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EVALUATION OF REMOTE SENSING METHODS FOR THE DETECTION OF HYDROTHERMAL ALTERATION ZONES IN MILOS ISLAND (GREECE)

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ABSTRACT

Data of Landsat 5 Thematic Mapper have been processed and analysed in the present paper, in order to detect the alteration zones in Milos island. These altered zones are important because they are connected with the presence of industrial mineral deposits such as bentonite and kaolinite.

Two different processing and analysis methods of satellite data, Crosta technique and band ratioing, have been used aiming at the evaluation of the results of each technique separately and their comparison by taking into account the local conditions which affect significantly the final result. These two methods have been proved to be complementary.

KEY WORDS: Remote sensing, alteration zones, PCA, band ratios, spectral reflectance, Milos island.

1. INTRODUCTION

In general, the hydrothermal alteration of certain rock types leads to the formation of industrial and/or metallic mineral deposits. The case of Milos island is a characteristic example. Intense hydrothermal alteration of volcanic rocks on Milos resulted in the formation of exploitable industrial mineral deposits (bentonite and kaolinite). In addition, various hydrothermal minerals such as barite, alunite, sulphur, galena, manganese and iron oxides, and epithermal gold have been formed (Kelepertsis et al. 1990, Liakopoulos 1991, Fytikas and Markopoulos 1992, Ballanti 1997).

Hydrothermal alteration mapping using earth observation satellite data is possible because certain minerals show characteristic spectral features that permit their remote detection (Fraser 1991, Carranza & Hale 1999).

The Thematic Mapper of Landsat 5 permits the recording of the spectral variations of various hydrothermal alteration minerals with positive results.

Two different techniques of mapping the alteration zones were used in this study:

a) The band ratioing technique (Goetz, 1989, Cracknell and Hayes, 1991, Gupta, 1991, Fraser 1991, Renez et al., 1994, Sabins, 1997, Harris et al., 1998, Parcharidis et al., 1998)
b) The Crosta technique, which is based on the Principal Component Analysis (Crosta and Moore 1989, Loughlin 1991, Ruiz-Armenta and Prol-Ledesma 1998).

Finally, these two techniques are evaluated by taking into account the local conditions (atmospheric conditions, climate, topography, land cover etc.), which influence significantly the efficiency of both techniques.

The above-mentioned methods will be applied in the case of Milos island for the mapping of the hydrothermal alteration zones. Furthermore, the advantages and disadvantages of the two methods will be examined, and their complementary character will be evaluated.

2. GEOLOGICAL SETTING OF MILOS ISLAND

(i) Main stratigraphic units

The volcanism in Milos island is characterized by a calk-alkaline activity, from the Upper Pliocene to the Upper Quaternary. There are five (5) volcanic phases: The three of them are of the Upper Pliocene and are characterized by rocks rich in SiO_2 such us rhyolites, rhyolitic tuffites and dacites. The fourth phase took place in the Lower Quaternary and gave rise to mostly basic volcanic rocks (andesites and andesitic breccias). The last volcanic activity took place in the Upper Pleistocene and the rhyolitic lavas and the tuffites of Fyriplaka-Trahila were formed. The area can be characterized as volcanically active, although it hasn't shown such an activity the

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last 80.000 years. The strong fumarolic activity is an evidence of the presence of a warm magmatic source in depth.Four different stratigraphic units can be noticed in Milos (Fytikas et al., 1986), (fig. 1).

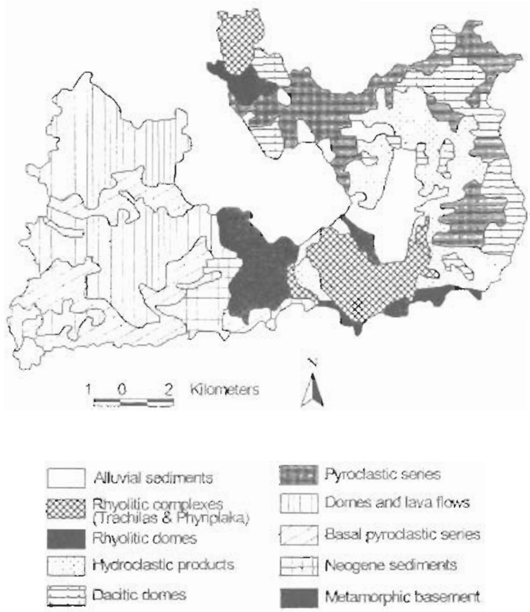

Fig.1: Geological map of Milos island (Fytikas et al., 1986).

- Metamorphosed alpine basement: it appears with small outcrops of strongly deformed metamorphic rocks, mostly in the southeastern part of the island.
- Neogene sedimentary sequence: some of its parts, from the Upper Miocene to the Lower Pliocene, appear in the southern part of the island (Fytikas, 1977).
- Volcanic sequence: volcanic and volcano-sedimentary units. This sequence can be classified in four main units: (a) A pyroclastic one occurring at the base (Middle-Upper Pliocene), (b) A complex of lava flow and domes (Upper Pliocene), (c) Pyroclastics and lava domes (Lower Pleistocene), (d) The acid complex of Fyriplaka and Trahila (Upper Pleistocene).
- Alluvial sediments: located in the Zefiria area and consist of clay, sand and gypsum of a total thickness of 80 m. Smaller outcrops appear around the Adamas village.

(ii) Tectonics

Milos island has been affected by the Post-Upper Pliocene tectonics. According to Papadopoulos (1993), the seismic activity of the island (March of 1992, Ms=5.3) is connected to structural deformations and not to the volcanic activity. The circulation of hydrothermal fluid in the crust is due to tensional faults (shear fractures) (Ballanti, 1997). Four main fault systems have been noticed: (a) NW-SE system, (b) E-W, (c) N-S, (d) ENE-WSW (Fytikas 1977, Tsokas 1985).

(iii) Hydrothermal activity

The widespread hydrothermal activity which is evident on Milos island (fig. 2) is related to the thermal anomalies due to the occurrence of shallow magma chambers (Vavelidis et al., 1998).

On the basis of geothermal studies (Fytikas 1977) and the presence of the active hydrothermal system in the southeastern coasts of Milos, it is concluded that there is a magmatic heat source, which provides the necessary thermal energy for the function of today's hydrothermal system. In addition, the southeastern part of the island is dominated by mineral outcrops, which are connected to a recent hydrothermal activity of an explosive character that created the hydrothermal craters in this area. Finally, the presence of hydrothermal alteration in the northwestern edge of the island, is an evidence of hydrothermal activity in this area. In any case, the extensive hydrothermal alteration zones occur in the eastern part of the island, north of the active hydrothermal system.

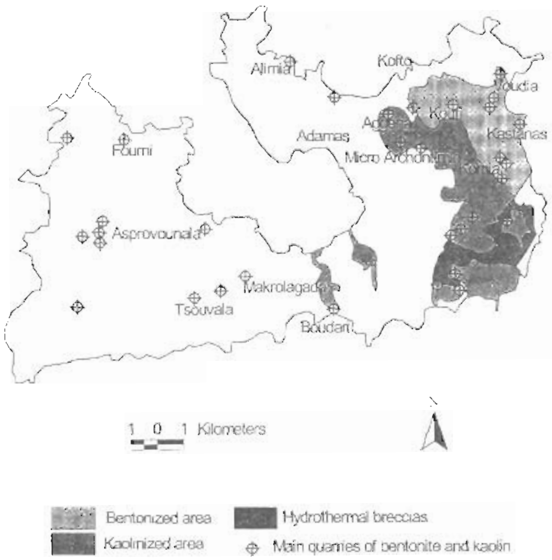

Fig.2: Map of the hydrothermal features of eastern Milos (Ballanti, 1997).

3. DATA USED AND THEIR PREPROCESSING

The study area is covered by the Landsat 5 TM image, path/row: 182/035 (column/row: 6920 x 5760), 7 spectral bands, dated 23/9/1987. This image has been chosen because of no cloud cover and of a high sun elevation angle, which offers better signal to noise ratio helping the mapping in this specific application. The ERDAS v.8.3.1 software has been used for the image processing of the satellite image and the ARC-VIEW v.3.1 for the digitising and manipulation of the spatial information.

The preprocessing of the Landsat TM data includes the radiometric and geometric correction of the data:

a) Atmospheric correction comes under the category of radiometric correction, which improves the ability to interpret and compare the digital satellite images. Relevant atmospheric parameters are the vertical profile of pressure, air temperature, humidity, ozone, aerosol type and content, which influence the absorption and scattering properties. In order to apply atmospheric correction the ATCOR2 for IMAGINE (Version 1.6) has been used.

b) The geometric correction, based on the EGSA87 georeference system by selecting a set of 19 ground control points, mainly along the shoreline, has been made. The nearest neighbor resampling method with a polynomial transformation of second order (and a new spatial resolution of 33m/pixel after the resampling) has been used.

4. SPECTRAL RECOGNITION OF THE ALTERATION MINERALS IN LANDSAT TM IMAGES

The characteristics of the spectral reflectance and emission of the rocks at various wavelengths are the result of their physical and chemical properties (Abrams et al. 1984, Goosens et al. 1994). The hydrothermal alteration minerals have a different distribution in the various types of the hydrothermal systems, which are characterized by groups of minerals that have spectral characteristics in the near and middle infrared. Referring to the clay minerals (kaolinite, smectite etc.), the spectral zone with a range from 2.1 to 2.4 μm is characterized by a high absorption whereas the maximum reflectance (takes places-occurs) at about 1.6 μm.

The iron oxides show a wide and strong absorption band of radiation, which is due to the transformation of their electrons, that is located in the region of the ultraviolet-visible blue, and it increases progressively to higher wavelengths. In addition, a spectral absorption channel of the Ferric iron (Fe^{+3}) is located in the region of the near infrared (Hunt et al. 1979, White et al. 1997).

The land cover, as far as it concerns the vegetation, is a serious problem because it presents absorption characteristics in the spectrum from 0.45 to 0.68 μm (due to the chlorophyll absorption) and a high reflectance at 1.6-2.2 μm (due to leaf water absorption).

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The Thematic Mapper (Landsat recording instrument) allows the recognition of individual minerals, because of the recording range of its spectral bands.

Clay minerals show radiation absorption at wavelengths identical with the spectral band TM7 in connection with the potential detection of spectral recording of the Thematic Mapper. On the other hand, they show high reflectance within the spectral band TM5 (fig. 3). The iron oxides show low reflectance in the spectral band TM1 and a high one in the spectral band TM3 (fig. 4).

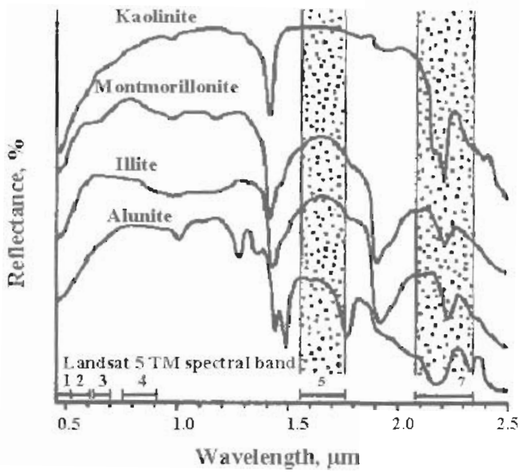

Fig.3: Spectral reflectance curves of the main clay minerals (Sabins, 1997).

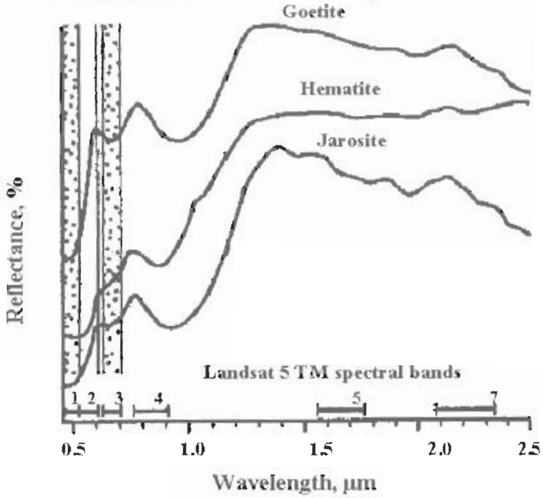

Fig.4: Spectral reflectance curves of the main iron minerals (Sabins, 1997)

5. THE PRINCIPAL COMPONENT ANALYSIS TECHNIQUE (CROSTA TECHNIQUE)

The principal components transformation is a statistic technique of many variables, which chooses non-correlated linear compositions (eigenvectors) of variables in such a way that each output principal component (linear composition) shows the minimum variance (Mather, 1991). This variable in the multispectral images is related to the spectral response of various surfacial characteristics.

The Crosta technique (Crosta and Moore, 1989) also known as Feature Oriented Principal Components Selection, permits the recognition of the principal components that give information related to the spectral responses of specific targets. An important advantage of the technique is that it predicts whether the surficial characteristics are enhanced by pixel with low or high digital number in the related principal component. The Crosta technique has been applied in the 6 bands (except the spectral band 6, thermal infrared). On table 1 the characteristic eigenvalues (in which the reduce in the variance of the information is shown for its component) as well as the eigenvectors, are shown.

We notice on table 1 that the component PC1 contains the 95% (very high rate) of the variance of the 6 spectral bands with values varying from 30.3 (TM1) to 48.5 (TM5) giving information mainly about albedo and the topography. In the second component PC2 the information is provided by TM4 (33.3) and TM5 (44.5) and it receives a negative contribution mainly by TM1 (-71.3). The importance of this image is that it contains the information for the vegetation distribution with the corresponding pixels having high digital numbers.

Table 1: Principal Component Analysis on six bands (eigenvector lodings in percentages).

Eigenvector matrix (%) of original bands							
Input Bands	TM1	TM2	TM3	TM4	TM5	TM7	Eigenvalues (%)
PC1	30,3	35,7	38,2	46,1	48,5	43,2	95,8
PC2	-71,3	-33,7	-22,9	33,3	44,7	12,2	2,6
PC3	5,5	-21,8	11,9	-57,8	8,3	77,0	1,1
PC4	5,4	-18,5	-58,8	-2,2	51,0	25,5	0,3
PC5	-29,1	50,0	14,6	-56,3	49,0	29,0	0,1
PC7	-14,0	65,1	-64,8	15,5	-24,0	25,5	0,1

According to the spectral analysis curves and the range distribution of the Landsat spectral bands the components PC5 and PC6 are those that contain the spectral information relevant to the hydroxyd minerals and iron oxides. The interest is focused mainly on the components PC3 and PC6. The component PC3 has a positive contribution by TM3 (11.9), TM5 (8.3) and TM7 (77.0) in which the iron oxides display a characteristic high reflectance and a negative or very low positive contribution by TM2= -21.8 and TM1=5.5 in which the iron oxides show characteristics of spectral absorption. Thus, in this image the iron oxides are correlated to pixels with high digital numbers. The component PC6 receives a negative contribution by TM5 (-24.0) in which the hydroxides show characteristics of high reflectance and positive contribution by TM7 (23.5) where the hydroxyls show characteristics of spectral absorption. According to the spectral characteristics of the hydroxyls in PC6 image, the relative areas appear with pixels of low digital numbers and for this reason the invert technique has been applied.

A False Color image has been created, with the use of the components PC2, PC3 and PC6 (presented as gray scale image in fig. 5). In this gray scale image, the dark gray levels are related to natural vegetation or crops (according to their characteristics), the medium gray levels are related with the areas that iron oxides dominate and the light gray areas with the clay minerals. The combination of the last two shades of gray indicates alteration zones where clay minerals and iron oxides coexist.

Through the observation of the image we have concluded that the western part of the island, in its major extension, is covered by vegetation. This vegetation cover makes the mapping of the alteration zones impossible. The vegetation in the eastern part is limited and comprises sparse bushy vegetation and crops. Alteration zones are located, mainly in the eastern part of the island and specifically in the areas Aggeries, Micro Arcontimio, Kato Komia, Koufi, in the western part in the areas Asprovounala and Fourni and in the middle of the northern part, along a zone with NE-SW direction from Tsouvala up to Makrolagada. However, few areas along the coastal zone (extend from Alimia to Kofto, Voudia, Kastanas and Boudari) appear on the image with similar levels of gray and have been described as coastal clastic deposits derived actually from the altered rocks.

6. BAND RATIOING TECHNIQUE

According to what has been described about the spectral response of hydrothermal alteration minerals and

*Fig.5: **Gray scale image of the components PC3, PC6, PC2.***

their recognition in Landsat TM images, we have come to the conclusion that:

- The ratio 5/7 of spectral images can be used for the recognition of clay minerals and at the same time, for the distinction of altered and non-altered rocks. These two rock types (altered and non-altered) appear to have the same reflectance in the image of spectral band TM5 and the non-altered rocks have the same reflectance in the image of the spectral band TM7. The ratio 5/7 gives values higher than 1, for the altered rocks.

- The iron oxides show a low reflectance in the spectral band TM1 and a high one in the spectral band TM3. Thus, the hydrothermally altered rocks, which are rich in iron oxides, have high values of the ratio 3/1.

The creation of Color Composite Ratios is a technique that enhances the information through the creation of three color composite ratios and their correspondence in colors Red, Green, Blue.

After that, three kinds of digital analysis have been made.

- Determination of the Color Composite Ratios (CCR) of the spectral bands.
- Application of the technique masking the vegetation
- Detection of the most important alteration zones.

The first step was the enhancement of the initial ratio images according to the equation: Ratio image = atan (spectral band A/ spectral band B)

Then using these enhanced images, a false color composite image with ratios 3/1, 4/3, 5/7 (R, G, B) was created (presented as gray scale image in fig. 6).

The second digital analysis concerned the presence of vegetation in the area, because it hides possible altered areas. For this reason the image of Normalize Difference Vegetation Index (NDVI) has been created according to the equation: NDVI = (TM4-TM3)/ (TM4+TM3)

The value "0" has been given to the pixels correlated to the vegetation and then the mask technique was applied (black color in the image).

Finally, using the latter image, the detection of the main hydrothermal zones has been made. In this image, the hydrothermally altered zones appear with dark gray levels. These zones are located especially in the areas Aggeries (with ring shape), Kato Komia and Asprovounala, mostly in the eastern part of the island. In the areas Voudia and Kastanas located along the coastal zone the appearance of similar gray levels on the image, due to clastic deposits derived from the altered areas.

7. CONCLUSIONS

We have observed the following after the analysis and the interpretation of the two different final products using as guide area, Voudia location in fig. 7:

a. In the composite image of the ratios, the mask technique (using and the good knowledge of land cover of the area) minimizes the influence of vegetation on the signal reflectance characteristics of the altered areas.

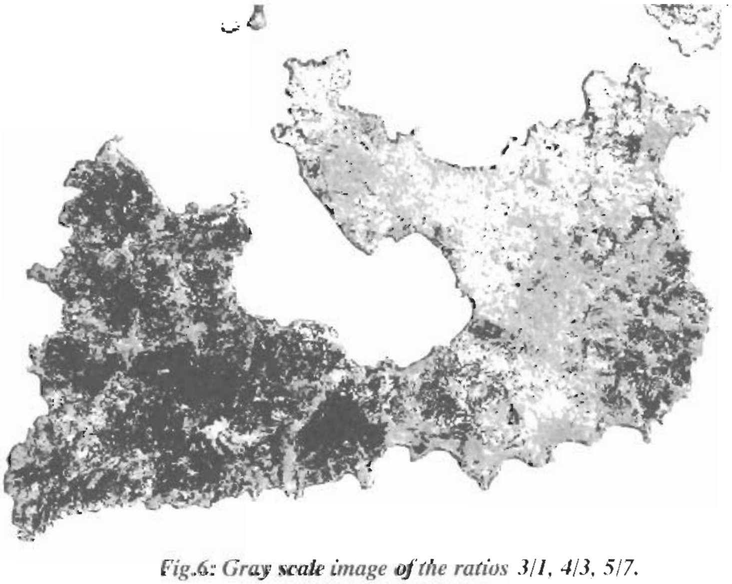

Fig.6: Gray scale image of the ratios 3/1, 4/3, 5/7.

b. In Crosta technique is obvious that principal component values do not form the ideal correlation, for the exact enhancement of the aiming characteristics (hydrothermal alteration minerals).
c. The geometry of the alteration zones is enhanced when the band ratioing technique is used.
d. The clay minerals alteration zones appear more clearly to the interpreter with the Crosta technique, in a quick visual interpretation.

In conclusion it can be deduced that in cases like the one of Milos (alternating morphology, semiarid climate and differentiation in vegetation from nude relief to dense bushy), both techniques have given good results and in many occasions, the two techniques complement each other.

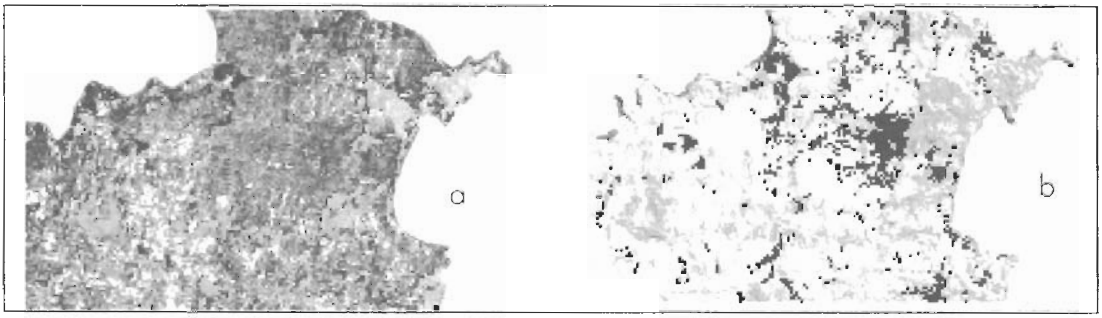

Fig. 7: Composite Images in gray scale, a) Crosta technique, b) Band ratioing technique, for the area Aggeries-Voudia.

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