IDENTIFICATION OF HYDROTHERMAL ALTERATION USING SATELLITE IMAGES IN AREAS WITH DENSE VEGETATION COVER

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Key Words: Remote Sensing, Principal Components Analysis, Exploration, Hydrothermal Alteration, Crósta Technique.

ABSTRACT

TM images were used in order to characterize areas with hydrothermal alteration. Processing of the images included principal components analysis and False color composition (RGB). The studied area is located in the western border of the Mexican Volcanic Belt and hosts still unexploited ore deposits (mainly opal and precious metals) of hydrothermal origin. The stratigraphic column includes products of the volcanic activity that formed the Sierra Madre Occidental during the Tertiary, and of the recent volcanic activity related to the still active Ceboruco Volcano. The main problem is to differentiate the hydrothermally altered rocks from vegetation covered areas in the satellite image. The band ratios did not yield good results in removing the spectral effect of the vegetation cover in areas that contained hydrothermally altered rocks, this was due to the high correlation between the bands as was shown when they were analyzed using the principal components approach. The removal of the vegetation spectral effect was done using the Crósta technique for bands: 1, 3, 4, and 5, for oxides analysis; and 1, 4, 5, 7, for hydroxyls analysis. All the zones of alteration mapped in the field coincide with the areas marked as hydrothermally altered in the resulting images.

1. INTRODUCTION

Remote sensing techniques have been used in the early stages of exploration in order to reduce the extension of the area to be studied with geophysical and geochemical methods (Blake, 1983; Guo and Zing, 1983; Podwysok, et al., 1983). The most important surface features for geothermal and mineral exploration that can be mapped with satellite images are the main structures and areas that contain hydrothermal alteration minerals (Buckingham and Sommer, 1983; Kaufmann, 1988; Drury and Hunt, 1989).

Hydrothermal alteration minerals (mainly hydroxyls) and their weathering products (mostly oxides) are recognizable by the processing of satellite images due to the reflectance anomalies that are present in the blue, red and middle infrared bands (Thematic Mapper bands 1, 3, 4, 5 and 7). TM bands 5 and 7 are especially useful for this purpose. In this study we will show the applicability of multispectral satellite image processing in identifying hydrothermally altered rocks in an area covered by diverse vegetation types: crops and shrubs in the lowland, and small trees in the higher elevation land.

2. GEOLOGIC SETTING AND DISTRIBUTION OF HYDROTHERMAL ALTERATION

The study area is located in the border between the Sierra Madre Occidental and the Mexican Volcanic Belt. between 20°53'N and 21°31'N, 104°38'W and 105°34'W. The geology is mainly composed of Cretaceous and Pleistocene rocks. Cretaceous rocks are mainly composed of sandstones, shales and limestones while Pleistocene rocks are mainly composed of volcaniclastics and volcanics. The Pleistocene volcaniclastics are mainly composed of andesite and basalt, while the Pleistocene volcanics are mainly composed of dacite and rhyolite. The Cretaceous rocks are mainly composed of sandstones, shales and limestones.

LEGEND

Fig. 1. Location of the studied area, simplified geology (after Romero et al., 1991), and mapped hydrothermal alteration areas.
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and 21°12'N and 104°20' and 104°38'W. It comprises an area of
1166 km². The surface geology in the area (Fig. 1) is characterized
mostly by igneous rocks, with ages ranging from Tertiary to
Recent; however, rare outcrops of older sedimentary and
metamorphic rocks are also found.

The fault patterns are represented by the NW-SE and the
NE-SW directions that form fault pairs and resulted in the formation of
the Ceboruco and Amatán de Cañas tectonic basins (Ferrari et al.,
1993). The structures in these basins are similar to those of a
graben. The Ceboruco basin is formed by three parallel normal
faults with strike N120°E; it is within this basin that the Ceboruco
Volcano is located. The Amatán de Cañas basin is formed by two
large normal faults, one to the East with strike N150°E and the one
to the West with strike N80°E (Ferrari et al., 1993).

Samples were collected from hydrothermally altered rocks
during two field trips to obtain control points for the image
processing at the points marked in Fig. 2, in the towns of Jihu,
Jomulco, Rosa Blanca and in the Sierra El Guamuchil. In the Sierra
El Guamuchil a correlation was observed between alteration and the
occurrence of intrusive rocks. The alteration mapped is mainly
contained in the rocks that belong to the Sierra Madre Occidental
along the NW-SE and NE-SW faults. Silicification, argillic and
propylitic alteration types were identified associated with the opal
mines and the precious metals mineralization. The northern part is
caracterized by opal and kaolin mines, and argillic alteration areas
of more than 250 m² are common. Most argillic alteration areas also
show intense oxidation, which makes them easier to identify with
the infrared images as the iron oxide spectra present anomalously
high reflectance values in the band-5 (Hunt, 1977). Propylitic and
argillic alteration types associated with the gold-silver veins are
more difficult to identify because they are encountered in the
southern part of the studied area (Sierra El Guamuchil) that is
covered by vegetation and the outcrops extension is generally
generally restricted to a few tens of square meters. However, after the data
processing the control points could be identified in the images.

3. IMAGE PROCESSING

The image processing techniques applied in this work were
selected on the basis of the characteristics of the area and the
objectives of the study. The processing was done on a subimage
(1024 x 1263 pixels) obtained from the SW quarter of the TM
image (Path 030, Row 845) taken by the Landsat 5 in April 1991.
This subimage will be referred as the Ceboruco subimage.

Two software packages were used in the processing of the image:
ERDAS (A Grid-Based Geographic Analysis System) release 2.0
developed by the Graduate School of Geography from Clark
University, and SPIPR (Remote Sensing Interactive Personal
System) release 2.0 developed by the IBM Scientific Center
(Mexico City) and the Mexican National Institute of Geography and
Statistics (WEGI).

The spectral characteristics of the hydrothermal and
supergene alteration minerals commonly found in fossil and active
geothermal systems allow classification into two groups. The first
group contains the hydroxyls (clays and micas) and the hydrated
sulfates (gypsum and anhydrite), and the second includes the iron
oxides (hematite, goethite and jarosite). The first group (we will
denote them as hydroxyls) present typical high reflectance in the TM

Fig. 2. First principal component shows the main features in the
image of the studied area. Control points where samples of
hydrothermally altered rocks were collected during the field trips
are marked with asterisks. A, B and C denote the Sierra del Guamuchil,
the Sierra Madre Occidental and the Ceboruco Volcano,
respectively.

Fig. 3. a) Characteristic spectra of typical minerals found in hydrothermally altered rocks
(After Hunt, 1977, 1979; Hunt and Ashley, 1979). Shaded areas indicate the Thematic
Mapper bands.
Fig. 3 b) Spectral response of vegetation. Shaded areas indicate the Thematic Mapper bands.

The identification of the principal components that contain spectral information of any materials whose spectral anomalies coincide with the analyzed image bands, and also the contribution of each of the original bands used in the principal component analysis (PCA).

In this study we used a modification of the Crónica Technique that utilizes in the PCA only the image bands that contain spectral features that characterize the minerals that are searched for and whose vegetation to be removed (Loughlin, 1991). The band TM4 contains the largest reflectance anomaly that characterizes vegetation, therefore this band was included in the analyses for oxides and hydroxyls. For the mapping of oxides the bands TM1, TM3 and TM5 were used (plus the TM4) as they include the features necessary to identify the oxide bearing minerals as explained above. The hydroxyls were mapped including the bands TM1, TM4, TM5, and TM7, in order to include the absorption (TM7) and reflectance (TM5) anomalies characteristic of clays, sulfates, carbonates and other hydroxyl bearing minerals.

4. RESULTS AND DISCUSSION

Tables 1 and 2 show the statistical variance percentage that corresponds to each component, the characteristic value and the eigenvectors for each band in each component, for the oxides and hydroxyls analysis respectively. From Table 1 it follows that the second principal component (PC2) contains mostly information on the vegetation cover as the eigenvector for the TM4 band is 93.40. This large positive value indicates that the vegetation covered areas will appear as bright pixels in PC2. The most important contributions to PC4 in the oxides analysis (Table 1) come from the TM1 and TM3 bands: 71.60 and -69.11, respectively. The signs indicate that the oxides will be represented in dark pixels as their spectrum has an absorption anomaly in TM1 and a high reflectance anomaly in TM3. Therefore, in order to have them shown in bright pixels, it is necessary to obtain the PC4 inverse image, which we will call the "O" image (Fig. 4). In this image the brightest pixels will represent the oxides-bearing rocks.

The hydroxyls analysis eigenvectors are shown in Table 2. As in Table 1, PC2 contains information about vegetation in bright pixels and PC4 is the component that contains more information related with the characteristic spectral features of the hydroxyls. The eigenvectors corresponding to the TM5 and TM7 bands have high values with opposite signs (34.79 and -73.85) that correlate well with their high reflectance in TM5 and high absorption in TM7. According to these values the hydroxyl bearing rocks will show in PC4 as bright pixels. This will be referred as the "H" image (Fig. 5).

Table 1. PRINCIPAL COMPONENT ANALYSIS FOR OXIDE MAPPING

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>PC1</th>
<th>PC2</th>
<th>PC3</th>
<th>PC4</th>
</tr>
</thead>
<tbody>
<tr>
<td>% VARIANCE</td>
<td>86.95</td>
<td>6.98</td>
<td>5.59</td>
<td>0.47</td>
</tr>
<tr>
<td>EIGENVECTOR</td>
<td>116.86</td>
<td>116.86</td>
<td>77.01</td>
<td>71.60</td>
</tr>
<tr>
<td>TM1</td>
<td>25.36</td>
<td>-0.11</td>
<td>65.03</td>
<td>116.86</td>
</tr>
<tr>
<td>TM3</td>
<td>36.43</td>
<td>8.17</td>
<td>61.88</td>
<td>-69.11</td>
</tr>
<tr>
<td>TM4</td>
<td>28.43</td>
<td>93.40</td>
<td>-20.00</td>
<td>8.20</td>
</tr>
<tr>
<td>TM5</td>
<td>84.97</td>
<td>-34.75</td>
<td>-39.25</td>
<td>5.53</td>
</tr>
</tbody>
</table>

Table 2. PRINCIPAL COMPONENT ANALYSIS FOR HYDROXYL MAPPING

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>PC1</th>
<th>PC2</th>
<th>PC3</th>
<th>PC4</th>
</tr>
</thead>
<tbody>
<tr>
<td>% VARIANCE</td>
<td>86.95</td>
<td>7.43</td>
<td>3.76</td>
<td>0.59</td>
</tr>
<tr>
<td>EIGENVECTOR</td>
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<td>109.41</td>
<td>55.32</td>
<td>8.64</td>
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<tr>
<td>TM1</td>
<td>24.16</td>
<td>-10.94</td>
<td>77.91</td>
<td>56.79</td>
</tr>
<tr>
<td>TM4</td>
<td>25.81</td>
<td>92.38</td>
<td>19.73</td>
<td>-20.25</td>
</tr>
<tr>
<td>TM5</td>
<td>82.01</td>
<td>-5.99</td>
<td>-48.25</td>
<td>34.19</td>
</tr>
<tr>
<td>TM7</td>
<td>84.99</td>
<td>-36.19</td>
<td>30.15</td>
<td>-73.85</td>
</tr>
</tbody>
</table>
Fig. 4. Oxide mapping after processing using the Crósta Technique. Bright areas denote oxide bearing rocks. A, B and C as in Fig. 2

Fig. 5. Hydroxyl mapping after processing using the Crósta Technique. Bright areas denote hydroxyl bearing rocks. A, B and C as in Fig. 2

The results obtained separately for oxides and hydroxyls must be combined in order to map hydrothermal alteration, this may be achieved by adding (overlay of the two images with addition of corresponding pixels) the "O" and the "H" images which yield as a result an image ("O+H") that will represent the hydrothermally altered areas as bright pixels (Fig. 6).

The comparison of the "O", "H" and "O+H" images with the alteration data collected in the field shows that the best correlation is obtained for the "O+H" image. The oxides image includes bright pixels that do not represent hydrothermally altered rocks but exposed soil on agricultural land which was prepared for planting at the time when the image was obtained. Also when hydroxyls are mapped, high reflectance anomalies are obtained for the Ceborouco volcano recent lava flows where hydrothermal alteration was not observed during field mapping. It was found that this is caused by lichen growing on the surface of the rocks (Satterwhite et al., 1985). The effect of soils and recent lava flows is reduced when the "O" and "H" images are added and only areas that include both hydroxyls and oxides are shown as bright pixels.

5. CONCLUSION’S

The spectral characteristics of vegetation, hydrothermal minerals and their weathering products make it difficult to differentiate hydrothermally altered rocks from areas covered with vegetation using multispectral satellite images. Therefore special methods must be applied in order to map rocks that contain oxides and hydroxyls. Band ratios do not give good results because the vegetation reflectance is too high in the middle infrared where the main characteristic features of the hydrothermal minerals spectra occur. The spectra overlapping problem is solved by applying the principal component analysis to the four TM bands in the visible and infrared regions of the electromagnetic spectrum that contain the high reflectance and absorption anomalies typical of the minerals found in hydrothermally altered rocks.

This modification of the Crósta Technique proved to be useful for mapping hydrothermally altered rocks in the studied area. It reduced the spectral effect of the vegetation and enhanced the spectral anomalies of the oxide and hydroxyl bearing rocks. This was done for an area that contained three vegetation types with distinct spectral features.

The non-alteration features included in the "O" and "H" images were successfully reduced in the "O+H" image, obtained by adding the oxide and hydroxyl images and resulting in the mapping of the minerals characteristic of hydrothermally altered rocks.

ACKNOWLEDGMENTS

Thanks are due to IBM-INEGI for providing part of the software used in this work, and to DGAPA (UNAM) for their support to research projects on exploration of hydrothermal systems (IN-101992 and IN-101694).
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