ evolution and salt exploitation by miners and also to understand and manage salt bodies’ environmental conditions that could be affected by climatic exceptional circumstances, as it is happening actually.

As a conclusion, the realization of this research project, apart to increase the geological and environmental knowledge of the region as well as of its mineral reserves will produce a positive impact in the understanding of RADARSAT-2 polarimetric data.

7. REFERENCES


