Mineral mapping in salt lakes from Sud Lipez (Bolivia) using ASTER images

Fernando Cáceres, Hamid Ali-Ammar and Eric Pirard
Université de Liège, GEOMAC, *Géoressources Minérales et Imagerie Géologique*,
Sart Tilman B52
4000 LIEGE
eric.pirard@ulg.ac.be

INTRODUCTION

This work is a contribution to an already large literature on remote sensing of evaporitic mineral sequences. Both optical (multi and hyperspectral) as well as radar sensors have already demonstrated a huge potential in this kind of environment, be it for mineral mapping or for monitoring purposes.

The Lipez region is situated in the extreme south of Bolivia and is essentially covered by a Neogene-Quaternary volcanic complex. As compared to the Altiplano which is a single large hydrographic basin, the Lipez region is characterized by the existence of more then thirty closed and independent intravolcanic basins. Because of the scarcity of the vegetal cover (Bolivian side of the Atacama desert) it is an outstanding region for testing the capabilities of remote sensors. In this preliminary work, ASTER images are combined and validated with previous results from field exploration.

A dry climate with low rainfall rates (100 mm/y) together with the closed topography of numerous drainage basins is responsible for the large amount of salt lakes formed in the region. The majority of these salt lakes (salars) are characterised by a dominant Na-Cl or Na-Cl-SO_4 composition. The nature of the precipitated evaporitic sequence is mainly conditioned by three factors (Risacher, 1992) : the origin of the feeding waters coming both from the drainage of volcanic rocks and the remobilisation of ancient evaporite deposits; the presence of sulphuric exhalations from the active surrounding volcanoes and the hydrogeological characteristics of the aquifers. All basins from the Lipez display a combination of salt lakes, salt crusts, playa lakes and shallow depth aquifers.

The spectral characteristics of evaporitic minerals have been studied by various authors (Crowley, 1991; Drake, 1995; Crowley and Hook, 1996). In the VNIR-SWIR region, these characteristics are attributed to internal vibrations of borates, carbonates and hydroxyl anions as well as to water molecules. The emittivity is mostly linked to sulphate carbonate and borate anions.

METHODOLOGY

A complete GIS with all data available from the region was built in order to improve data processing and understanding. ASTER 1B images were acquired between 2000 and 2002 and were corrected for reflectance in the VNIR-SWIR regions. In order to improve the results of spectral classification, the salt lakes were manually delineated and subsequent operations were performed using these limits as masks for the image.

Spectral unmixing algorithms provide an efficient tool for the interpretation and classification of multi/hyperspectral images. They are based on the identification of the purest pixel signatures which are considered to be end-members that combine linearly to explain all remaining pixels in the image.

The literature presents several methods to extract pure pixels in a scene, in this work, a pure spectral approach (PPI) and a spatio-spectral approach (AMEE) were used and compared.

The Pixel Purity Index technique (Boardman et al. 1995) is based on the geometrical properties of convex sets considering each pixel as a vector of an N-dimensional space. The algorithm is not applied on the raw image but on the result of the data reduction process based on the minimum noise fraction transform (Green et al. 1988). It starts by generating a large number of random n-D vectors (skewers) onto which all pixels of a scene are projected. Pixels which appear to be the most extreme for each skewer are labelled and their counter is incremented. Finally a resulting image with the number of votes per pixel is produced. Only those pixels which were voted for more than a thousand times are retained as possible end-members.

Candidates to be realistic end-members are further selected on the basis of a spectral reference library by exploring their position in n-D space. This supervised selection procedure requires the user to be familiar with remote sensing and mineral spectroscopy. A major drawback of the PPI technique is that it is poorly interactive and cannot be used for quickly classifying a large number of images. Many authors consider the random nature of the skewers to be a limitation of the algorithm.

AMEE (Plaza et al. 2002) stands for Automated Morphological Endmember Extraction.

It extends the use of the spatial processing tools developed in the framework of mathematical morphology to multispectral data. Therefore each pixel is given a measure of distance in the n-D spectral space by comparing its spectrum to the average spectrum within a selected neighbourhood (structuring element). This distance metric allows for using dilation and erosion operations. The distance operator propagates the maximum distance values, which are supposed to correspond to more outlying pixels or pixels with the highest local purity. On the contrary, the erosion operator favours the minimum distance value corresponding to the most mixed local pixel signature. The difference between dilation and erosion provides a measure of local contrast and is called the morphological eccentricity index (MEI).

The algorithm is multiscale in that it is run successively on increasing local neighbourhoods, starting typically with a 3x3 kernel and ending up with a 15x15 kernel or more. A final MEI image is built by taking the maximum of MEI obtained at all scales. This MEI image is automatically thresholded using the Otsu method. A final region growing algorithm is used to filter and refine the MEI classification image. The average spectra of the regions defined in that way are considered as end-members.

The AMEE algorithm, as developed by the authors, is based on square structuring elements but could obviously benefit from a combination of linear structuring elements in order to fit more adequately with stratified and folded geological structures. Another drawback is that it may exaggerate the purity of a pixel, typically in regions where all pixels are pure and refer to different end-members. But, this does not appear to affect significantly the algorithm.

RESULTS

This work focuses more precisely on two salt lakes out of the thirty : the "Salar de Capina" (playa lake – Na-Cl-(SO_4) and the "Salar de Pastos Grande" (playa lake – Na-Cl). Both the PPI and the AMEE methods have been used. This last one was tried at different scales and with variable region growing criteria. As a result, it appears that modifications in the size of the structuring elements does not affect the final results : all selected end-members remain the same although they come out in a different order. This is most probably due to the very homogeneous nature of salt lakes and should not be expected in more variable geological environments. The authors of the technique typically recommend using structuring elements slightly larger than the smallest homogeneous spots encountered in the image. The "spectral angle" used by the region growing algorithm is a very sensitive parameter and should be used with care. The most significant end-members appear to spring out for almost any value of the spectral angle, but many end-members appear in duplicate form when reducing the spectral angle value.
A value of 0,1 was used for the Capina image whereas a value of 0,001 was preferred for Pastos Grandes wherein end-members display a larger heterogeneity.
Final end-members were selected by comparing the output of both the AMEE and the PPI method. On both salt lakes, five end-members appeared to be common out of the seven retained by PPI and six proposed by AMEE. This is considered as a proof of significance of the end-members.
Further classification of the multispectral ASTER scenes was tried using both the Mixture-Tuned Matched Filtering Method (MTMF) and the Spectral Angle Mapper Method (SAM). Both methods reveal spatial variations that are in good accordance with geological exploration data and mineralogical maps published by Risacher (1992) and other authors.
This is an encouragement in using future hyperspectral remote sensing for prospecting borate or trona deposits.

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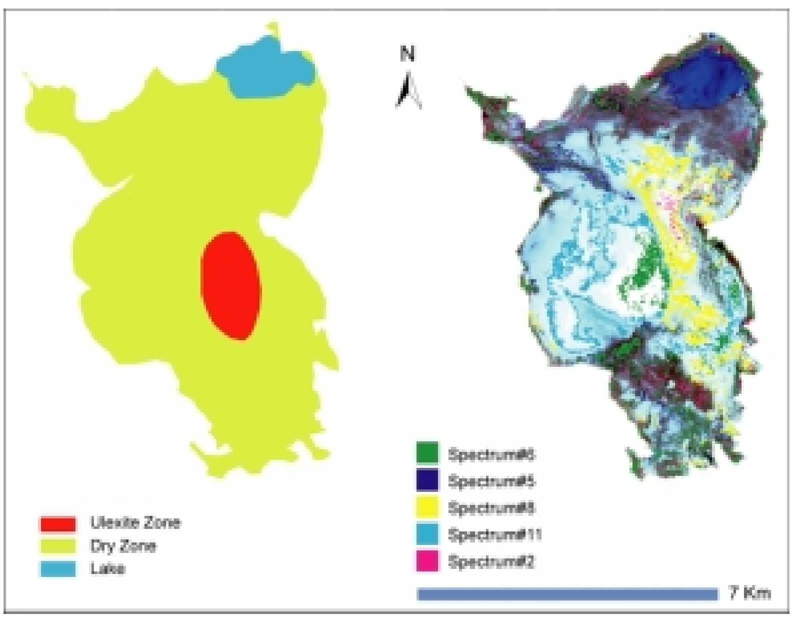

Fig1 : Comparison between the sketched geological map of Salar de Capina (Ballivian & Risacher, 1981) and the thematic mapping resulting from MTMF classification of AMEE end-members in an ASTER scene. The yellow spectrum closely resembles Ulexite.

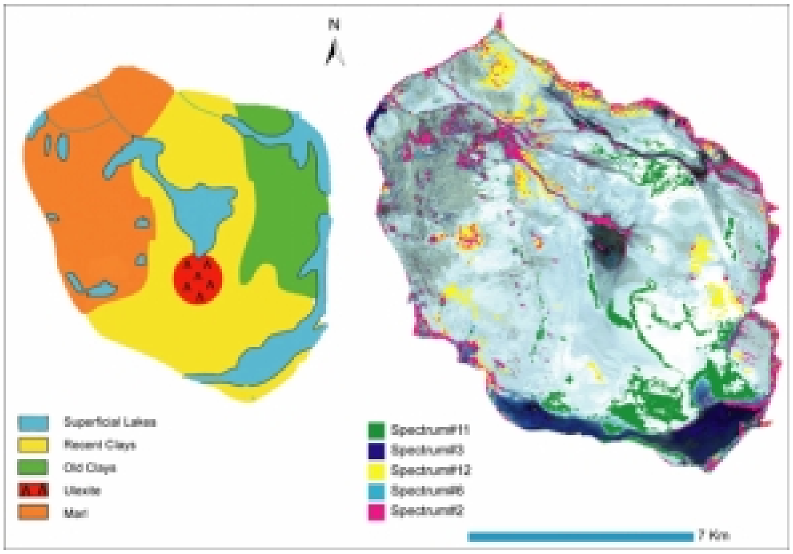

Fig1 : Comparison between the sketched geological map of Pastos Grande (Servant-Vildary et al., 2002) and the thematic mapping resulting from MTMF classification of AMEE end-members in an ASTER scene.