Landsat ETM+ Imaging for the Exploration of Epithermal Deposits in the Azuero Peninsula (Panama)

/ ISAAC CORRAL (1,), FELIPE GONZÁLEZ (2), ALBERT GRIERA (1), MERCÈ CORBELLA (1), DAVID GÓMEZ-GRAS (1), ESTEVE CARDELLACH (1)*

(1) Departament de Geologia, Unitat de Cristal·lografia i Mineralogia. Universitat Autònoma de Barcelona. 08193, Barcelona (España).
(2) Departamento de Geologia. Universidad de Huelva. 21071, Huelva (España).

INTRODUCTION.

Remote sensing can be understood as the science, technology and art of acquiring, processing, and interpreting airborne or spaceborne images that record the interaction between matter and electromagnetic energy (Sabins, 1997, Aranoff, 2005). Nowadays a plethora of satellites surrounding the earth provides continuous sets of data of quite different nature used for navigation, positioning, meteorology, surface temperature, sea water condition, etc. Among the most interesting satellites dedicated to systematically provide global covered of earth resources are the Landsat family. The currently operative Landsat sensors (Thematic Mapper "TM" and Enhanced Thematic Mapper "ETM+") record three wavelengths intervals (bands) of visible energy (blue, green, and red) plus four inferred bands, including a thermal one. Such broad spectral coverage together with their mid-range spectral and spatial resolution allows the identification and analysis of the vast majority of surface materials, including rocks, soils, vegetation, snow and/or ice, and man-made materials (Crosta and de Souza, 2009). In geologic terms Landsat provides data especially useful for mineral exploration. It can be used to identify areas containing minerals useful in the search for mineral deposits, including iron oxides and/or hydroxides (hematite, goethite and limonite), clays (kaolinite, dickite and montmorillonite), micas (illite, sericite and muscovite), sulfates (jarosite and alunite) and carbonates (calcite and dolomite). The aim of the present work is to use Landsat imagery for reproducing the hydrothermal alteration system of a well-studied mineralized area, such us the Cerro Quema epithermal Au-Cu deposit, in order to apply an additional exploration criterion in similar terrains. Here we present the preliminary results of this research.

GEOLOGIC SETTING.

The Cerro Quema Au-Cu deposit is located in the Azuero Peninsula, SW Panama (Fig. 1). The deposit is constituted by several mineable bodies named (from East to West) Cerro Quema, Cerro Quemita and La Pava. The estimated total resources are about 10^6 metric tons with an average gold grade of 1.26g/t (Torrey and Keenan, 1994).

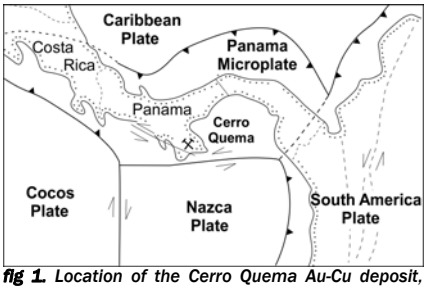

fig 1. *Location of the Cerro Quema Au-Cu deposit, adapted from Corral et al. (in press).*

The study area is constituted by volcanic and volcaniclastic sediments interbedded with hemipelagic limestones, submarine dacite lava domes and by crosscutting basaltic-andesitic dikes, belonging to the Río Quema Formation (RQF; Corral et al., in press), representing a fore-arc infill sequence. The Cerro Quema Au-Cu deposit is hosted by dacite lava domes of the RQF and is characterized by a widespread hydrothermal alteration typical of high sulfidation epithermal systems.

HYDROTHERMAL ALTERATION.

The Cerro Quema hydrothermal alteration develops concentric alteration halos in the host rock following E-W trending regional faults (Corral et al., in press).

Results of the mineralogical study show an alteration pattern composed of three zones:

- An inner zone; characterized at the surface by vuggy silica with hematite, goethite, barite, pyrite and rutile. This mineral paragenesis corresponds to an advanced argillic alteration.
- An outer rim; composed of quartz, kaolinite, illite, smectite and interlayered illite-smectite, corresponding to an argillic alteration zone.
- A propylitic zone; only observed in a few drill core samples, apparently unrelated with the previous alteration zones. It is characterized by pyrite, chlorite, epidote, calcite and siderite.

METHODOLOGY.

The scene employed in this study consists of a Landsat ETM+ image that covers the eastern Azuero area. It was acquired on 17/01/2001 and identified by path 12 and row 55. Imagery pre-processing included the conversion of raw Landsat ETM+ images to radiance values using constants provided by the attached header file, and then the transformation to apparent reflectance following the Bidirectional Reflectance Distribution Function (Vermote et al., 1994). Image improvement was done using brightness corrections, contrast and edge enhancement. Band combination and rationing were applied to the ETM+ images to emphasize the geologic properties of the studied area. Image processing was performed with the remote sensing package of gvSIG software. The ETM+ bands used in the study are indicated in Fig. 2.

The satellite image processing was initially applied to the Cerro Quema Au-Cu deposit, (central Azuero Peninsula), a mineralized area previously mapped in detail (Corral et al., in press). The "calibrated" methodology was then applied to the Juan Diaz prospect,

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* corresponding author: **Isaac.Corral@uab.cat**

(eastern Azuero Peninsula), an area with similar geologic features with only weak field evidences of hydrothermal alteration (advanced argillic alteration and argilic alteration).

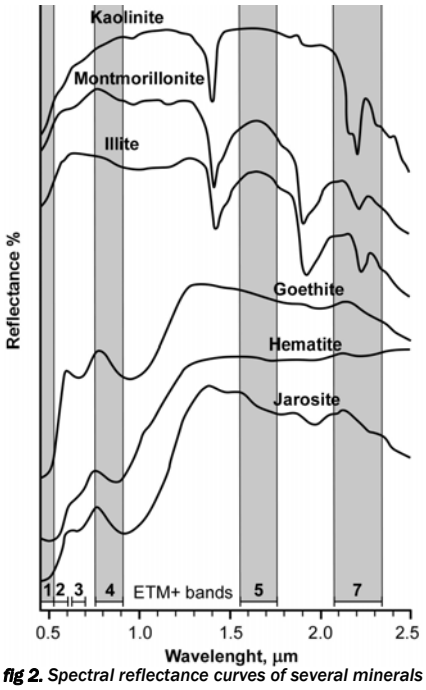

fig 2. *Spectral reflectance curves of several minerals (from Sabins, 1997, 1999) with indication of ETM+ bands. Those in gray color represent bands used in the study.*

CERRO QUEMA AU-CU DEPOSIT.

The hydrothermal alteration map of the Cerro Quema Au-Cu deposit shows several zones of silicification surrounded by an external halo of argilitization with a superimposition of iron oxides. Such scheme represents the alteration pattern of a high sulfidation epithermal deposit. In order to reproduce this pattern with the Landsat image we used a combination of bands 1, 4, 5 and 7 (fig. 2), to emphasize clay minerals, iron oxides and silicificated rocks. The result is an overlap of the ratios 5/1, 5/6 and 5/4 (fig. 3), where 5/1 ratio (not shown) emphasizes iron oxides, 5/6 ratio, in gray color, emphasizes clay minerals, and 5/4 ratio, in white color, emphasizes silicification. This result is in good agreement with the hydrothermal alteration map.

JUAN DIAZ PROSPECT.

The image processing successfully employed in Cerro Quema was also applied in the Juan Diaz prospect (Fig. 3). A satellite image of this area shows only a few rock outcrops where just some points with hydrothermal alteration are visible, mostly along the coastline. Fig. 3 represents the hydrothermal alteration map derived from the Landsat ETM+ image, processed as in Cerro Quema. Clay minerals are represented in gray color and silicification in white. In the image it is also observed an inner zone with silicification surrounded by a clay halo. This alteration pattern follows a fault zone broadly oriented NW-SE.

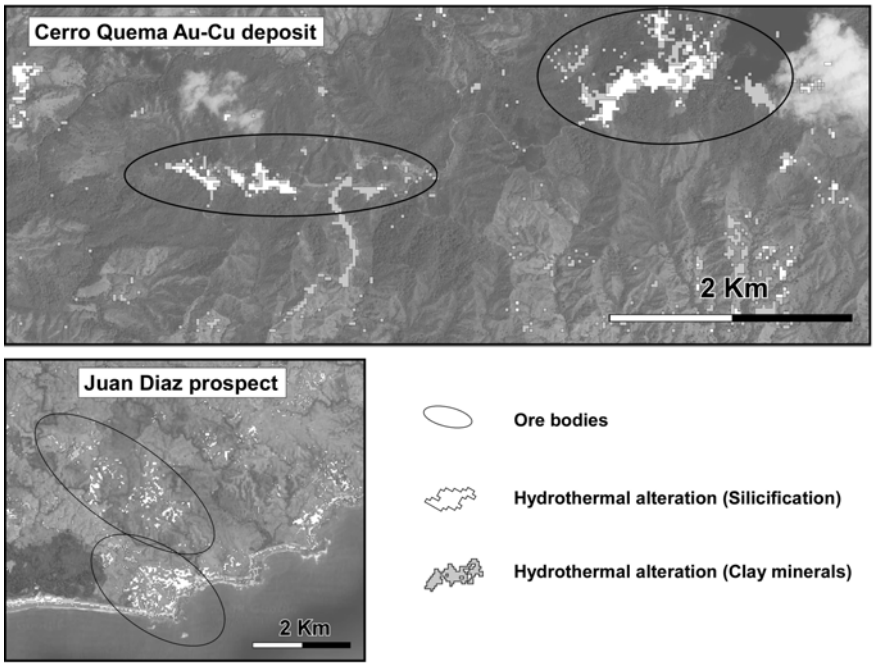

fig 3. *Processed Landsat images of Cerro Quema deposit and Juan Diaz prospect, both showing hydrothermal alteration.*

CONCLUSIONS.

Remote sensing is a valuable mineral exploration tool for high sulfidation epithermal deposits as it permits differentiation between areas with argillic alteration, silicification, and those with iron oxides. However, the accuracy of this tool dramatically increases when applied in conjunction with detailed field geology. In the present study, Landsat ETM+ band rationing method was used and calibrated in Cerro Quema, a well-studied Au-Cu deposit, and then applied to Juan Diaz, an adjacent area with similar geologic features. The data obtained in this prospect provide promising results in order to plan new exploration programs.

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